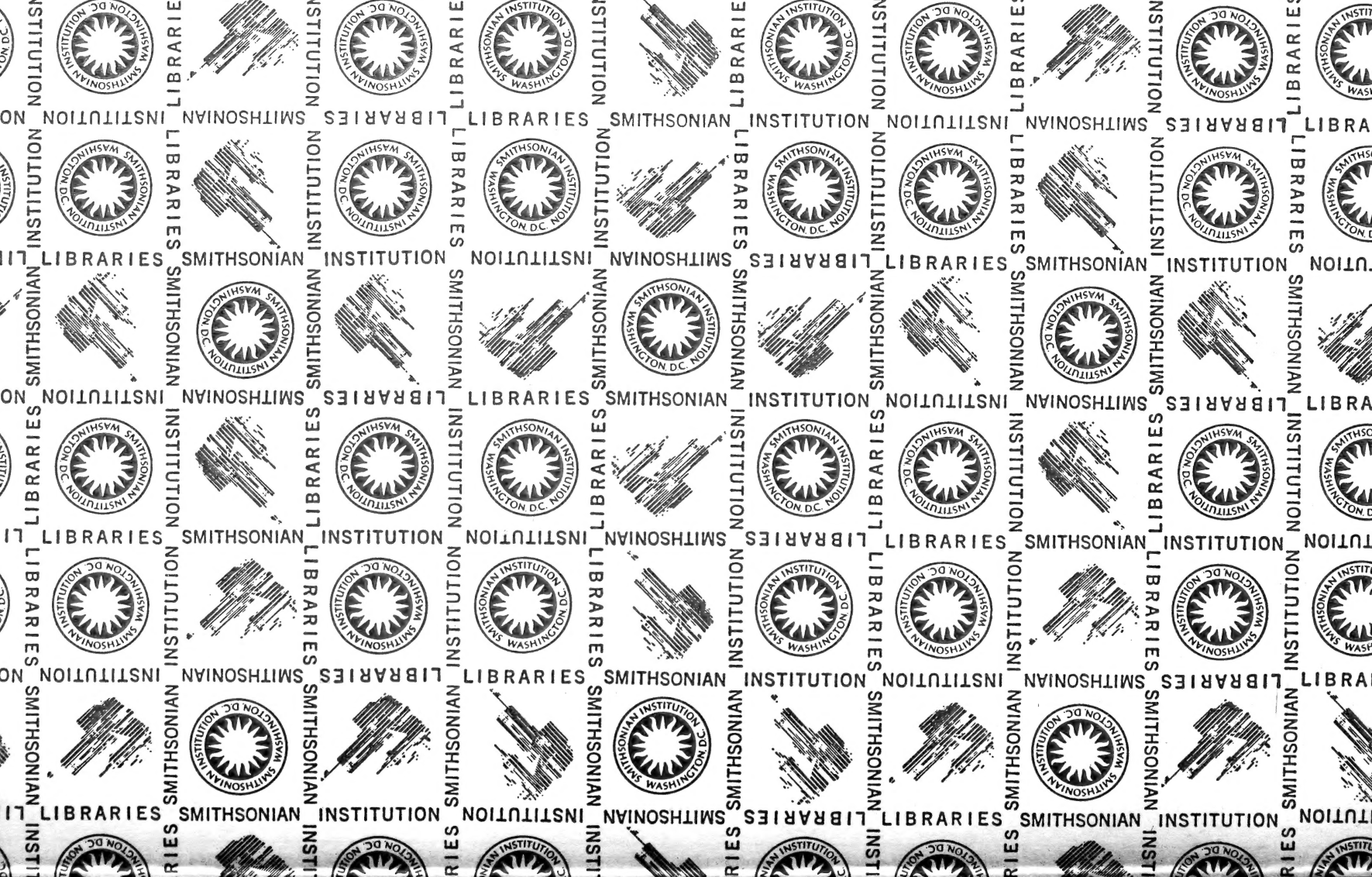
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PROCEEDINGS

of the

ENTOMOLOGICAL SOCIETY OF ONTARIO

Volume One Hundred and Five

1974

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FELLOWS OF THE ENTOMOLOGICAL SOCIETY OF ONTARIO

(With date of election)

A. W. A. Brown (1969)

E. M. DuPorte (1969)

R. Glen (1969)

G. P. Holland (1971)

G. F. Manson (1968)

C. R. Twinn (1963)

ENTOMOLOGICAL SOCIETY OF ONTARIO

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1973-1974

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CONTENTS

I. THE SOCIETY

IN MEMORIAM

The following entomologists, all but one of whom were members of the Society at some time, died since Vol. 104 of the Proceedings went "to press" in 1974. We are indebted to them for their many contributions to Entomology.

Albert Wesley (Jack) Baker (1891-1974), Professor of Entomology and Zoology at the University of Guelph for forty-four years, died at Sunnybrook Hospital, Toronto, 26 August 1974.

Professor Baker was born at Walkerton, Ontario. Even as small boys both he and his brother, A. C., had developed an interest in insects. He became a member of the Society in 1908 and remained one until his death. He graduated from the Ontario Agricultural College in 1911. On graduation he joined the Department of Entomology and Zoology at Guelph, becoming head of the department in 1922, a position he held until his retirement in 1955.

Professor Baker was blessed with a brilliant mind and an inexhaustible amount of energy. He spared neither. In the University community he was an articulate spokesman and presented entomology as an essential subject for all students in agriculture. He insisted that only dedicated and sincere students should enter entomology and many of his students will remember that he could not be convinced easily. His students, however, were a special lot and not one left his place until he had mastered histology, taxonomy and morphology.

Always the academic, Professor Baker was active in curriculum development, not only in entomology and other areas of zoology but for the entire college. He played a key role in the development of the graduate study program of the Ontario Agricultural College campus, serving as the first secretary of the conjoint committee of the Guelph and Toronto faculty which administered the program when it was established in 1926.

Professor Baker's interest in students embraced not only academic concerns but social and athletic activities as well. The Baker home was always open to students and served as a centre where students gathered and where they were invited to meet scientists who visited the Guelph campus. An avid athlete he was active in student athletics, both in an executive capacity and as basketball coach for 26 years.

In addition to campus activities, Professor Baker's interest in his profession made him an active and forceful member of the Entomological Society of Ontario. He was Secretary of the Society from 1911 to 1925 and President 1927 to 1929. Always an historian he promoted the Society Library and extended its acquisitions through arrangements with sister societies throughout the world for an exchange of publications. Although a strong supporter of the Ontario Society he recognized the need for a national body to represent entomology in Canada. To support this he became one of the founding fathers of the Entomological Society of Canada encouraging, through persuasion and logic, participation of all regional societies. He served as President of the Entomological Society of Canada 1952-1954. Both before and after retirement Professor Baker was a regular attendant at all society meetings.

Professor Baker joined the Royal Canadian Navy in 1943 and established the University Naval Training Division, first at Guelph, followed by divisions at campuses across the country. His interest in the navy continued. How well we all learned naval "lingo" during hospitality sessions at the Baker home. He was a member of the Naval Defence Conference and a director of the Naval Benevolent Fund.

Professor Baker had many activities in fields related to entomology. He was an enthusiastic naturalist and was past President and Honourary Life Member of the Conservation Council of Ontario and Past President and Life Member of the Federation of Ontario Naturalists. He was a fellow of the American Association for the Advancement of Science. He was active in the O.A.C. Alumni Association and was on the Planning Committee for the O.A.C. 50th Anniversary, Chairman of the 75th celebrations and Honourary Chairman for the Centennial in 1974.

Professor Baker's contributions to his profession and to Agriculture were also recognized in other ways. He was an Honourary Member of both the Entomological Society of Canada and the Entomological Society of Ontario. He was named alumnus of the year by the O.A.C. Alumni Association in 1973 and was given a centennial medal by the O.A.C. in 1974. He was named Professor Emeritus at the University of Guelph in 1974.

Professor Baker's keen wit, sharp mind and dedication to his profession did not dim with advancing years. He retained an incomparable grasp of the history of entomology in Canada, a history he knew from a lifetime of service to the discipline. Entomology has lost a great friend.

This obituary prepared by former colleagues in the Department, was published in the Bulletin, Entom. Soc. of Canada 6 (4): 136-7, 1974.

* * * * * *

J. W. M. (Bain) Cameron (1910-1975), Director of the Insect Pathology Research Institute died at the General Hospital, Sault Ste. Marie, Ontario, 4 January 1975.

Dr. Cameron was born in Scotch Hill, Nova Scotia in 1910. At the age of 15 he graduated from Pictou Academy. After attendance at Nova Scotia Agricultural College, he obtained his B.S.A. degree in 1930 from Macdonald College, the Agriculture faculty of McGill University. As an undergraduate summer assistant he worked for Dr. W. H. Brittain during the latter's classical apple pollination studies in the Annapolis Valley. He obtained his M.Sc. (1932) from Macdonald College, and while studying for his Ph.D. (1938) was a demonstrator and lecturer in zoology and entomology. On the Macdonald Campus he met Evelyn MacKenzie of Brockville, Ontario. They were married in 1937 and had four sons and a daughter.

From 1939-1941 Bain was Provincial Entomologist for Nova Scotia and taught zoology and entomology at the Nova Scotia Agricultural College. In 1941 he joined the Royal Canadian Air Force as a navigation instructor. After 18 months he was seconded to a post in the Chemical Warfare Service to work on entomological problems.

In 1945 he joined the Forest Insect Control Board as a Research Officer and was transferred to the Forest Insect Laboratory in Sault Ste. Marie which had been newly opened as a joint project of the Federal and Provincial governments. When the Insect Pathology Research Institute was established in 1950, as an autonomous national institute Dr. Cameron became its first Director, the post he held until his death.

Although he disclaimed any expertise as an insect pathologist, because of his long and close association with insect pathology in Canada during the post war period, he had a broad overview of this discipline that was denied specialists. In this capacity as Director he recruited, encouraged and guided many scientists, some of whom have since played important roles in other institutes and jurisdictions. As many of us who worked under him know from personal experience, his advice and encouragement were invaluable. In spite of an ever-increasing workload as the Institute expanded, Bain was the author and co-author of many review papers concerning the application of insect pathogens as potentially useful agents. His own papers were marked by a direct and lucid style that was widely admired and appreciated. As an internal editor he saved many of us from our own woolly phrases, solecisms, tables and captions that confused rather than enlightened.

Dr. Cameron's professional affiliations were varied and many. He was one of the small group that spearheaded the founding of the Entomological Society of Canada, later serving it as President in 1967, and in many ways, officially and unofficially. Similarly he served several terms on the executive of the Entomological Society of Ontario including a term as President.

Characteristically, he had a distinguished record of service to his community. He was a member of the Board of Education of the City of Sault Ste. Marie, Chairman of the Korah and Tarentorus District High School Board, the first Chairman of the Sault Ste. Marie Conservation Authority, President of the Algoma Tuberculosis and Respiratory Disease Association. At the time of his death, Dr. Cameron was Chairman of the Board of Governors of Algoma University College, an affiliate of Laurentian University.

Dr. and Mrs. Cameron attended a number of international congresses of entomology and insect pathology and his contacts especially in Eastern Europe were wide and varied. The many visitors to the Sault Ste. Marie laboratories undoubtedly have pleasant memories of the gracious hospitality of the Camerons in the home they built on the heights overlooking Sault Ste. Marie. In spite of the demands on a science administrator, Bain never lost his early love of growing things and he was constantly seeking new specimens for the wild flower collection he and Evelyn maintained.

Bain was a man of strong convictions which he did not lightly alter nor shrink from advancing. His office door was always open and when his opinion was sought it was frankly given. You were always sure that it was based on a real desire to find a fair and reasonable solution to a problem. All of his staff deeply grieve his untimely passing; he was denied a pleasant and well-earned retirement. We know that this sentiment will be shared by Bain's many friends and colleagues who will wish to extend their sympathy to Mrs. Cameron and the family.

This obituary was prepared by the staff of the Insect Pathology Research Institute and was published in the Bulletin, Entomological Society of Canada 7 (2): 36-37, 1975.

* * * * * *

L'Abbe Ovila Fournier (1899-1974) Former Professor, University of Montreal. President, Société Entomologique du Québec, Filiale de Montréal, 1952-53; President, Entomological Society of Canada, 1955-56. Died October 18th, 1974 in Montreal.

* * * * * *

Brian Hocking (1914-1974). Former Professor of Entomology, University of Alberta. President, Entomological Society of Canada 1960; Founder and Editor of "Quaestiones entomologicae", now in its eleventh volume; President, Entomological Society of Alberta, 1967; Fellow of the Royal Society of Canada, 1968; Gold Medallist, Entomological Society of Canada, 1973. Died May 23, 1974 in Edmonton. For additional information, see Bulletin, Entomological Society of Canada 5 (3): 70-72, 1973.

* * * * * *

Henry Hurtig (1918-73). Former Research Coordinator (Environmental Quality) Research Branch, Agriculture Canada. Planning and coordination of research programme involving pesticides; liaison with industry, other governmental and foreign agencies (F.A.O., W.H.O., O.E.C.D., U.P.A.C.) on pesticide research, use and regulation. Honours include recognition by Belgium, France, Israel and Finland. Died on December 13, 1973. An obituary, prepared by Research Branch personnel was published in the Bulletin, Entomol. Soc. of Canada, 6 (1): 24, 1974. In Vol. 7 (2) of the same publication, an international tribute was paid to Dr. Hurtig when the scientific programme and publications of the Third International Congress of Pesticide Chemistry were dedicated to him and a Congress Commemoration medal was awarded postumously.

* * * * * *

Howard Loomis (Hod) Seamans (1891-1974). Former Head, Field Crop Insect Unit of the old Entomology Division, Agriculture Canada. In 1919 appointed Asst. Prof. of Zoology at Montana State College. Named Officer-in-Charge of the Dominion Entomol. Laboratory at Lethbridge in 1921, where he remained for 23 years until his transfer to Ottawa. Honours awarded include: the Professional Institute Medal in 1938 for meritorious achievement, and in 1961 by the University of Alberta (Calgary) an Honourary L.L.D. Died, December 17, 1974 in Ottawa. Bulletin 7 (2): 41-2, 1975 of the Canadian Society contains an obituary written by George Manson and additional information, prepared after his retirement is contained in the Entomology Newsletter 35 (2): 1-2, 1957 of the Research Branch, Can. Dept. of Agric.

* * * * * *

William Elgin Van Steenburgh (1899-1974). Former Director-General of Scientific Services, Canada Dept. Mines and Technical Surveys. Junior Entomologist (1927-8) Chatham Laboratory; Assistant Entomologist (1928-38) Dominion Parasite Laboratory (Chatham and Belleville); Officer-in-Charge (1938) Dominion Entomological Laboratory, Harrow; Military service and defence research activities (1939-47). Research Advisor (1947-9) and Associate Director of Science Services (1949-56); in 1956 transferred from Agriculture to the Department of Mines and Technical Surveys with responsibility for directing the scientific programs and planning future developments; Deputy Minister, Department of Mines and Technical Surveys (1963-66) when he retired for the first time. In 1966-67 he served as Special Scientific Advisor to the Privy Council Office, returned to Mines and Technical Surveys as Consultant and took final retirement in 1968. Honours awarded include: O.B.E., E.D., L.L.D. (Dalhousie University), Gold Medallist (Professional Inst. of Public Service of Canada), Medal of Service (now designated "Officer of Canada") of the Order of Canada. Died Easter Sunday, 1974 in Ottawa. The Bulletin 6 (3): 84-6, 1974 of the Entomological Society of Canada, contains an obituary written by Dr. Robert Glen.

II. GENERAL

PROTECTING AN ENDANGERED SPECIES

W. Y. Watson

Department of Biology, Wilfrid Laurier University, Waterloo, Ontario

Hidden virtually unnoticed among the great mass of humanity exists a species that is in great danger of completely disappearing. Like all endangered species, its basic problems are that members of the species have little opportunity of contacting each other and that they are given little encouragement to exist. This species is not only of value in its own right but is of great value through what it can do for others. The species in question is the amateur entomologist.

Dr. G. J. Spencer in his address to the Centennial Meeting of the Entomological Societies of Canada and Ontario stated that "With the appointment in 1908 of, ... a university trained Doctor of Science in Zoology and Entomology as Dominion Entomologist, the era of naturalists and hobbyists in Entomology in Canada came to an end. . . . . .". And he went on to say "This passing of the amateur entomologist is deplorable."

Although the amateur entomologist is not as numerous as he once was, it is my belief that there are still a number of them around. It is also my belief that this number will grow with the increasing number of young people who are now exploring entomology during their schooling. Not all of the students in university who take courses in entomology will become professional entomologists; many will retain entomology as an interest. It is this group plus others who have become interested in entomology simply because of its unique fascination who will form the band of dedicated amateurs for the future.

"The era of naturalists and hobbyists in entomology" may have come to an end. The need for them has not! Despite the growth of professional entomology in Canada the immensity of our ignorance about insects in Canada far outstrips this growth. Most professionals recognize this and can only attempt to do the best they are able, knowing full well that there are many areas of the subject which must remain untouched. Many of these areas are open to the keen serious amateurs. The taxonomy of many groups, the fauna of specific localities, life history studies, studies on variation of adult forms, are all aspects of entomology where the well-informed amateur can do useful and lasting work.

I have just finished reading a short biography of Per-Olaf Ljungstrom. Although only 24 when he died in 1973, and although he never completed secondary school, Mr. Ljungstrom was already being recognized as a world authority on earthworms. Within nine years he had 18 publications of significance to his credit. Mr. Ljungstrom was a serious and dedicated amateur.

An amateur is one who is devoted to his avocation, and one who will spend countless hours over details and improvements with little thought of reward beyond personal satisfaction. A real amateur is not "amateurish". He has the capability to be every bit as professional as the highly trained person. Equally, he has the responsibility to share with others what he has found.

It is possible that we hear little from the amateur because he has succumbed to the myth of professionalism. Like any group of professionals, the entomologists have built a world of science full of esoteric drawings of genitalia, tables of undigestable facts, and have wrapped the whole thing in a jargon, so that the amateur, no matter how keen, feels he has no entry. Instead of bringing the amateur with him, the professional has left him behind. There is an awesome gap between them.

Unfortunately this gap is the inadvertent fault of the professional entomologist, whether he be in university, government service, or private practice. In his haste to be and to be seen a professional among professionals, he has neglected to recognize his service to the amateurs. He has not communicated with them. Indeed he has largely ignored them.

As a result of this the amateur has soon recognized that he has no tools in the form of handbooks and keys with which to identify his material. Rightly or wrongly he soon loses interest and feels that his work is defeated before it starts. Identification of material is still one of the great stumbling blocks in entomology to the professional and even moreso to the amateur. At present there are few handbooks available for insect groups in Canada; most foreign publications are marginally useful by extrapolation. The need for publications of this sort is clearly evident. Also necessary are books of a more general nature dealing with insects in this country.

Not all of the responsibility lies on the shoulders of the experts. It is one thing to write a good, useful book. It is another to make the book known and available. Canadian publishers, whether Queen's Printer or commercial, must assist in this, and recognize the market that might exist. Surely with all the technical and automated capacity and ability in the printing industry in this country it ought to be possible to produce and market various useful natural history books. Such books need not be fancy, they need not be hard-covered. They must have quality in the form of accuracy, they must be useful, and they must be available.

The amateur must also have a place to exhibit his findings. Whereas the regular scientific journals are usually crowded, the provincial societies have publications, often with very wide circulations, that have room for short papers. Journals, such as the proceedings of this society, might well develop policy to encourage the amateur. There could be a section of field or short notes which could serve in part as a bulletin board from one amateur to another. Contributions such as this should not be without some guidance; they must be real contributions and not simply repetitions of known information.

The amateur entomologist exists but he is an endangered species, endangered through neglect. The professional and the amateur need each other. Let us try to work towards bridging the awesome gap that now exists between them. Perhaps "the era of naturalists and hobbyists in Entomology" need not come to an end.

THE STATUS OF ENTOMOLOGY IN CANADA

C. R. Harris

Research Institute, Agriculture Canada, London, Ontario

It is always a pleasure to attend the annual meeting of the Entomological Society of Ontario. However, it is with real pleasure that I find myself this year in the position of being able not only to attend the annual meeting, but also to bring you greetings from the national society and our good wishes for a very successful meeting.

I suppose that as President of the Entomological Society of Canada I should utilize my time here by putting in a plug for membership in the national society, or by attempting to justify increases in publishing costs in *The Canadian Entomologist* or the small increase in membership fees in the coming year, or perhaps even to try and convince at least some of you that *The Canadian Entomologist* is not just a "systematists' paradise" but actually does accept papers in other entomological fields. I don't intend to do this. Rather I would like to talk to you in the time allocated to me about a much broader problem which concerns me and I hope all of you, i.e. the status of entomology in Canada today.

The importance of insects in our ecosystem is often underestimated. Many species are beneficial. Some, of course, are pests and Canada certainly has its share of those. Although the fact is not often recognized insect pests can exert major limiting influences on the development of many sectors of our economy. One needs only to mention such major pests as grasshopper, biting flies, and the spruce budworm to illustrate the point. The tremendous importance of insect problems in relation to our economy has, in the past, been recognized by those in authority and for many years entomological research, extension, and education were strongly supported, and Canadian entomologists provided results without which our high productivity in agriculture and forestry today would never have been accomplished. And as the development of northern Canada continues, Canadian entomologists will be again called on to play significant roles in environmental impact studies, and on biting-fly control.

Considering its record of productivity, one would think that strong support of entomological programs in Canada would be continuing. However, such is not the case and entomology is receiving less and less support as time goes on. Entomologists are not alone. Science in general is in disrepute with both the public and those who control the purse strings. For several years scientific research in this country has been subjected to investigations, reorganizations, more investigations, and more reorganizations usually by people who have little concept as to what science is really all about. New advisory bodies have been established, new government departments have been created to administer scientific research, new fund granting councils are being created and so on and, as the cost of administering scientific research soars, research budgets have been restricted to the point of little or no actual growth if inflation is taken into consideration. This is one instance where the old saying that there are "too many chiefs and not enough Indians" has real application.

A very high percentage of scientific research in this country is done within government departments. I am not going to engage in an argument as to whether or not this approach is justified. My point here is that when policy decisions to restrict scientific research budgets are made, it then falls on those departments carrying research programs to curtail or reduce them. The entomological research component is very strong in some government departments and perhaps for this

reason it has been fair game for administrators forced to cut expenditures while straining to maintain a balanced overall research program. Being quite honest about it, I think that many entomologists will agree that some selective cuts in entomological research programs were justified relative to other research programs. However, I submit to you that in recent years the situation has gotten entirely out of hand. In the Canada Department of Agriculture, for example, where the strongest entomological research component exists, the average age of entomologists is in the mid 50's and as entomologists retire they are virtually all being replaced with scientists in other disciplines assigned a higher priority. The argument, of course, can be made that not all research should be done by government agencies and this indeed may be the case. However, the agricultural chemical industry in this country is hardly in a position to carry out extensive research programs of the kind required in entomology. With few exceptions, provincial agencies show little sign of assuming any further responsibilities and Universities, with only a limited number of jobs available to students on graduation, are certainly not being encouraged to expand their emphasis on entomological training and research. One only needs to look at the insect pest problems in this country, at the average age of our entomologists, and at the total number of entomologists left to realize that unless some drastic steps are taken to relieve the manpower situation in the near future, our capability for research on insect control is going to be drastically impaired.

What can we as entomologists do about the situation? One approach would be to sit by complacently anticipating our early retirement. A second approach would involve a little wishful thinking: thinking, for example, of how appropriate it would be for our science policy makers to get their tail-ends so thoroughly bitten by biting flies when they visit northern Canada that they would at least understand the significance of this one entomological problem. But even if such a notable event did occur it would only result in an unbalanced entomological program with greatly expanded emphasis on the one problem at the expense of others.

A third approach would be to campaign for reassessment of present policies toward entomological research in Canada and for development of some moderate, realistic long-term goals. Certainly this would seem to be the most logical approach. However, as I mentioned earlier any hopes of accomplishing this goal on an individual basis are long gone in this era of bureaucratic decision making. Only by organization will we be able to make ourselves heard.

Entomologists are not the only scientists in Canada who face a dim future. Others are in a similar position and some tentative steps have been taken toward organizing scientific advisory bodies which can influence policy decisions concerning science. Such bodies as the Biological Council of Canada and SCITEC are examples and the Entomological Society of Canada has supported them since their inception. No doubt these advisory bodies will, in time, serve a useful function in helping to establish guidelines for overall science policy in Canada. However, I suggest we are deluding ourselves if we think that they will be able to protect our specific interests. That responsibility rests with us.

Our entomological societies have always been inward looking. We have had good annual meetings. We have published papers in good scientific journals and we have felt that the results of our work were obvious for all to see and justified strong support. Now the situation is different and support for entomology is rapidly going downhill. Perhaps it is time that our societies, both regional and national became much more active in identifying priorities and in actively lobbying for their acceptance.

It is rather astonishing when one looks at our various scientific societies in Canada and realizes how little actual influence they have. In the case of the Entomological Society of Canada, for instance, we do not have official representation on such influential committees as the Canada Committee on Pesticide Use in Agriculture, the Canada Committee on Biting Flies, or the NRC Assocate Committee on Environmental Criteria which includes a subcommittee on pesticides. Nor do we have official representation on NRC granting committees. At the provincial level where there is an Environmental Council or a Pesticide Advisory Committee, do any of the Provincial Entomological Societies have official representation?

We are equally poorly prepared when we talk about the future shortage of trained entomologists in this country as I have done today, because, for lack of statistics on manpower, we are forced to generalize. Nor do we have an adequate inventory of entomological research programs so that we can establish research priorities. Until we obtain such data, we are in a very difficult position when it comes to speaking out.

Assuming that we did have such information, we must also accept the fact that we do not have an eager audience of policy makers impatiently waiting to carry out our recommendations. In the present competitive atmosphere for research dollars, we would have to actively lobby for our priorities and programs—a step which many scientists find repugnant.

We are really faced with a choice. We can sit idly by watching support for entomological programs slowly disappearing or we can actively fight for a reassessment of the present policies toward entomological research and development of some realistic long-term goals. Entomology in Canada today is at a very important crossroad. Actions which we do or do not take could have much to do with the path it follows.

III. SUBMITTED PAPERS

THE CORN BORER PERIOD, 1923 TO 1940 THE EFFECTS OF AN INSECT PEST ON THE PRODUCTION OF CORN FOR GRAIN IN SOUTHERN ONTARIO

P. D. KEDDIE

Department of Geography, University of Guelph, Guelph, Ontario

Abstract

This paper grew out of the author's interest in the history of corn for grain production in southern Ontario. It develops the story of the European corn borer, *Ostrinia nubilalis* (Hübner), in southern Ontario over the period from 1923 to 1940 when it was probably the most important single factor affecting corn for grain acreage in the province. It develops this story from a different perspective and point of view than that found in earlier reviews.

* * * * * *

Over the past few decades one of the most notable agricultural trends in Ontario has been the dramatic increases in the acreage of corn, for silage and especially for grain. As Fig. 1 indicates, in 1950 the acreage of corn for grain was recorded as 280,000 acres while by 1971 over 1,260,000 acres were reported (O.M.A.F., 1930, 1961, 1973). What is less generally appreciated today is that acreage of corn for grain was substantial in the early decades of the century, but declined precipitously in the mid 1920's, and that this decline was associated largely with the ravages of an insect pest, the European corn borer, *Ostrinia nubilalis* (Hübner). Silage corn acreage declined as well, but less dramatically, and the role of the corn borer, while important, is less clearly demonstrable.

The period from 1923 to 1940 has been isolated as one when the European corn borer was of overriding significance to the production of corn for grain in southern Ontario. The corn borer did not appear on the scene for the first time in 1923, nor was it totally eliminated as a problem by 1940. However, corn for grain acreage declined precipitously after 1923 and did not increase again rapidly until after 1940. Thus these seemed the most appropriate dates to demarcate as the "corn borer period". After 1940 other factors became of overriding importance in an evaluation of changes in corn for grain production.

From 1923 until 1927 a rapid and dramatic reduction in the acreage of corn for grain occurred in southern Ontario. From about 285,000 acres in 1923 acreage fell to a low of 103,000 acres by 1927. This decline is clearly associated largely with the initial ravages of the European corn borer. Stirrett (1938) claims that acreage was declining due to falling prices. He suggests, further, that increases in the acreage of tobacco and truck crops may also account for some of the decline, particularly in the counties of Essex and Kent.

In 1917 the European corn borer was found in the vicinity of Boston, Massachusetts. By 1919 the insect was reported in western New York state, chiefly on the shores of Lake Erie. With its appearance on Lake Erie the Entomological

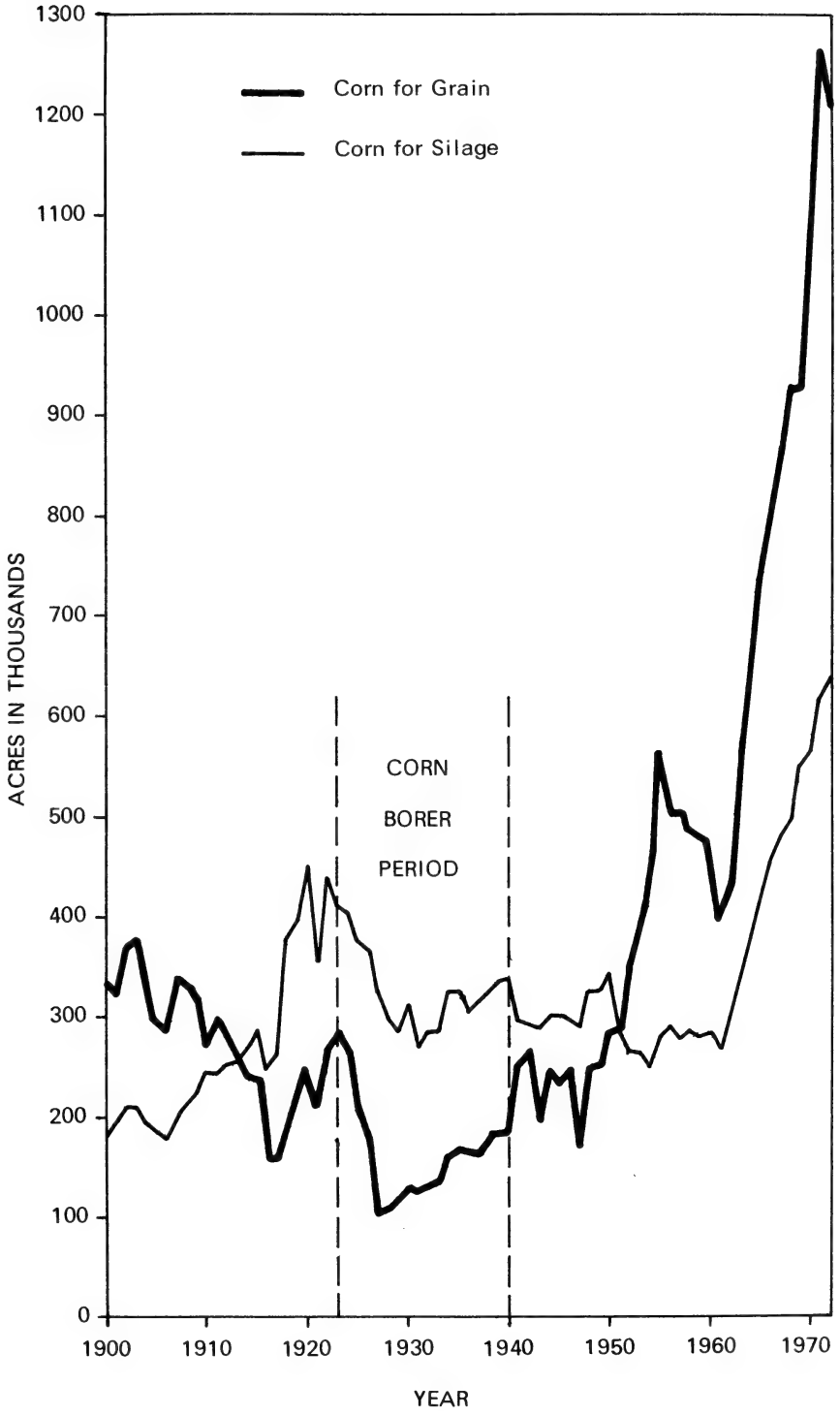

FIGURE 1. Ontario corn acreage, 1900-1972.

Branch of the Ontario Department of Agriculture took steps in an endeavor to determine if it had invaded Canada and an embargo was placed on the importation of corn from infested areas in the United States (McLaine, 1920a).

Field investigators, during the summer of 1920, reported infestation in the Niagara Peninsula and in the vicinity of St. Thomas; it was assumed that both areas had been infested from the United States. A series of articles by McLaine (1920b, 1922, and 1923) have made it possible to map the early spread of the borer (Fig. 2). The western infestation, in the vicinity of St. Thomas, was much greater than initially suspected. A later report stated that infestation in the St. Thomas area probably started in 1909 or 1910, the insect arriving with importations of broom corn from Austria (Caesar, 1924). The area of infestation increased very rapidly (Fig. 2). By 1922 infestation covered the area encompassing the bulk of the corn for grain acreage in southern Ontario.

Lawson Caesar, Provincial Entomologist, provides useful insights into the seriousness of the infestation (Caesar, 1924). He observed the insect's ability to endure the climate and natural control factors acting upon it, and noted the rapidity with which it increased and spread over the province. He concluded that it was by far the worst insect pest ever introduced into Ontario and predicted that it would ruin the corn industry if not checked.

As proof of his pessimistic conclusions, Caesar observed that although the insect had been in the province only 14 or 15 years, by 1924 it numbered in the billions and had spread over nearly all of the southern portion of the province and eastward as far as Prince Edward county. He further noted, that in Elgin county there was scarcely a field of corn with less than 40 percent of the stalks attacked and that in Kent and Essex, where only a few borers were present in 1921, by 1924 nearly all of the southern portion was heavily infested. He found it alarming that only three or four years were required to record such an increase. Another report stated that the infestation in Ontario was recognized as the worst infestation under field conditions in North America, further testimony to the seriousness of the situation (Grisdale, 1922). By 1927 every county where corn was grown to any appreciable extent was infested and the borer was reported in Algoma to the east of Sault Ste. Marie and as far north as New Liskeard (Caesar, 1929).

The apparent delay between initial infestation and marked declines in acreage probably reflects the fact that yields were only seriously affected with considerable infestation. In addition, it was not until 1921 that the borer was first observed in Kent and Essex, the heart of the corn for grain production zone.

Further reports by Caesar give graphic evidence of the role of the borer. In a 1925 report he wrote:

> "To illustrate the damage it is capable of doing when very abundant it will be sufficient to say that in an area in Essex and Kent about twenty miles long by twenty miles wide nearly every field of early corn this year (1925) —and most of the corn was early—has been almost totally ruined. Most of the fields have an average of twenty borers to a plant. In these fields practically every tassel has been broken off; every leaf has been killed and either fallen or hangs close to the stalk; the ears have been broken down, about one-third of them have rotted, the remainder are stunted and most of them riddled by the borers; the stalks are punctured by borer holes, have numerous castings on the outside and are tunnelled on the inside in all directions. The result is that almost every plant has died long before it was mature and many of them have broken over, thus forming a tangled filthy mass almost

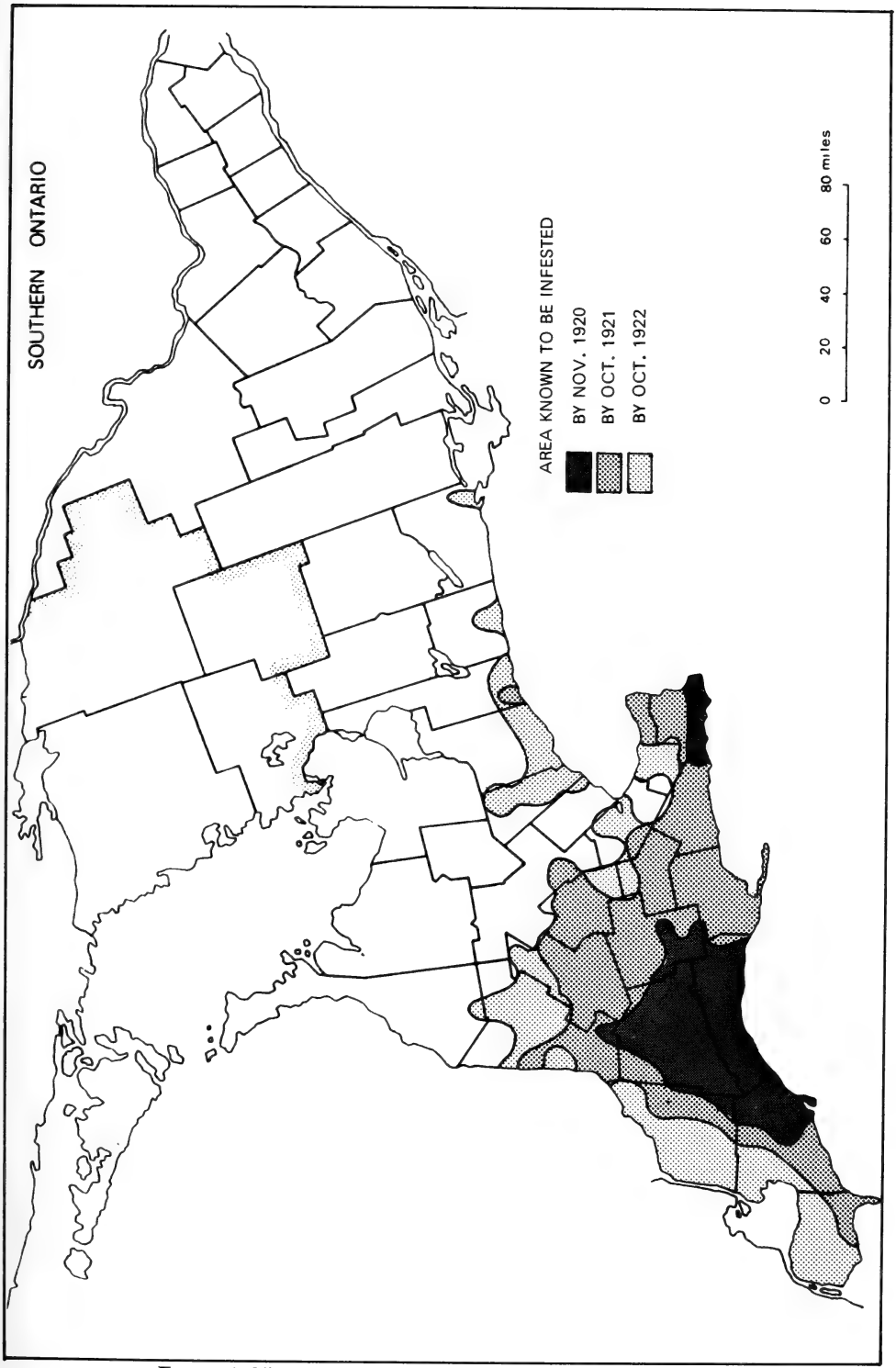

FIGURE 2. The spread of the European corn borer, 1920-1922.

worthless as food for cattle and fit only for hogs to run in and feed upon whatever ears have escaped destruction. No one who has seen these fields can doubt the borer is a terrible menace." (Caesar, 1925).

More precise details of the borers' effects on acreage are contained in a later report by Caesar in which he stated:

"Perhaps the most convincing proof of the insect's destructiveness is that in six years from the discovery of the first borer in Essex the corn acreage of that county has been reduced from 81,256 acres to 20,214 and this almost solely because of the borer. The reduction in Kent has been almost as large as in Essex." (Caesar, 1928a).

Attempts to control the borer were not long delayed. Starting in 1920 a series of quarantines, acts and regulations were initiated. It is not possible here to detail the full content of the quarantines, acts and regulations initiated to control the borer but sufficient will be provided to give the needed insights into control measures.

In the fall of 1920 the first quarantine came into effect. It read in part as follows:

". . . by this notice of Quarantine No. 2 (Domestic) do order that no corn fodder, or corn stalks including broom corn whether used for packing or other purposes, green sweet corn, roasting ears, corn on the cob or corn cobs, shall be moved from any localities in the said quarantined townships to points outside those townships . . . .
Any person who contravenes this quarantine will be prosecuted as provided for in the Destructive Insect and Pest Act". (McLaine, 1920b).

While the area initially quarantined was not large, as infestation spread, the boundaries of the area under quarantine were appropriately expanded. In particularly heavily infested areas a double quarantine came into effect and from such areas corn could not be moved into the surrounding areas under only single quarantine.

L. S. McLaine made the following comments regarding the quarantine:

"To assist in maintaining this embargo, warning notices were placed at all road intersections leading out of the quarantined area. In addition large canvas banners, two and one-half feet by eleven feet, were strung across the main automobile highways warning motorists and others not to take corn from the infested area. On several Sundays and holidays inspectors were stationed on these highways to stop and search cars for sweet corn. . . . A careful watch was also kept on all markets, in co-operation with the fruit and seed inspectors. . . . In addition inspectors were stationed at all the large fall fairs". (McLaine, 1922).

Apparently, judging from the spread of the borer, the quarantines had little if any effect in curtailing the spread of the insect. The ten year delay between initial infestation in Elgin and discovery of this infestation by the authorities concerned had given the borer a major head start.

In 1926, Acts and Regulations were passed as further control measures, the ineffectiveness of the quarantine being readily apparent. The more outstanding features are given below.

The Act read in part:

"4. Every inspector appointed under this Act shall have authority to enter upon any premises where he has reason to believe that the corn borer exists

and shall give such advice and instruction to the owner or occupant of such premises as to the methods to be adopted to control and eradicate the corn borer as the inspector may deem necessary and as may have been approved by the Provincial Entomologist.

5. Where such premises are unoccupied or the owner or occupant neglects or refuses to carry out the instructions of the inspector, the inspector may, by himself, or with such assistance as he may deem necessary, carry out such measures as may have been approved by the Provincial Entomologist for the control and eradication of the corn borer on such premises and he shall certify any expense so incurred to the clerk of the municipality and the amount shall thereupon be entered on the collector's roll and be collected in the same manner as other taxes." (Caesar, 1928a).

The Regulations were essentially a statement of the control measures to be enforced and supervised by the County inspectors. Caesar provides an excellent summary of the control measures.

"1. Cut low or break off all corn stalks.

2. Destroy all the borers in the stalks and ears by ensiling, feeding, shredding or burning.

3. Destroy all left on the field in the stubble, weeds or debris by plowing these down completely.

4. Avoid dragging up the stubble when cultivating. Hence do not use toothed implements, but a disc, and sow the field with a disc drill.

5. Have all of the above control measures completed before June 1st.

6. In heavily infested areas plant most of the corn as late as possible without risking failure of a crop." (Caesar, 1928a).

The difference in methods of handling corn in Essex and Kent, compared to the greater part of the acreage in other areas, was the apparent reason for the more serious infestation in the two south-western counties. Caesar observed that:

"The methods of handling corn in Essex and Kent until this year (1927) have been much more favorable for the rapid increase of the borers than the methods practiced in any other county in the Province. In Essex and Kent the old practice, with a good many exceptions, was not to cut the corn but merely to drive through it, break off the ears, haul them away and husk them. Then in the spring the corn stalks were disced and the ground worked up well and sowed without ploughing. This left the borers in the stalks and weeds on the surface and thus gave them almost ideal conditions to survive. But in the other counties the practice has been to cut all or almost all of the corn and either ensile it or feed it whole, thus killing most of the borers. Moreover the majority of the corn fields are ploughed before the next crop and this too destroys many borers. It is for this reason then that the borers, though increasing rapidly all over the province, have not increased nearly so rapidly in the rest as in Essex and Kent" (Caesar, 1928a).

Caesar (1928b) states that initially only Essex, Kent, Lambton, Elgin, Middlesex, Oxford, Norfolk and Prince Edward were placed under the Act, which was put into operation for the first time in the fall of 1926 (Fig. 3). They were all important corn for grain counties, accounting for 79 percent of the provincial acreage of 285,000 in 1923, 75 percent of 179,000 in 1926 and 67 percent of 103,000 in 1927. Despite their climatic advantages for the production of corn for grain, one notes a reduced percentage of provincial acreage over the three years cited as well as the marked reduction of total acreage. In 1923 the

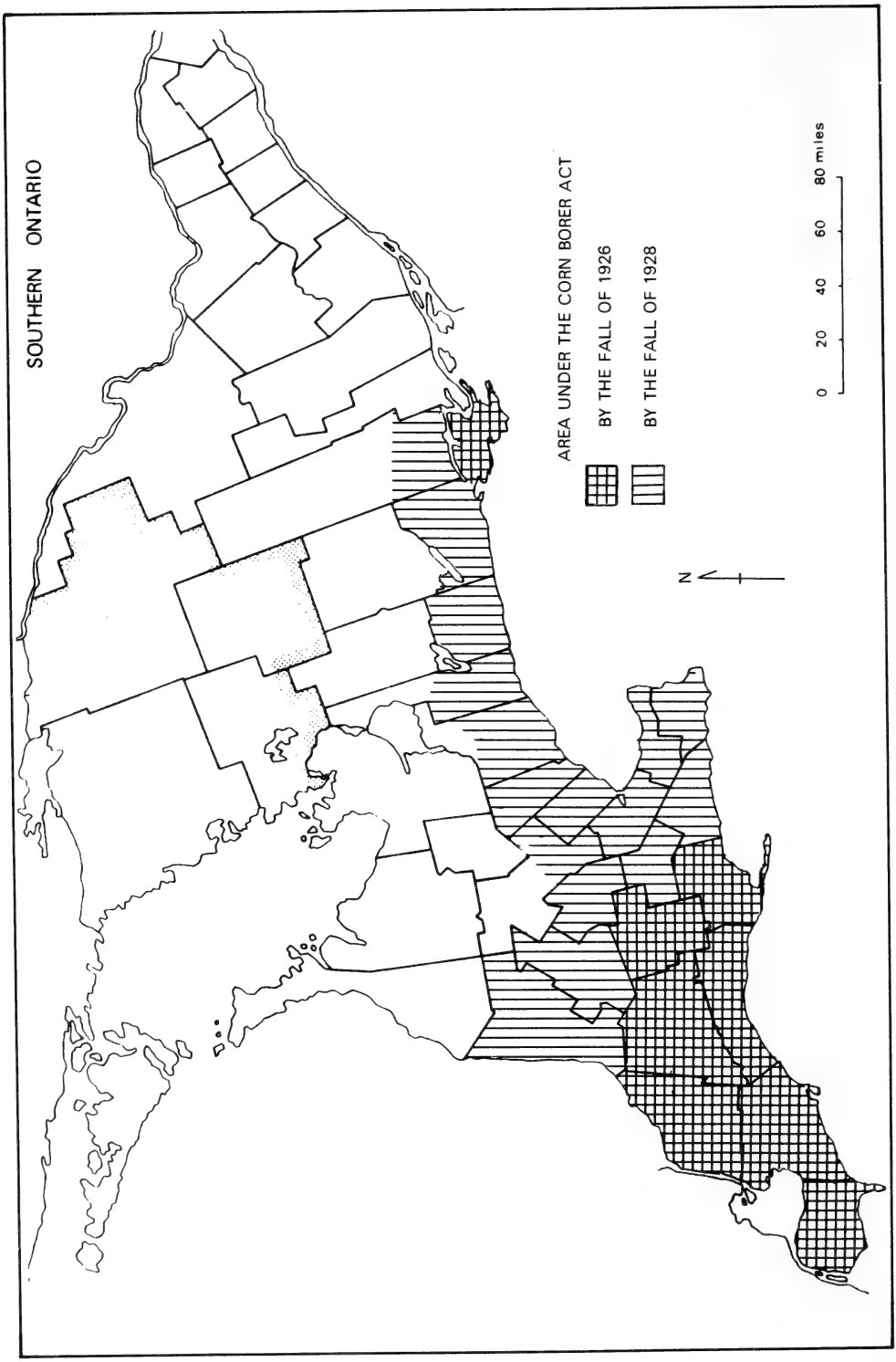

FIGURE 3. Area under the Corn Borer Act.

two major grain corn counties, Essex and Kent, accounted for 51 percent of provincial acreage. This was reduced to 43 percent in 1926 and to only 34 percent in 1927. In the fall of 1927 seven more entire counties and parts of nine others were put under the act and by the fall of 1928 (Fig. 3) the act and its regulations encompassed twenty whole counties and parts of four others. (Caesar, 1929).

Yet a third method of potential control was initiated in the early 1920's. In 1923 the U.S. Bureau of Entomology furnished the Entomological Branch of the Dominion Department of Agriculture with a supply of an imported corn borer parasite (Anon., 1923). A laboratory set up at St. Thomas for breeding and colonizing was moved to Chatham in 1925. By 1928, six European parasites of the corn borer had been introduced and more than three and one half million adult parasites had been liberated (Baird, 1929).

In 1927 the acreage of corn for grain reached its lowest level in southern Ontario since the turn of the century. After this date a slow and fairly uniform recovery of acreage took place, the period of slow recovery terminating in 1940. We have seen evidence of the spread of the corn borer and of the devastation caused by it. Control measures initiated in the period from 1920 to 1927 have also been introduced although little has been said about their effectiveness. Let us now turn to the period of recovery and within this period attempt to evaluate the factors making recovery possible. At this point it might be well to mention again that the corn borer did not suddenly disappear in 1940, only its overriding significance came to an end.

Table I shows the story of the corn borer infestation over much of southern Ontario from 1926 to 1942 (Thompson, 1943). It is partly in the light of this table that the attempt to evaluate the factors making recovery possible must be made. An inspection of the table reveals marked annual fluctuations in the degree of stalk infestation by the corn borer. It also reveals that in 1940, the terminal date of our period, infestation was, with few exceptions, at higher levels than at any time previously. Despite this, as already noted, grain corn acreages increased substantially in 1941 over 1940 levels, suggesting that the 1940 infestation did little damage.

The table immediately raises questions about the role played by the various control measures. We have already seen the ineffectiveness of the quarantine as a method to control the spread of the borer. The quarantine of course cannot be viewed as an attempt to accomplish any more than to contain the areal extent of infestation.

It does not appear that the various parasites introduced played a significant role in control. Caesar (1927) observed that one should not expect any appreciable control through parasites for at least 10 years and probably not for 20 or more. A report by Wishart (1943) indicates that there had been no appreciable success with parasites. Indeed field studies of that year found only a six percent degree of parasitism, while in 1943 this was down to two and one-half percent. A review article by Wressell (1954) does not mention parasites in the discussion of control measures. A more comprehensive review by Wressell (1961), while discussing parasitism, is non-commital on its effects.

The Act and Regulations passed in 1926 were viewed by Caesar as essential to the control of the corn borer. As we have already noted it was in Kent and Essex that methods of handling corn prior to 1927 were most favorable to borer survival. These two counties experienced a marked drop in borer infestation as measured by percentage stalk infestation after a few years under the control measures initiated by the Act and Regulations. Generally by 1928 and 1929 levels of infestation were lower than levels recorded in 1926 and 1927 (Table I).

TABLE I. Average percentage of stalks infested by corn borer.

County	1926	1927	1928	1929	1930	1931	1932	1933	1934	1935	1936	1937	1938	1939	1940	1941	1942
Brant	10	16	15	10	....	7	15	15	....	3	4	19	....	25	63	25	25
Durham	....	6	....	21	12	11	....	....	9	17	15	18	27	....	49	....	19
Elgin	48	37	24	21	9	17	23	17	7	18	16	25	50	40	70	29	33
Essex	83	65	42	36	17	28	28	30	9	20	32	47	34	29	68	34	31
Haldimand	4	30	12	8	....	....	....	....	6	4	6	15	....	....	62	....	24
Halton	....	....	....	9	12	13	12	17	11	8	15	7	20	....	57	....	28
Hastings	....	....	....	10	27	13	....	....	....	....	25	13	....	....	....	....	....
Huron	11	17	12	16	....	....	....	28	....	14	....	16	....	....	46	19	19
Kent	70	49	35	21	22	27	29	35	6	24	20	44	42	34	73	34	35
Lambton	34	57	21	14	7	....	35	23	8	21	20	31	41	38	81	40	36
Lennox	.5	2	12	22	33	27	19	18	....	....	46	18	....	....	....	....	....
Lincoln	5	43	30	11	9	11	13	20	5	4	12	6	....	5	39	33	24
Middlesex	29	36	18	10	9	15	22	20	5	6	14	22	34	33	64	29	25
Norfolk	16	10	20	6	5	5	11	9	3	9	4	30	26	27	70	26	18
Northumberland	....	....	....	18	16	8	....	....	5	....	15	13	....	....	41	....	15
Ontario	....	....	....	9	4	5	....	....	15	17	23	19	21	....	50	....	....
Oxford	31	14	15	18	....	13	16	17	6	17	19	34	29	38	70	22	24
Peel	....	....	10	19	17	22	29	39	11	12	12	11	....	....	63	36	32
Pelee Island	....	....	15	24	5	6	7	12	4	9	13	22	13	17	26	....	....
Perth	....	8	9	16	....	....	....	6	....	12	....	20	....	45	64	25	17
Prince Edward	....	....	18	21	28	17	....	....	....	44	27	22	....	....	....	....	....
Waterloo	....	....	8	5	....	....	13	11	....	7	....	12	....	25	66	22	20
Welland	24	41	26	5	14	10	....	7	2	4	4	16	12	....	35	31	19
Wellington	....	....	....	8	5	....	9	....	....	7	10	3	....	....	65	26	17
Wentworth	....	22	25	9	13	8	17	19	8	6	7	12	17	21	39	28	24
York	....	....	....	....	....	5	22	....	....	16	8	28	....	....	68	26	19

Caesar recognized that, despite the clean-up campaign, levels of infestation would vary from year to year depending on climatic conditions. For example, in a 1930 report, he observed that a hot dry July and early August were very unfavorable to the borer and that high larvae mortality resulted from such conditions (Caesar, 1931). In 1931 he reported that July and early August had been warm and moist and that there was an increase in borers except where the clean up was very good (Caesar, 1932). He went on to observe that:

> "I have felt for the last year that if the borer were to make a very noticeable increase for a season it would be a blessing to all concerned because many of the farmers have begun to think that there was no longer anything to fear from the insect and that the Corn Borer Act should therefore be less strictly enforced. But now I hope that they will see that when we told them that the borer was just as dangerous as ever and could only be kept in control by strict enforcement of the Act we were speaking the truth." (Caesar, 1932).

Despite the observation above, a later report by Caesar (1934) notes that farmers were wondering about the necessity of the act, as no appreciable damage had occurred for seven years. In part he felt that this was because farmers, who were hit by the depression, wished to avoid any added costs. In addition, the County Councils were looking for ways to cut costs and were responsible for half the cost of the salary and activities of the inspector. The result was that in some counties there was strong agitation for repeal or suspension of the Act. The upshot was that any county east of Ontario was allowed to withdraw and a number did, these being Ontario, Northumberland, Durham, Lennox and Addington, and Prince Edward.

Data on levels of stalk infestation would seem to bear out in part the importance of the Act as a significant control. Levels of infestation in the major corn for grain counties dropped markedly in the early 1930's. Wressell, however, had the following to say on the relationship between the Act and borer population:

> "For several years after the Act was passed, it was thought that this measure greatly reduced the borer population. In retrospect it is evident that this means of control was over-rated. It is true that infestation in Ontario was reduced after the introduction of the Act, but other factors appear to be responsible.
>
> The principal factor in the reduction of the borer population in the early 1930's was the weather. Stirrett showed that high temperatures and low precipitation during June and July were associated with low infestation by the borer. This was especially true in 1934, when the infestation by the borer was the lowest ever recorded." (Wressell, 1954).

The comprehensive environmental study by Stirrett (1938) documents the relationships between borer population and the weather more fully.

While the Act may have been over-rated as a means of control, Caesar's evidence of its role in Kent and Essex is difficult to dismiss. Surely, here and in other areas of corn for grain production with similar handling methods prior to 1927, the destruction of stalks and weeds ideal to borer survival must have played a part after this date. This does not negate the importance of the weather.

From Wressell's remarks one could conclude that a series of years climatically favorable to the corn borer would result in a dramatic increase in levels of infestation. In a 1940 report R. W. Thompson, of the Ontario Agricultural College, stated that three good climatic years for the borer in a row accounted for the high level of infestation in that year (Thompson, 1941). However, in 1941

grain corn acreage was considerably higher than in 1940, despite the high levels of infestation in 1940. The notes of alarm evident in the reports of the 1920's are also entirely absent. An important new variable in the situation was hybrid corn.

By 1937 experiments had begun at Guelph with both hybrid and standard varieties, observations being made on variations in borer infestation and stalk break down. The first report by Thompson (1938) on hybrid resistance to borer infestation is non-commital. In his report the next year he stated that a number of hybrids indicated promise for borer resistance in contrast with standard varieties included in the test (Thompson, 1939). Perhaps, more significantly, there were markedly less broken and bent stalks among the hybrids, a condition attributable to the greater strength of hybrid stalks and better root and aerial root systems. Breaking and bending were caused by both borer feeding and strong winds.

A few years later Thompson (1941) observed that it was still difficult to demonstrate hybrid resistance to the borer, despite the fact that some hybrids showed small borer populations throughout three years of testing. He went on to say that the more outstanding characteristic of hybrid corn was the greater stiffness and sturdiness of stalk. Not only was it better able to withstand storm and heavy winds, but it demonstrated an ability to remain erect despite many borer holes. The upright position aided harvesting. Also, if upright, it could be cut shorter and buried more readily, making the disposal of refuse easier.

The 1940 report of the Department of Field Husbandry at the Ontario Agricultural College stated that the use of hybrid corn was now the rule rather than the exception in the corn for grain areas of the province (Dept. of Field Husb., 1941). A report by Thompson (1941), already mentioned in another context, stated that in spite of the big increase in borer abundance there was by no means the damage to corn in Kent and Essex as occurred in 1926 and 1927 when the crop was threatened with complete destruction. The relationship is even more clearly stated in his 1941 report:

> "It should be noted that, especially in the husking corn area of western Ontario there was a big increase in the use of hybrid seed. In Essex and Kent it is estimated that fully 80% of the corn acreage in 1941 was planted to hybrid corn. Such fields, even when heavily infested, showed little or no stalk breakage as was common previously in fields of open pollenated corn." (Thompson, 1942).

It hardly seems surprising that the recovery of corn acreage was slow after the devastation of the mid-1920's. While levels of infestation in the late 1920's and 1930's were by and large consistently below those of 1926 and 1927, they fluctuated. For many farmers in the hard hit areas of corn for grain production the possibility of a complete crop loss must have been a constant threat. The hard times of the depression must have given added reasons for caution. Until the experience of 1940, with high infestation but little damage due to the introduction of hybrid corn, the slow recovery of acreage must have reflected a prevailing mood of caution.

During the 1930's Essex and Kent, the two major grain corn counties, averaged about 63 to 65 percent of provincial grain corn acreage, a recovery from the low of 34 percent in 1927. This represents a higher percentage than in the early 1920's before the real borer devastation began. However, by 1940, even in Essex and Kent, acreages had not returned to the early 1920 averages. But in 1940, as we have noted already, there were very high levels of borer infestation in Essex and Kent with little damage, largely because by this data hybrid corn was the rule

rather than the exception in this area. This experience would seem to account for the fact, that while 1941 saw a provincial increase of 59,000 acres in grain corn, Essex and Kent together experienced an increase of 79,000 acres. Other areas declined in acreage between 1940 and 1941, presumably because they were without hybrid corn or had lower proportions of hybrid corn, and experienced high infestation rates in 1940. While production success with hybrids, despite high infestation, was an important factor in the upswing in Kent and Essex, good market conditions also played a part. Apparently there was a curtailment of imports during the war (Anon., 1954). In 1941, Essex and Kent, with the dramatic increase, accounted for over 81 percent of provincial acreage. As the first counties to capitalize on the new variable, hybrid corn, they were in a new and stronger position of dominance in corn for grain acreage in Ontario, a position which they did not long enjoy. Continued hybrid improvements and other changes in production technology have since led to substantial acreage increases in other counties to the north and east.

In the period after 1940 the corn borer continued as a significant pest but was no longer the critical factor. The 1930's were in fact a period of quiesence (Wressell, 1961) but the previous experience and economic circumstances helped to keep acreages depressed despite the fact that losses were not serious. Significant changes occurred in the life history of the borer in the early 1940's with the development of a second generation (Wishart, 1943 and Beall, 1944). This led to a greater use of chemical control by sweet corn producers who had formerly avoided serious losses by planting late (Wressell, 1961). No evidence has been found on the effect of the development of a second generation on corn for grain production where insecticides have played only a minor role in control. In reviewing the literature it seems reasonable to conclude that a period beginning with the noticeable effects of a new variable, the corn borer, came to an end with the field introduction of another new variable, hybrid corn. Consequently, in viewing the history of corn for grain production in southern Ontario, the years from 1923 to 1940 seem the appropriate ones to demarcate as the "corn borer period".

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THE DISTRIBUTIONAL PATTERN OF *CRIOCERIS ASPARAGI* (L.) (COLEOPTERA: CHRYSOMELIDAE) ON ASPARAGUS[1,2]

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Abstract

Studies on the distributional pattern of the asparagus beetle, *Crioceris asparagi* (L.), were carried out in plots of asparagus in eastern Ontario during 1971 and 1972. Counts of 7 life stages were overdispersed and did not conform to the Poisson distribution owing to a preponderance of uninfested and highly infested plants. However, when the negative binomial series was fitted to the observed distributions, the discrepancies were not significant when tested by chi-square. For all stages, the variance was proportional to a fractional power of the mean.

[1]Contribution No. 421, Ottawa Research Station.

[2]From a thesis submitted by the senior author to Department of Biology, Carleton University, in partial fulfillment of the requirements for a M.Sc. degree.

Introduction

An appreciation of the spatial arrangement of an insect pest is fundamental to proper estimation of its numbers. Such knowledge contributes not only to the development of precise and efficient sampling designs for detailed population studies, but also to the establishment of appropriate methods of transforming the data for statistical appraisal. Moreover, it may form the basis for more extensive sampling as in sequential techniques designed for crop protection.

In the study of insect populations, counts are usually made of the number of individuals in natural units of their habitat. These may be summarized in a frequency distribution showing the number of units containing 0, 1, 2, 3 . . . individuals of a given species. If an insect distributes itself over a number of units at random, the distribution of numbers per unit will approximate a Poisson series, the variance of the population (s^2) being equal to its mean (m). If aggregation occurs, there are more zeroes and high values than expected, and as a result the variance exceeds the mean. This departure from randomness is termed "overdispersion."

The negative binomial is the most useful distribution so far proposed for overdispersed insect counts. Successive terms of the distribution are obtained from the coefficients of powers of x in the expansion of $(q\text{-}px)^{-k}$, where $p = m/k$ and $q = 1 + p$. The parameter k, which is a measure of aggregation, increases in size as the variance approaches the mean, and decreases as the variance departs from the mean. The statistics of the negative binomial have been outlined by several authors (Fisher 1941, Anscombe 1950, Bliss and Fisher 1953).

More recently, Taylor (1961, 1965) has shown that the spatial pattern of a large number of plants and animals is such that the variance is proportional to a fractional power of the mean: $s^2 = am^b$, where b is the slope and a the intercept on a plot of log (variance) against log (mean).

In the present study, the Poisson and negative binomial distributions were fitted to 129 sets of field data pertaining to the asparagus beetle, *Crioceris asparagi* (L.). In addition, the relationships between variance and mean expected with the above two distributions and with Taylor's power law were plotted and compared with those of the observed counts.

Life History and Habits of *C. asparagi*

In eastern Ontario, the adults emerge from hibernation about the middle of May and feed on the new asparagus growth for a few days before they begin to lay their eggs. The eggs are slightly over 1 mm long, dark brown, and are attached singly on end to spears and developing foliage. The incubation period is 7 to 12 days, depending on temperature. The grey, slug-like larvae feed on the foliage throughout their development and pass through four instars over a two- to three-week period. When fully fed, they drop to the ground and form shallow cells just beneath the soil surface in which they construct tough silken cocoons impregnated with soil. The adults emerge in 7 to 10 days. There are three generations a year with peaks of egg-laying at the beginning of June, early July and early August. The adults overwinter in the dead stalks and ground litter.

Sampling Procedure

Most of the counts were taken during 1971 and 1972 from an isolated half-acre field of Viking asparagus near Richmond, Ontario. The crop, produced from 3-year old roots planted in the spring of 1971, was grown in accordance

with commercial practice and was not harvested to avoid disturbing the insect stages. Clean cultivation was practiced but at no time were insecticides used in the area.

The sample unit chosen for the above-ground stages was the individual plant, which produced an average of five shoots. The field was laid out in a 4 x 4 grid to give 16 plots of equal size. On each date of sampling, six plants were chosen at random from each plot and four plants were taken from the field as a whole, making a total of 100 plants. The plants were examined from base to tip for eggs, larvae, and adults.

For pupal counts, the sample unit chosen was a 12" x 12" quadrat of soil, selected at random from beneath the foliage canopy. On each date of sampling, one such unit was selected at random from each plot and the soil removed to a depth of 1 inch. The soil was washed through a 10-mesh wire sieve to recover the pupae.

Handling of the Data

To compare the Poisson and negative binomial series to the observed distributions, a computer program was adapted from Davies (1971). This program tests the fit of the Poisson distribution by the index of dispersion method (Southwood, 1966) and then generates theoretical values for the negative binomial, performing a chi-square test to check the goodness of fit between observed and expected values. It calculates the individual values of k for the negative binomial using the maximum likelihood method of Bliss and Fisher (1953).

Scope of Study

Numbers of the insect were recorded on 47 occasions. Since two or more stages were present each time, a total of 110 stage samples were obtained. In addition, 19 samples were taken from commercial fields of asparagus at Collingwood, Ontario and St. Amable, Quebec. Individual plant totals and sample means ranged as follows:

	Egg	First & Second Instars	Third Instar	Fourth Instar	Pupa	Adult
Totals	0-104	0-63	0-42	0-58	0-9	0-27
Means	0.1-10.2	0.1-5.1	0.1-3.7	0.1-3.4	0.1-2.5	0.1-11.9

Results and Discussion

When Poisson distributions were fitted to the observed distributions, the index of dispersion test showed that discrepancies between observed and expected values were significant in 127 of the 129 cases (Table I). As a rule, there were greater numbers of uninfested and highly infested plants than expected. However, when the negative binomial series was fitted to the observed distributions, few of the discrepancies were significant when tested by chi-square.

The relationships between variance and mean for 121 counts[2] of the above-ground stages of *C. asparagi* are illustrated in Figs. 1 and 2. The overdispersed nature of the data is clearly shown by the plotted values which depart noticeably from the line of Poisson expectation ($s^2 = m$). The values approach the line of negative binomial expectation ($s^2 = m + m^2/k$) derived with a common k, al-

[2]Counts of pupae were not sufficient for graphic presentation.

though the use of a single value in fitting the line may not be appropriate. The plotted points also encompass a line of the form $s^2 = am^b$, supporting the power law concept of Taylor (1961).

TABLE I. Results of fitting the Poisson and negative binomial distributions to counts of *C. asparagi*, 1971-72.

Stage	No. of counts	Counts not fitting*	
		Poisson	Negative binomial
Egg	24	23	8
First and second instars	16	16	4
Third instar	19	19	1
Fourth instar	21	21	1
Pupa	8	8	1
Adult	41	40	7
	129	127	22

*Discrepancies significant at 5% level.

Common k values for the negative binomial were obtained by plotting the $\overset{*}{m}$-m (mean crowding-mean density) relationship as described by Iwao (1968). To test the validity of fitting a common k, the reciprocals of the individual k values for each stage were plotted against individual log means as suggested by Southwood (1966). In all cases, significant trends in the data occurred, indicating that a common k value was not appropriate.

The fact that Taylor's power law relationship holds for the asparagus beetle is not surprising since the growth of insect populations follows a geometric rather than arithmetic scale. The statistics of this relationship, and the biological assumptions underlying it have yet to be worked out (Harcourt, 1965).

Transformation of Counts

Many methods have been proposed for stabilizing the variance of overdispersed insect distributions. A common practice with the negative binomial is to convert the original data to the logarithmic scale, using a transformation such as $\log (x + k/2)$, where x is equal to the observed count (Anscombe, 1948). Based on Taylor's power law, Healy and Taylor (1962) have tabled values for a transformation of the form $x^{1-b/2}$. The appropriate conversion usually leads also to additivity (Bliss and Owen, 1958).

Each of these transformations require the calculation of one or two parameters prior to converting the data. To obviate this need, $\log (x + 1/2)$ might be used without significant loss of precision. A further possibility would be use of the transformation tables provided by Healy and Taylor (1962) using 1.37, the average value for b obtained for *C. asparagi* in the present study. Either transformation should nearly satisfy the assumptions underlying the analysis of variance.

Acknowledgments

The authors are indebted to Dr. G. R. Carmody, Biology Department, Carleton University for assistance in adapting the computer program. Financial support from the National Research Council of Canada is gratefully acknowledged.

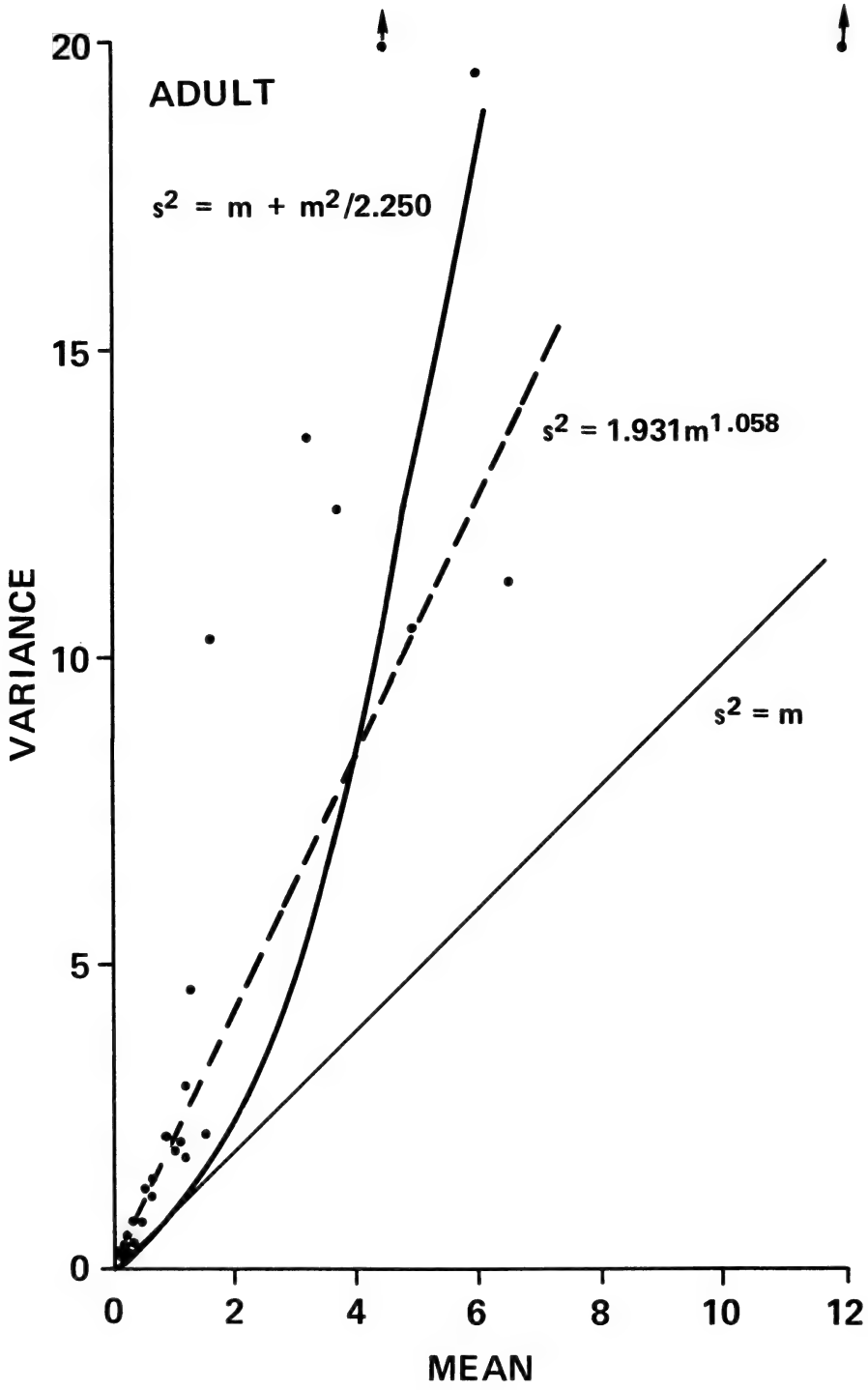

FIGURE 1. Variance-mean relationships for counts of adults of *C. asparagi*. Each point plotted is based on a sample of 100 plants.

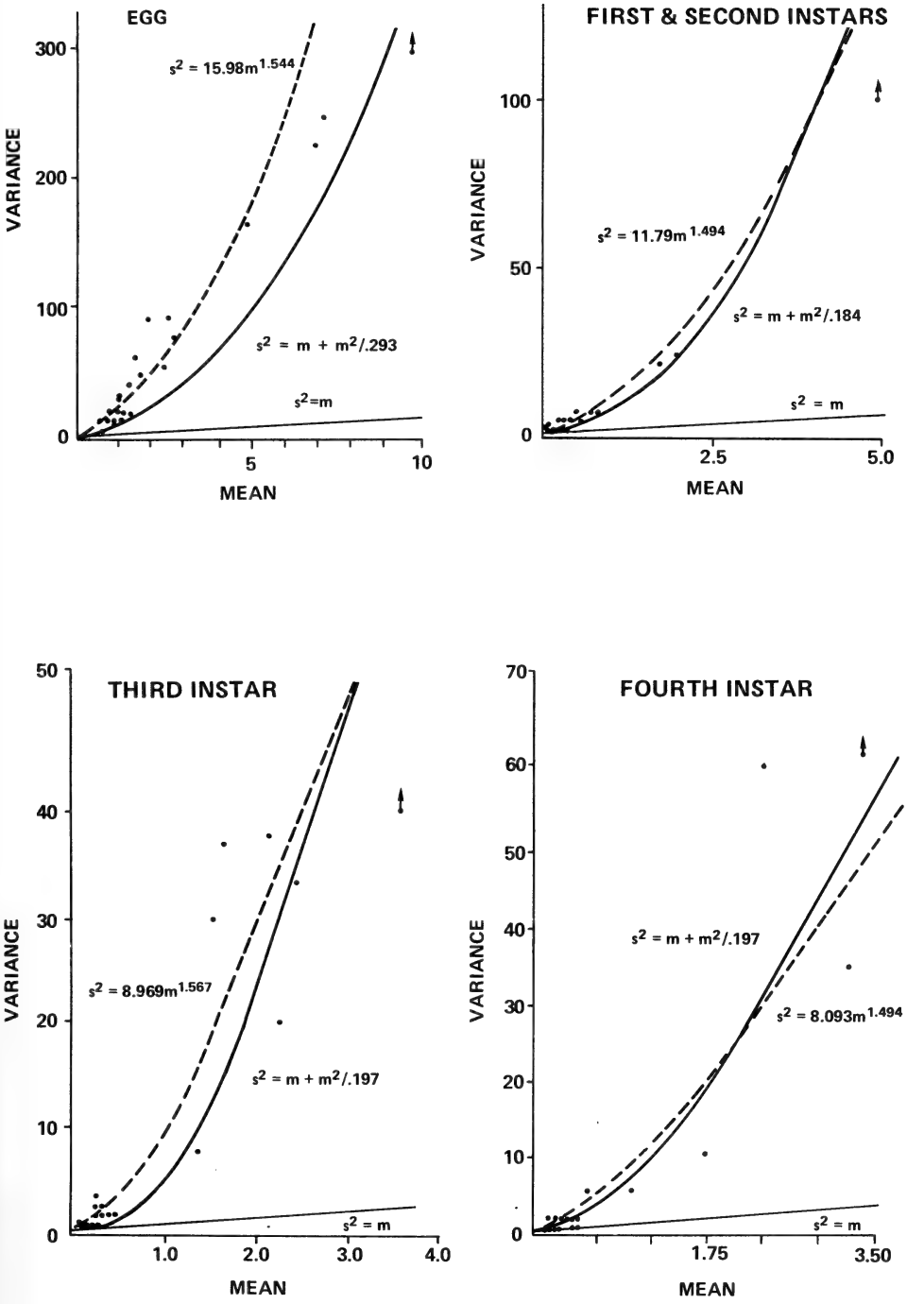

FIGURE 2. Variance-mean relationships for counts of five stages of *C. asparagi*. Each point plotted is based on a sample of 100 plants.

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THE ARTHROPOD FAUNA IN UNSPRAYED APPLE ORCHARDS IN ONTARIO II. SOME PREDACIOUS SPECIES

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Abstract

One hundred and nine predacious insects in 6 orders and 21 families were recovered from unsprayed apple orchards at Vineland, Ontario. Fifty Araneida in 14 families and 6 Acarina in 4 families were also observed.

Although the early larval instars of the codling moth appeared to be generally important as a food source the numbers of this pest were neither regulated nor controlled by the predators.

* * * * * *

Introduction

Several predacious arthropods have been reported previously from unsprayed and commercial apple orchards in Ontario (cf. Putman, 1963). Hikichi (1953) mentioned 13 predators of the codling moth in orchards in Norfolk county. Garlick (1955) in more detailed investigations in an orchard at Vineland reported about twice this number of predacious species feeding on several prey. However, these authors did not report on groups such as the Staphylinidae, and only a few species of Carabidae, Diptera, Hemiptera and Araneae were mentioned. This study was undertaken therefore to determine the species currently present in the orchards and to assess their relative importance as factors influencing the periodicity of pest populations.

Materials and Methods

Studies were conducted in two unsprayed blocks of mature apple trees at Vineland, Ontario (Hagley, 1970) during the period 1969-1974. Prior to 1969 both blocks had received 1 or 2 insecticide and 4 to 7 fungicide sprays per season. During the study period only the fungicide Cyprex (65% WP at 1.4-2.4 kg/hect) was applied.

Predators were collected on sticky traps ca. 12 x 14 cm in size, made of hard weather-proofed cardboard coated with tanglefoot on both sides and hung at eye level in the tree canopy; in pitfall traps made from wide-mouthed mason jars 16 cm long x 7.5 cm in diam. into which was fitted a celluloid cylinder with a platform of saran screen in the middle. The screen prevented the death of insects by drowning due to accumulation of water in the jars after rain. A suction trap was also used in one block throughout the season. All traps were examined twice weekly from about the last week in May to early September.

Collections were also made by tapping branches over a cloth tray during May and June; throughout the season by weekly examination of 50-100 fruit clusters taken at random in the orchards; and in light traps (Ellisco, 15-watt, multidirectional) used for monitoring the activity of some pests. The feeding preferences of some predators were studied in the laboratory. Insects collected in the orchard were held in glass jars 8 cm high by 7.5 cm in diam. A piece of Whatman No. 1 filter paper, together with a piece of crumpled paper towelling was placed in each jar and moisture was provided by a moistened dental wick. The jars were held in the laboratory under ambient conditions and live prey, collected in the orchard, was provided to the predators as needed.

Log transformations were made on all data prior to analysis.

Results and Discussion

With the exception of the Hemiptera, predator populations were generally low during 1969-1971. This was probably due to the previous use of insecticides as the numbers of predators increased considerably during 1972-1974. The species recovered are listed below.

(A) Coleoptera

(i) Carabidae — Carabids were monitored in pitfall traps only during 1973 and 1974. They were not numerous in the study orchards and fewer than 50 specimens were taken annually in either orchard. However, about 40 species were recovered, many of which had been previously reported from commercial peach orchards on the Niagara peninsula (Herne, 1963). In 1973 *Agonum* sp., *A. decorum* Say. and *Diplochaeila impressicolis* (Dej) were most abundant, while in 1974 *Harpalus affinis* Schr., *Amara aenea* Dej., *Pterostichus chalcites* Say and *P. melanarius* Ill. predominated. Other species recovered were: *Agonum placidum* Say, *A. lutulentum* LeC., *Amara* sp., *Anisodactylus sanctaecrucis* F., *A. interstitialis* Say, *A. sericeus* Harris, *Bembidion bifossulatum* LeC., *B. chalceum* Dej., *B. quadrimaculatum oppositum* Say, *Calosoma frigidum* Kirby, *Carabus granulatus granulatus* L., *Chlaenius pennsylvanicus* Say, *C. sericeus* Forst, *C. tricolor* Dej., *Harpalus pennsylvanicus* Dej., *Lasiotrechus discus* F., *Loricera pilicornis* F., *Patrobus longicornis* Say, *Pterostichus lucublandus* Say, *P. mutus* Say, *Stenolophus comma* F., and *S. ochropelus* Say.

Several species were also taken frequently at light. These included *Agonum* spp., *Bradycellus rupestris* Say, *Colliurus pennsylvanicus* L., *D. impressicolis* Dej.,

Lebia atriventris Say, *L. fuscata* Dej., *L. solea* Hentz, *L. viridis* Say, and *S. comma.*

In the laboratory some carabids readily consumed all larval stages of the cankerworm, *Palaeacrita vernata* (Peck), the codling moth, *Laspeyresia pomonella* L., the budmoth, *Spilonota ocellana* (D & S), and the green apple aphid, *Aphis pomi* DeG. Larvae of the tent caterpillar, *Malacosoma americanum* L., mature *Hedia nubiferana* (Hübner) larvae, and rosy aphids, *Dysaphis plantaginea* (Pass.), were not readily eaten.

The nocturnal habits of many carabids particularly the larger and more voracious species, e.g., *P. chalcites, D. impressicolis* and *H. affinis* should enable them to prey on the larvae of several tortricids which move around at night. This is especially true of those species that are present during May and early June when the larvae of several pests are present and also during July and August when codling moth larvae are present in large numbers. Rivard (1974) has also suggested that carabids might be important predators in apple orchards in Quebec.

The smaller carabids, e.g., *Bembidion* spp., were probably more important as predators of the eggs and young larvae of these tortricids (cf. Wishart *et al.* 1956; Frank, 1971). Coaker and Williams (1963) also reported species of *Harpalus* and *Amara* as predators of cabbage root fly eggs.

Some species fed on apple blossoms in the absence of insect prey and readily consumed cadavers of their own species. With the possible exception of *Agonum* and *Pterostichus* spp. the insects were unable to capture and remove prey from rolled leaves and in no case were pupae attacked.

(ii) Coccinellidae (Fig. 1) — The numbers of coccinellids varied greatly from year to year and fewer than 40 adult specimens were collected annually at Vineland between 1970-1972. However, 17 species were recovered during this period and the most abundant were: *Hippodamia tredecimpunctata tibialis* (Say) in 1970 1972 and 1973; *Chilocorus bivulneratus* Mulsant in 1971; *Adalia bipunctata* L. in 1974. *Ceratomegilla maculata lengi* Timb. which was found primarily on the tree trunk and branches was present in large numbers in all years and preyed extensively on eggs of the European red mite, *Panonychus ulmi* (Koch), (cf. Putman, 1967). *Coccinella transversoguttata richardsoni* Brown, *C. trifasciata perplexa* Mulsant, and *Scymnus* sp. were also frequently observed. The coccinellids, like the syrphid flies are predominantly aphid predators although they have been reported (Putman, 1964) to feed on other insects and on pollen, nectar, honey dew and fungal spores. It has also been reported, (Jaynes and Marucci, 1947), that adults of some species feed on codling moth eggs. Adults emerged from overwintering quarters very early in the spring when few pests were present and, although larvae of some species were observed on the foliage during the summer, the low numbers present suggested that they had little effect on the pest populations present.

Other species recovered were: *Anatis mali* Auctt., *A. quindecimpunctata* (Oliv.), *Brachyacantha ursina* F., *Coccinella novemnotata* Herbst., *C. undecimpunctata* L., *Cycloneda munda* (Say), *Hyperaspis undulata* (Say), *Neomysia* sp.

(iii) Staphylinidae — *Philonthus rectangulus* Sharp, *P. varius* Gyll, and *P. varians* Payk. were frequently taken in both study orchards. Although these insects were not studied in laboratory feeding trials, several authors (Wishart *et al.* 1956; Eghtedar, 1970; Coaker and Williams, 1963) have reported that larvae and adults of other *Philonthus* spp. are predacious on the eggs and young larvae of several Diptera. Other species that occurred were: *Homeotarsus sellatus* LeC.,

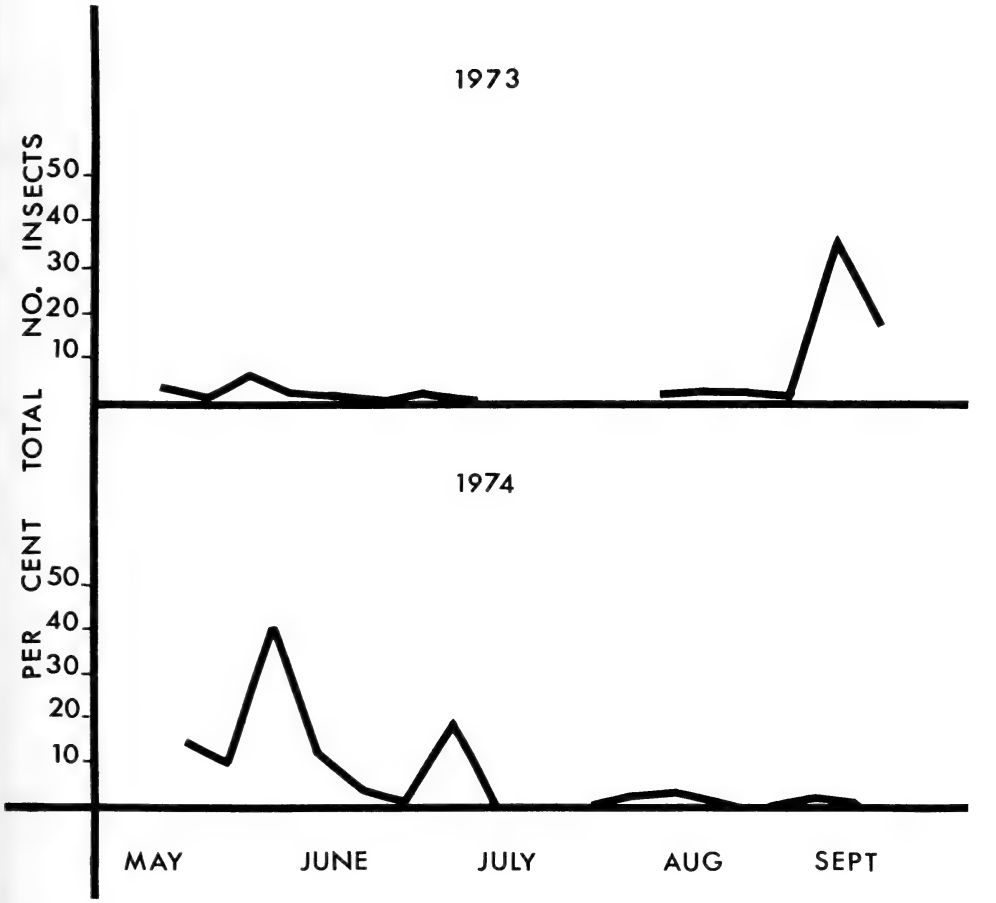

FIGURE 1. Occurrence of Coccinellidae in 1973 and 1974.

Lathrobium sp., *Nudobius* sp., *Paederus littorarius* Gray, *Tachyporus chrysomelinus* L., and *T. elegans* Horn.

(iv) Trogositidae — *Tenebroides corticalis* Welsh was frequently recovered from the tree trunks in both orchards. The larvae and adults have been reported feeding on codling moth larvae (Garlick, 1955) and as important general predators (Putnam, 1963).

(v) Cantharidae — Adults of *Cantharis* sp., *Podabrus flavicollis* LeC., *P. rugosulus* LeC. and *P. tomentosus* Say were frequently recovered on apple foliage. The larvae of these species live under bark and trash and feed on immature and small imaginal insects. Arnett (1968) has reported that the adults feed on the nectar and pollen of many flowers.

(vi) Pyrochroidae — *Dendroides canadensis* Latr. occurred occasionally on the foliage of apple trees. Its habits were similar to those of the cantharids (Arnett, 1968).

(B) Diptera (Fig. 2)

(i) Syrphidae — Several syrphid species including *Syrphus knabi* Shan., *S. torvus* O.S., *S. vittafrons* Shan., *Allograpta obliqua* (Say), *Allognostra fuscitarsis* (Say) and some *Metasyrphus* spp. were observed. The larvae of these aphidophagous species fed primarily on *A. pomi* and *D. plantaginea.* Generally the abundance of these syrphids appeared to be dependent upon the numbers of the latter pests which were seldom abundant. Consequently, only 22 and 80 syrphids were collected in 1972 and 1973 respectively, at Vineland. In both years *Syrphus* spp., particularly *S. knabi* and *Metasyrphus* sp., predominated. In 1974, 26 syrphids were recovered, *M. americanus* (Wied) and *A. obliqua* being the main species reared from aphid colonies. Other predacious syrphids recovered were: *Mesograpta marginata* (Say), *Metasyrphus lapponicus* (Zett), *Sphaerophoria* sp., *S. robusta* Cn., *S. contiqua* Macq. and *Syrphus* sp.

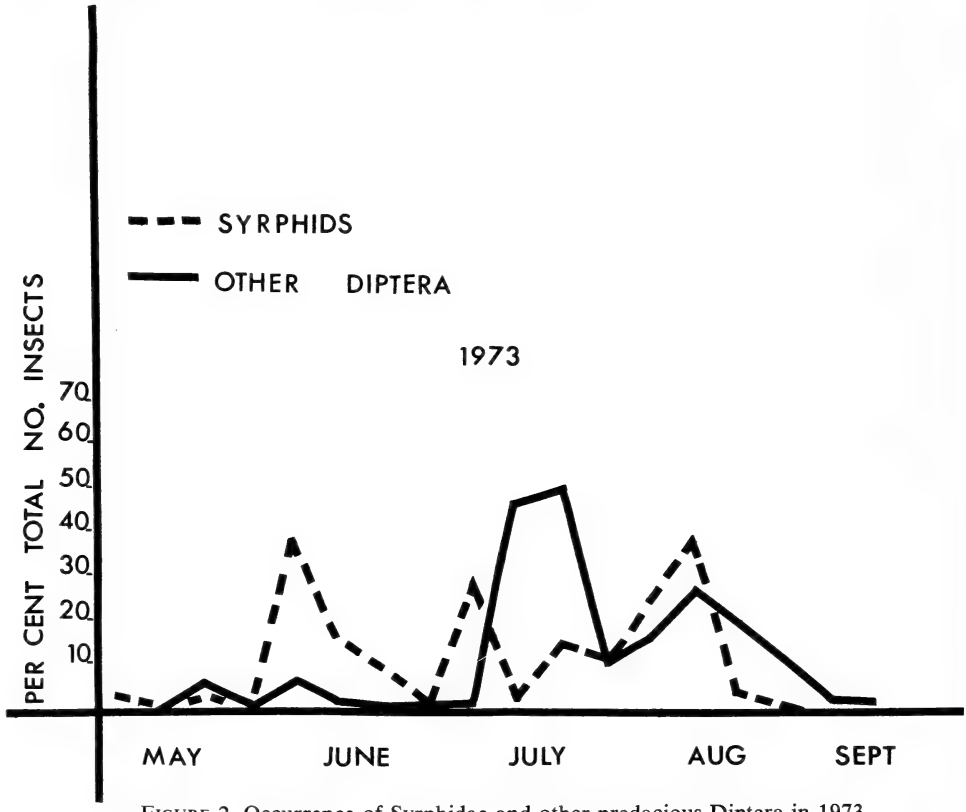

FIGURE 2. Occurrence of Syrphidae and other predacious Diptera in 1973.

Large numbers of scatophagids and dolichopodids were also recovered in 1973. The predominant species that occurred, as well as those of other predacious Diptera frequently recovered in traps and observed on the foliage of apple trees, were: (i) Scatophagidae — *Scatophaga furcata* (Say), *S. stercoraria* (L); (ii) Asilidae — *Dioctoria baumhaueri* Mg., *Sphecomiella valida* (Harris); (iii) Dolichopodidae — *Dolichopus* sp., *D. bifractus* Lw, *Condylostylus patibulatus* (Say); (iv) Rhagionidae — *Rhagio tringarius* (L.), *Chrysopilus ornatus* (Say), *C. thoracicus* (Fab.)

The larvae of many of these species live in the soil and on grass and other plants and are not of importance as predators. The adults, however, are active general predators feeding on immature and small adult insects.

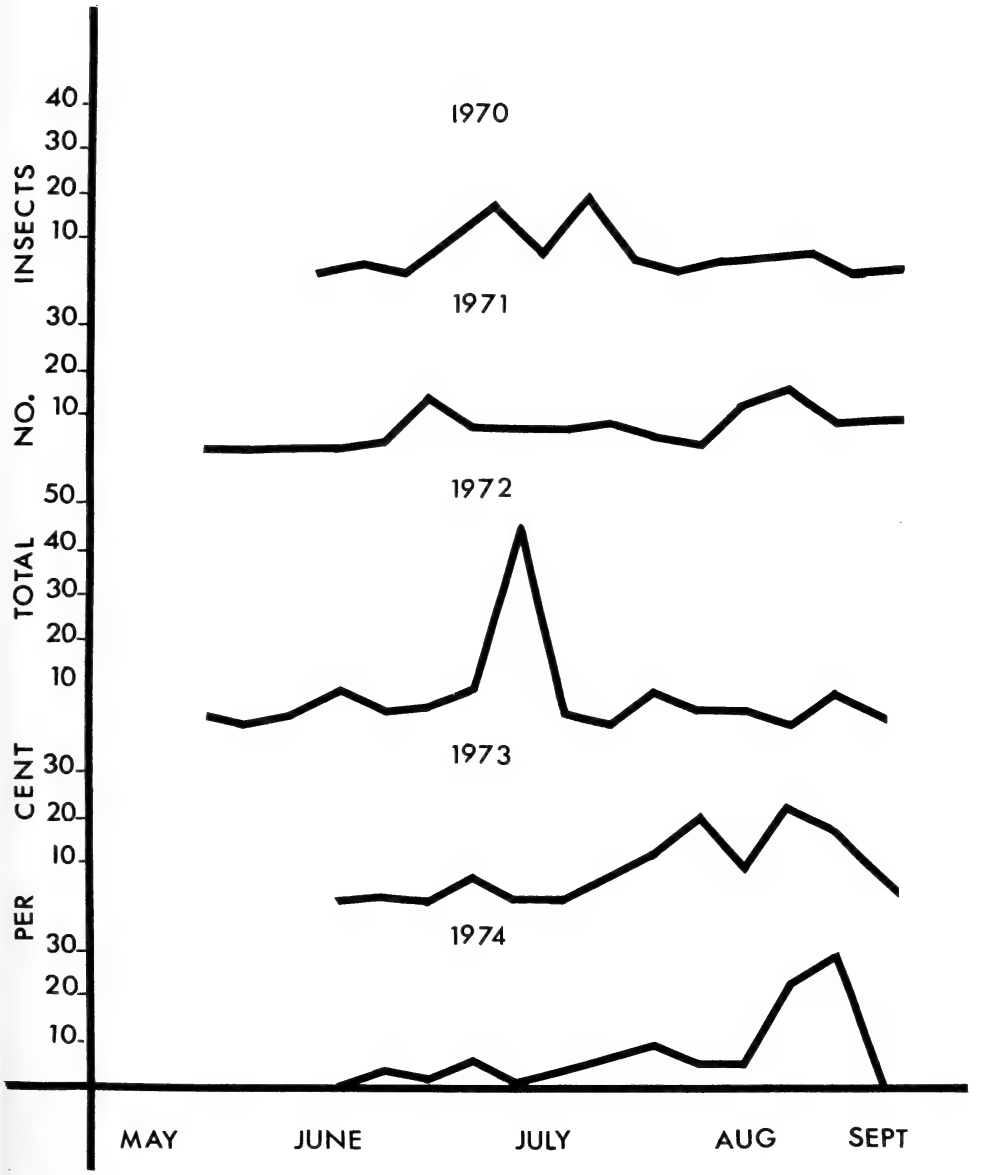

FIGURE 3. Occurrence of predacious Hemiptera, 1970-1974.

(C) Hemiptera (Fig. 3) — The mirid, *Phytocoris* sp., was generally the most abundant predator, and ranged from 22% of total predacious Hemiptera in 1970 to 70% in 1973. The only year in which it did not predominate was 1970 when *Deraeocoris fasciolus* Knight was most abundant. These mirids probably attacked young insect larvae leafhoppers and mites. The adults and nymphs of the pentatomid, *Podisus maculiventris* Say, also attacked several species of Lepidoptera including 4th and 5th instar codling moth larvae. Most other Hemiptera were very effective aphid predators particularly the mirids, *Campylomma verbasci* (Meyer) and *Pilophorus perplexus* D & S, and the anthocorid, *Anthocoris nemoralis* (F.). MacLellan (1962) has reported that four mirids, including *Phytocoris* sp. and *P. perplexus,* are important predators of the eggs and young larvae of the codling moth. Peak occurrence of all Hemiptera usually occurred in the study orchards about mid-July and in the latter part of August and/or early September, and these species probably fed extensively on codling moth larvae which were abundant at these periods. Other species recovered were: (i) Miridae — *Deraeocoris* sp., *Hyalioides vitripennis* (Say), *Plagionathus* var *politus* Knight, *Phytocoris* sp.; (ii) Nabidae — *Nabis* sp., *N. ferus* (L.); (iii) Pentatomidae — *P. modestus* (Dallas) *P. serieventris* Uhler; (iv) Reduviidae — *Reduvius personatus* (Linn.), *Acholla multispinosa* DeG.; (v) Zelinae — *Zelus audax* Banks.

(D) Neuroptera (Fig. 4, 5)

Adults of the green lacewing, *Chrysopa oculata* Say (Fig. 4) and the brown lacewing, *Hemerobius humulinus* L. (Fig. 5), were common in both orchards. Larvae of these species, although infrequently seen on the foliage, were often recovered in aphid colonies and appeared to feed mainly on these insects. *C. oculata* has also been reported to feed on the eggs and young larvae of several insects (Garlick, 1955; Lavallee and Shaw, 1969), and on the European red mite (Cutright 1951). Putman (1932), however, did not consider *C. oculata* to be an important predator of eggs and larvae of the Oriental fruitmoth, *Grapholitha molesta* Busck., and Jaynes and Marucci (1947) also reported that chrysopid larvae did not feed on codling moth eggs.

A few individuals of *Sympherobius amiculus* (Fitch) were also recovered.

(E) Orthoptera

The crickets, *Gryllus pennsylvanicus* Burmeister and *Allonemobius fasciatus* (De Geer), were abundant. Monteith (1971) has suggested that these species are important predators of pupae of the apple maggot, *Rhagoletis pomonella* Walsh, in an unsprayed apple orchard in eastern Ontario.

(F) Thysanoptera

Haplothrips subtilissimus (Haliday) (=*H. faurei* Hood) was infrequently recovered from apple foliage. This species has, however, been reported as an important predator of codling moth eggs (Putman, 1963, McLellan, 1962).

(G) Araneida

Spiders were few in number on the foliage and on the trunks of trees in the study orchards. However the following species were present; (i) Amaurobiidae — *Amaurobius bennetti* (Blackwall); (ii) Araneidae — *Araniella displicata* Hentz, *Araneus diadematus* Clerck, *Araneus* sp., *Neoscona arabesca* (Walck.); (iii) Clubionidae — *Clubiona moest* Banks, *C. abboti* Koch, *Clubiona* sp., *Micaris* sp., *Trachelas tranquillus* (Hentz); (iv) Dictynidae — *Dictyna* sp., *D. sublata* (Hentz); (v) Erigonidae — *Erigone blaesa* Crosby and Bishop; (vi) Graphosidae — *Zelotes subterraneus* (C. L. Kock); (vii) Lycosidae — *Trochosa*

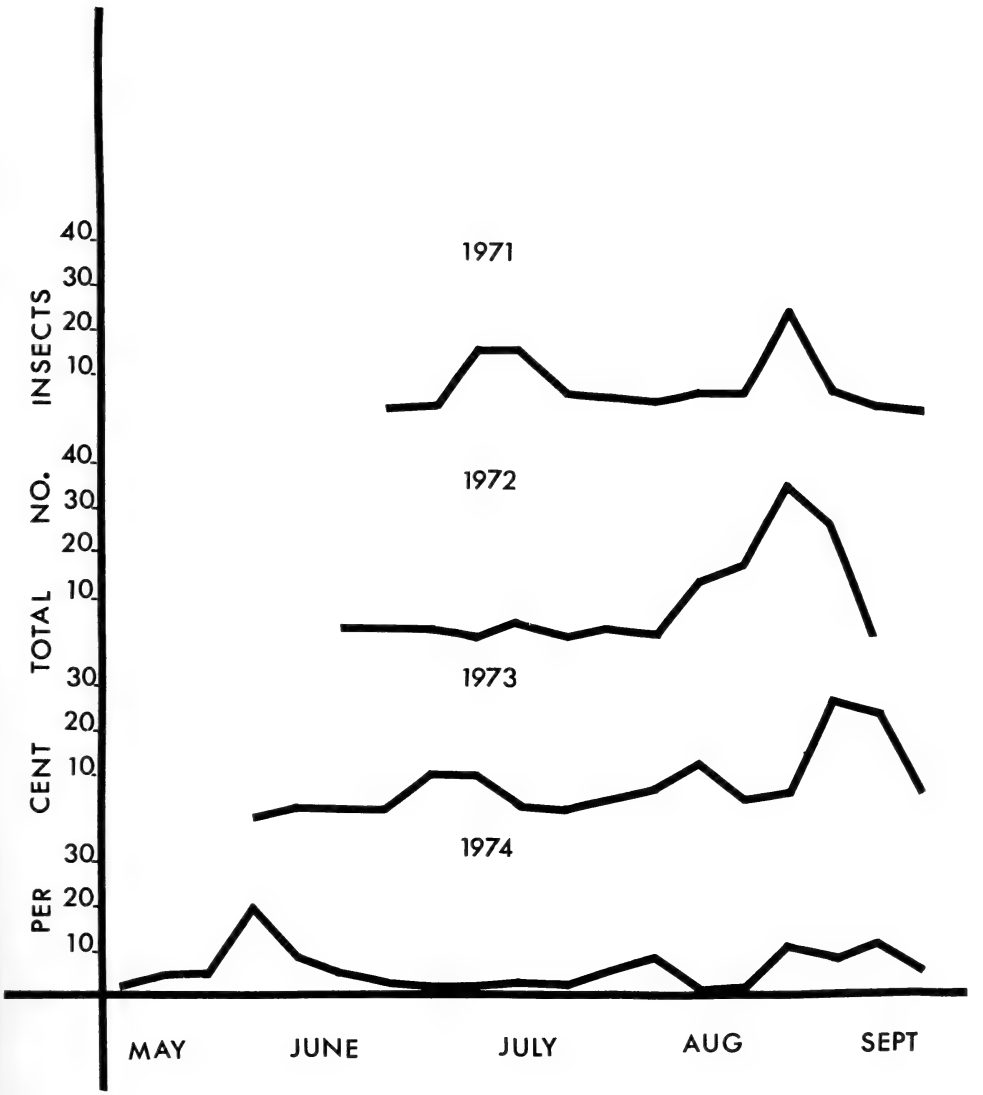

FIGURE 4. Occurrence of *Chrysopa oculata*, Say 1971-1974.

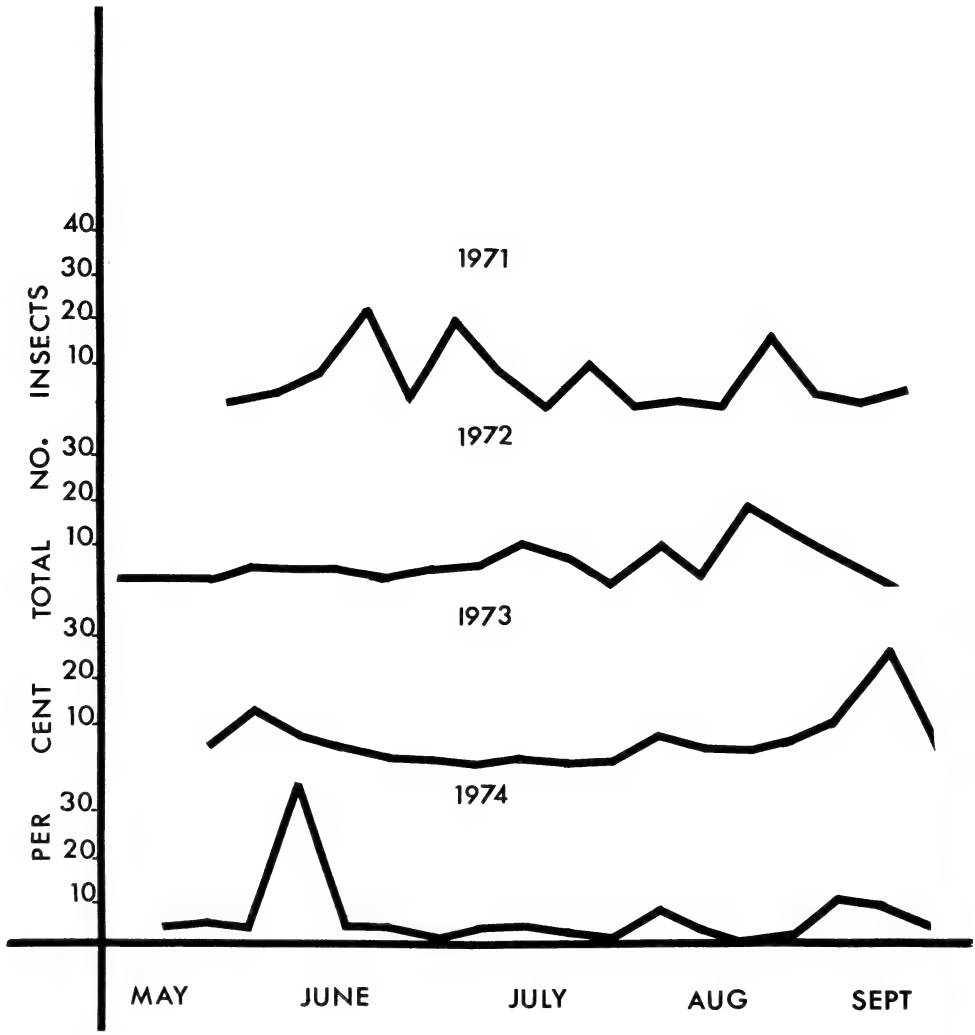

FIGURE 5. Occurrence of *Hemerobius humilinus* L., 1971-1974.

terricola (Thorell), *Pardosa* sp. *P. saxatilis* (Hentz), *Pirata minutus* Emerton; (viii) Phalangidae — *Phalangium opilio* (L.); (ix) Philodromidae — *Philodromus cespitum* (Walck), *P. praelustris* Keyserling, *P. rufus* Walck, *P. vulgaris* (Hentz), *Philodromus* sp., *Tibellus* sp.; (x) Pholcidae — *Pholcus phalangioides* (Fuesslin); (xi) Salticidae — *Hentzia mitrata* (Hentz) *H. palmarum* (Hentz), *Icius* sp., *Metacyrba undata* (De Geer), *Metaphidippus protervus* Walck, *Metaphidippus galathea* (Walck), *Phidippus audax* (Hentz), *Phidippus* sp., *Paraphidippus marginatus* Walck, *Salticus scenicus* (L.); (xii) Tetragnathidae — *Tetragnatha versicolor* Walck, *T. laboriosa* Hentz; (xiii) Theridiidae — *Achaearanea* sp,. *A. tepidariorum* (C. L. Koch), *Enoplognatha ovata* (Clerck), *Steatoda* sp., *Theridion murarium* Emerton, *Theridion differens* Emerton *Theridion* sp.; (xiv) Thomisidae — *Coriarachne* sp. (prob. *utahensis* Gertsch), *Misumena vatia* (Clerck), *Misumenops* sp., *Pellenes* sp., *Xysticus* sp.

Putman (1967) reported that *Philodromus* spp., particularly *praelustris,* and *T. murarium,* were most abundant in peach orchards on the Niagara Peninsula. These species were also commonly found in the unsprayed apple orchards studied, as were several other species reported by Dondale (1958), Specht and Dondale (1960) and Legner and Oatman (1964). Many species readily ate the early instars of several Lepidoptera pests but tended to avoid the larger instars and adults. Putman (1967) stated that chironomids were the main prey of most spiders in peach orchards, but also observed them feeding on the European red mite, the brown mite, flies and aphids.

(H) Acarina

The erythraeid mite, *Balaustium putmani* Smiley, occurred in both orchards in large numbers and was readily recovered in tapping collections and from fruit clusters. Putman (1970) stated that in the orchard this mite fed on all stages of *P. ulmi* and San José scale, *Quadraspidiotus perniciosus* (Comstock), on the apple aphid, *A. pomi,* and on newly hatched nymphs of the cicadellid, *Paraphlepsius irroratus* (Say). In the laboratory *B. putmani* fed erratically on eggs of the Oriental fruitmoth, *Grapholitha molesta* Buck. Under similar conditions in the present study it also fed on codling moth eggs.

The smaller and very active mite, *Anystis agilis* Banks, was also frequently observed on the foliage in both orchards.

The stigmaeid, *Zetzellia mali* (Ewing) and the following phytoseid mites were also recovered (Herne, unpublished data 1972-74) in the same orchard: *Amblyseius fallacis* (Garman), *A. findlandicus* (Oudeman) (=*hibisci*), *Typhlodromus longipilis* Nesbitt (=*galendromus*).

(I) Predators in relation to codling moth abundance. The total number of codling moth eggs and 1st instar larvae recovered were not correlated in either study orchard. Hence, larval mortality was probably due to biological agents which are density dependent. McLellan (1962) reported total mortality of eggs and early instar larvae at 14.4% and 58.5% respectively. In Ontario estimates based on available data (unpublished) indicate total mortality in these stages to be in the same range.

There was, however, a positive correlation ($r = .61$, $P < .05$) between the degree of fruit infestation and the number of larvae that survived to maturity. It was, therefore, evident that natural mortality in the later instars was not of great importance. As predator numbers were highly correlated ($r = .94$, $P < .01$) with the abundance of codling moth larvae (Fig. 6) the latter probably served as an important food source although their numbers were neither controlled nor regulated by the predators. The positive correlation ($r = .58$, $P < .01$) between

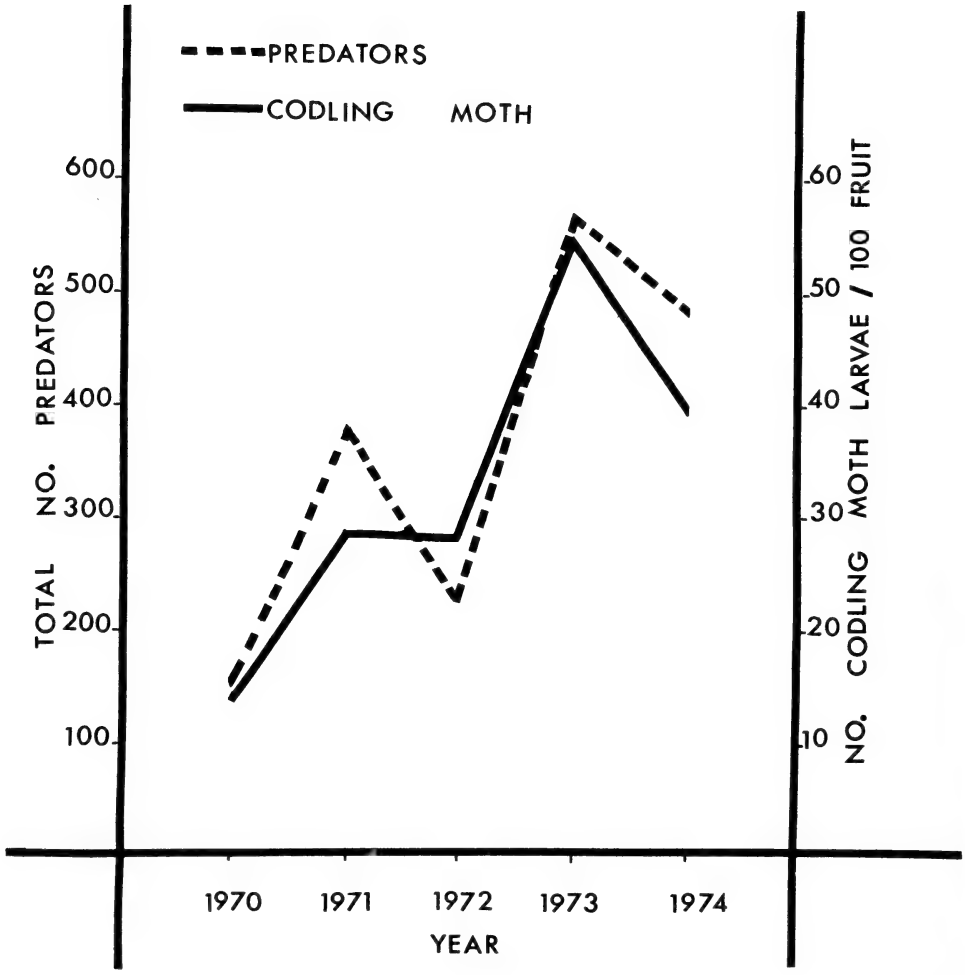

FIGURE 6. Relationship between total numbers of predators and codling moth larvae.

the total number of fruit available and the degree of larval infestation also supports this view.

Fruit damage due to other pests was generally $< 4\%$ indicating that they occurred in relatively low numbers and were probably not individually important as a food source. Heavy infestations of the rust mite and white apple leafhopper in some years, however, served as important food sources for some species (cf. Herbert and Sanford, 1969).

Results of preliminary studies in sprayed orchards show that the predator species complex can be changed due to insecticide pressure on the populations. In some cases modification of spray schedules to maximize the effect of one or more predators against certain pests appears to merit consideration. These studies are continuing in commercial orchards and will be reported on elsewhere.

Acknowledgement

Sincere thanks to the Insect Taxonomists at the Biosystematics Research Institute, Ottawa, who identified all species collected, and to Mr. D. Barber for his technical assistance.

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NOTES ON THE VEGETABLE LEAFMINER, *LIRIOMYZA SATIVAE* (DIPTERA: AGROMYZIDAE), IN ONTARIO

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Abstract

The vegetable leafminer, *Liriomyza sativae* Blanchard, was found on greenhouse crops of tomatoes, chrysanthemums, lettuce and cucumbers in Ontario. Preliminary observations have not disclosed the source of this annual fall influx into greenhouses, but cage studies verified a wide range of possible hosts.

A controlling factor in the greenhouses was the chalcid parasite, *Diglyphus begini* (Ashmead), which was widespread in 1973 but scarcer in 1974. Pest management of the leafminer is discussed.

* * * * * *

Introduction

A leafminer was recorded from greenhouse tomato crops in Essex Co. (Anon. 1967), but it was only noted occasionally prior to 1970. Specimens from tomatoes and chrysanthemums were identified as *Liriomyza munda* Frick by G. E. Shewell (Biosystematics Research Institute, Ottawa). *L. munda* is now considered a synonym of *L. sativae* (Spencer 1973).

This species is common in the southern areas of the United States (Frick 1957, Steyskal 1964) and has a very diverse host range. Precise identifications are difficult because there is a complex of very similar species. It was first recorded from greenhouses in 1964, when Neiswander (1964) found it on tomatoes in Ohio.

A project was initiated at the Harrow Research Station to study the epidemiology of the leafminer infesting greenhouse vegetables, with the objective of establishing control measures. This paper reports the preliminary observations, the presence of indigenous parasites, and the direction of the research.

Distribution and Host Plants

Greenhouse Crops

A survey of greenhouse tomato crops in the Leamington area in August 1973 indicated that 60% of the crops had leafminer damage. The mines were primarily on the lower leaves, and adult feeding scars were noted on the younger foliage. Samples of the mined leaves were collected from six greenhouses and kept in covered trays for emergence records.

The emerged Agromyzidae were all *Liriomyza* sp. and were similar in external characteristics to the *L. sativae* identified previously. Specimens were preserved in 75% alcohol for future preparation of genitalia slides necessary for species confirmation. Leafminer parasites also emerged and will be discussed later.

A similar survey, extended to cover the southern half of Essex Co., was made in early October 1974. At that time 75% of the Leamington area greenhouses had leafminer infestations. They were present in some greenhouses at Harrow, Kingsville, and north of Leamington, but not at Wheatley. Leaf mines were noted on chrysanthemums in some Brampton greenhouses in the fall of 1974 (J. Hughes, personal communication).

Infested crops were primarily tomatoes and chrysanthemums. One crop of lettuce near Leamington was moderately infested in October 1974, and in March 1975 a greenhouse cucumber crop was lightly mined.

Field Crops and Weeds

Many of the host plants listed for the southern United States (Stegmaier 1966) are found in southern Ontario. Surveys made near Harrow in 1973 yielded various Agromyzidae, but they were distinctly species other than *L. sativae,* on the basis of external differences observable at 30 X magnification.

In 1974 leafminer specimens from a single plant of rough daisy fleabane, *Erigeron strigosus* Muhl (Compositae) collected May 31, were tentatively identified as *L. sativae.* Positive identification is proposed as part of a cooperative project with the Biosystematics Research Institute at Ottawa. Similarly specimens from field tomatoes collected at Harrow August 20 and September 20 were considered to be this species.

Obviously the extensive greenhouse infestations of vegetable leafminer in the fall of the past several years are not explained by these preliminary findings, and a thorough ecological study is planned.

Cage Host Studies

A thriving colony of *L. sativae* was established in 1973 from larvae collected from greenhouses, and they were reared on lima bean. Potted plants of various species were introduced into the rearing cage and remained there for 2 weeks. The degree of leaf mining was rated and the formation of puparia noted. Table I presents the results of the host plant tests.

Although several new hosts were found, many others are likely possible since this species is quite polyphagous. Thus the scarcity of vegetable leafminers in the field is not likely due to limited hosts, but is more apt to be caused by natural control factors.

Parasites

In the southern United States there is a wide range of hymenopterous parasites of the vegetable leafminer (Harding 1965, Stegmaier 1966). Most of them

TABLE I. Infestation of various plants exposed to a caged population of *Liriomyza sativae* for 2 weeks.

Plant Identification	Degree of Leaf Mining[1]	Puparia Formed	Previously Recorded
Chenopodiaceae			
Chenopodium album L., lamb's quarters	***	+	Oatman 1959
Compositae			
Ambrosia trifida L., giant ragweed	—		
Chrysanthemum morifolium Ramat, greenhouse chrysanthemums	***	+	Smith 1962
Lactuca sativa L., Bibb lettuce	***	+	
Taraxacum officinale, Weber, dandelion	***	+	
Cruciferae			
Brassica oleracea var. *capitata* L. Early Market Copenhagen cabbage	*		Stegmaier 1966
Cucurbitaceae			
Cucumis sativus L., Burpee Hybrid cucumber	*	+	Harding 1965
Euphorbiaceae			
Euphorbia pulcherrima Willd., Annette Hegg poinsettia	*		
Gramineae			
Agropyron repens (L.) Brauv., quackgrass	—		
Digitaria sanguinalis (L.) Scop., large crabgrass	**	+	
Zea Mays L., Seneca Chief sweet corn	—		
Labiatae			
Leonurus Cardiaca L., motherwort	**	+	
Nepeta Cataria L., catnip	***	+	
Leguminosae			
Medicago sativa L., alfalfa	***	+	Oatman 1959
Phaseolus limensis Macf., lima bean	***	+	Harding 1965
Phaseolus vulgaris L., white bean	***	+	Harding 1965
Glycine Max Merv., soybean	—		
Malvaceae			
Gossypium hirsutum L., cotton	—		Oatman 1959
Malva neglecta Wallr., common mallow	***	+	
Passifloraceae			
Passiflora caerulea L., passion flower	*		Stegmaier 1966
Plantaginaceae			
Plantago major L. common plaintain	***	+	Stegmaier 1966
Polygonaceae			
Polygonum Persicaria L., lady's thumb	—		
Onagraceae			
Oenothera biennis L., evening primrose	—		
Solanaceae			
Lycopersicon esculentum var. *commune* Bailey, Michigan-Ohio tomato	***	+	Harding 1965
Solanum tuberosum L., Avon potato	**	+	Harding 1965
Umbelliferae			
Apium graveolens var. *dulce* Pers., celery	**	+	Oatman 1959

[1] Legend: *** heavy, ** moderate, * light, — none

are nonspecific and have been recorded from leafminers which are widespread. The study of parasites of the vegetable leafminer in this area included a general collection of parasites of Agromyzidae. The broad aspects of the study are in cooperation with the Biosystematics Research Institute and will not be reported here. However, it is of interest to note that there is a high degree of parasitism in most samples of leafminers.

Two species were found in association with vegetable leafminer infestations in greenhouse tomatoes. They were kindly identified by the Biosystematics Research Institute as *Diglyphus begini* (Ashmead) (Hymenoptera: Eulophidae), and *Opius dimidiatus* (Ashmead) (Hymenoptera: Braconidae).

D. begini, referred to as *Diaulinus* or *Solenotus begini* in earlier literature, has a widespread distribution in the United States, and probably has been present for many years in southern Ontario and Quebec (Peck 1963). The host records include leafminers now referred to as *L. sativae* (Hills and Taylor 1951). This parasite was present in all greenhouse collections of mined leaves in 1973. The leafminer populations dropped rapidly in November, when there was up to 67% parasitism. In 1974 *D. begini* was present, but only in about half the collected samples of mined leaves.

The braconid *O. dimidiatus* was not as numerous as *D. begini,* but it still accounted for 27% of the total parasites in 1973. It also has a widespread distribution and range of leafminer hosts, and likely is common in southern Ontario although not previously recorded here. In the leaf collections from greenhouses in 1974 only 1 specimen of *O. dimidiatus* emerged. This reduced incidence may have been due to fairly extensive spraying carried out to control the leafminers.

The parasite *D. begini* proved amenable to laboratory rearing which simply involved the provision of a supply of bean plants infested with vegetable leafminer larvae. The silk screen cage was kept in a growth cabinet at 28°C and illuminated with a 16 hr photophase. The parasites showed a slight preference for half-grown leafminer larvae. I had no success in rearing *O. dimidiatus.*

Discussion

The vegetable leafminer was found to be consistently present in greenhouses in the Leamington area, but these preliminary studies disclosed few details of its life-history. The source of the large numbers of adults responsible for the fall infestation of greenhouses was not discovered. They could possibly be migrating into the area.

The proliferation of leafminers in the greenhouse is due to the favourable environment and succulent plant growth plus a temporary escape from biological control by parasites. Later the parasites, particularly *D. begini,* find their way into greenhouses and limit the leafminers.

A good pest management program would include the introduction of reared parasites when the leafminers were first noticed. Since the leafminers do not attack the tomato fruit, some leaf damage can be tolerated. Biological control would be preferred to chemical, to avoid disruption of the control of whiteflies by the parasite *Encarsia formosa* Gahan (McClanahan 1972).

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TRIHABDA BOREALIS BLAKE (COLEOPTERA: CHRYSOMELIDAE): A MAJOR PHYTOPHAGOUS SPECIES ON *SOLIDAGO CANADENSIS* L. (ASTERACEA) IN SOUTH-EASTERN ONTARIO

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Abstract

Trihabda borealis Blake, and not *T. canadensis* (Kirby) as stated by Ĉapek (1971), was recorded as the major species of *Trihabda* on *Solidago canadensis* L. in south-eastern Ontario. Some life history details of *T. borealis* on the principal host are included. Comparison of the number and dry weight of *T. borealis* with the total arthropod fauna sampled by sweeping indicates that it is a phytophagous species of major importance on *S. canadensis*.

* * * * * *

Introduction

Capek (1971) reported that the chrysomelid *Trirhabda canadensis* (Kirby) is probably the most important phytophagous insect species on goldenrods in Canada. However, during recent studies on the insect fauna associated with the goldenrod *Solidago canadensis* L. in south-eastern Ontario, only the sibling species *Trirhabda borealis* Blake was very abundant (i.e. Reid, Loan and Harmsen 1975).

This paper has two objectives: firstly, since little is apparently known about *T. borealis,* to describe in some detail the biology of this species as it occurs on *S. canadensis;* secondly, to quantify the observation of Capek (1971) that *Trirhabda* species are important phytophagous insects on goldenrod by reporting the relative numbers and biomass of *T. borealis* on *S. canadensis.*

Materials and Methods

Two stands of *Solidago canadensis* L. were selected for study. Each stand covers an area of approximately 1,000 sq m, with a density in the order of 100 *S. canadensis* plants per sq m; both areas are located in the Belleville-Kingston region of south-eastern Ontario.

The two study plots (labelled A and B in this paper) were sampled weekly from 4 June to 1 August 1974. A sample consisted of 50 sweeps using a 12-inch

diameter net. Upon collection each sample was placed in a 1-pint glass jar containing 70% ethanol, and returned to the laboratory. *Trirhabda* specimens were then removed, counted, dried thoroughly at 70°C, and weighed using a Mettler® microbalance. The remaining arthropods in each sample were sorted into various groups and similarly counted, dried and weighed.

Results and Discussion

T. borealis versus *T. canadensis*

A total of 1194 *Trirhabda* adults was collected from the two study areas and all specimens were identified as *T. borealis*. While several specimens of *T. canadensis* have been collected by us from other *S. canadensis* stands in south-eastern Ontario, there appears to be little doubt that *T. borealis,* and not *T. canadensis,* is the predominant species on this host in this region.

The designation of *T. canadensis* as the major species by Capek (1971) is therefore suspect, especially since his work was carried out in the same region of south-eastern Ontario. A problem which arises is that Capek collected *Trirhabda* from 3 species of *Solidago,* including *S. canadensis*. Since several *Trirhabda* species including *T. virgata* Lec., *T. canadensis* (Dillon and Dillon 1972), and *T. adela* Blake (Wilcox 1954) are listed as feeding on goldenrods, specific *Trirhabda-Solidago* associations may well occur.

Capek could then have been working with *T. canadensis* collected from a species of *Solidago* other than *S. canadensis*. However, since *S. canadensis* was sampled as well, it is surprising that *T. borealis* was not recorded. It would seem likely therefore that at least some of the specimens labelled as *T. canadensis* by Capek were in fact *T. borealis*.

T. borealis on *S. canadensis*

The numbers of larvae and adults of *T. borealis* recorded from plot A are shown in Fig. 1. Presumably the egg is in the overwintering stage, as has been recorded for *T. canadensis* (Balduf 1929). The larvae, which are most numerous

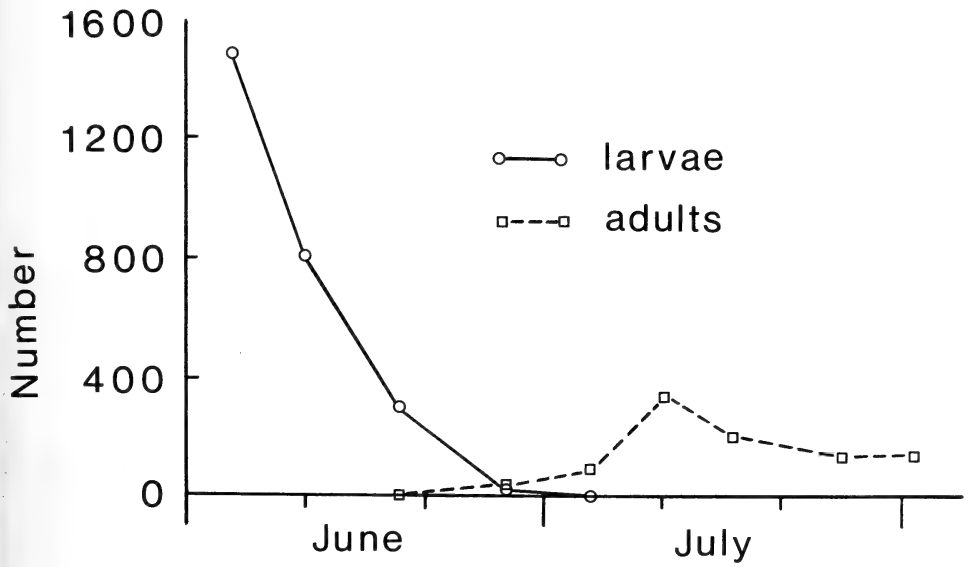

FIGURE 1. Numbers of *T. borealis* recorded from plot A.

in early June, were found on the leaves until the end of June. Pupation occurs below the soil surface and as a result *T. borealis* is not abundant on *S. canadensis* during late June and early July. Adults first appear in late June, peak in numbers on 10 July, and are present through to 1 August and probably well beyond this date. The results from plot B are closely similar.

Fig. 2A shows the number and dry weight of the total (larvae + adults) *T. borealis* recorded from plot A. However, to determine the importance of it as a phytophagous species on *S. canadensis,* it is necessary to consider this species relative to other phytophagous species. A somewhat conservative means of obtaining such a relative measure is to express the number and the dry weight of *T. borealis* as percents of the total arthropod fauna (Fig. 2B).

While the percent numbers curve shown in Fig. 2B indicates that *T. borealis* is one of the most abundant species, the ecologically more important percent dry weights curve clearly establishes the dominance of this single species: except for a period in late June when *T. borealis* is in the pupal stage, 60% or more of the entire arthropod biomass on *S. canadensis* during June, July, and early August is accounted for by *T. borealis.* Assuming a more or less linear relationship between biomass and goldenrod consumption, *T. borealis* is the most important phytophagous species on *S. canadensis* in south-eastern Ontario.

It should be pointed out however, that in neither of the two plots during the study period, and only very rarely elsewhere in the general region, have we observed obvious, serious defoliation of *S. canadensis* by any component of the phytophagous insect load. In competitive plant communities, it must be realized though that relatively low levels of defoliation of one plant species or another could lead to a switch in the dominance hierarchy. Whether the feeding activities of *Trirhabda* in particular, or of the entire phytophagous insect load in general, has any effect on the rate of vegetation succession leading to the loss of dominance of *Solidago,* and its ultimate disappearance from any particular community, can not be ascertained without controlled experiments.

Acknowedgements

The authors wish to thank Dr. D. D. Munroe, Biosystematics Research Institute, Ottawa, for identifying a number of the *Trirhabda.* Plant specimens were identified with the aid of staff members of the Fowler Herbarium, Queen's University, Kingston, Ontario. We also wish to acknowledge Dr. A. S. West, Queen's University, for his critical reading of this manuscript.

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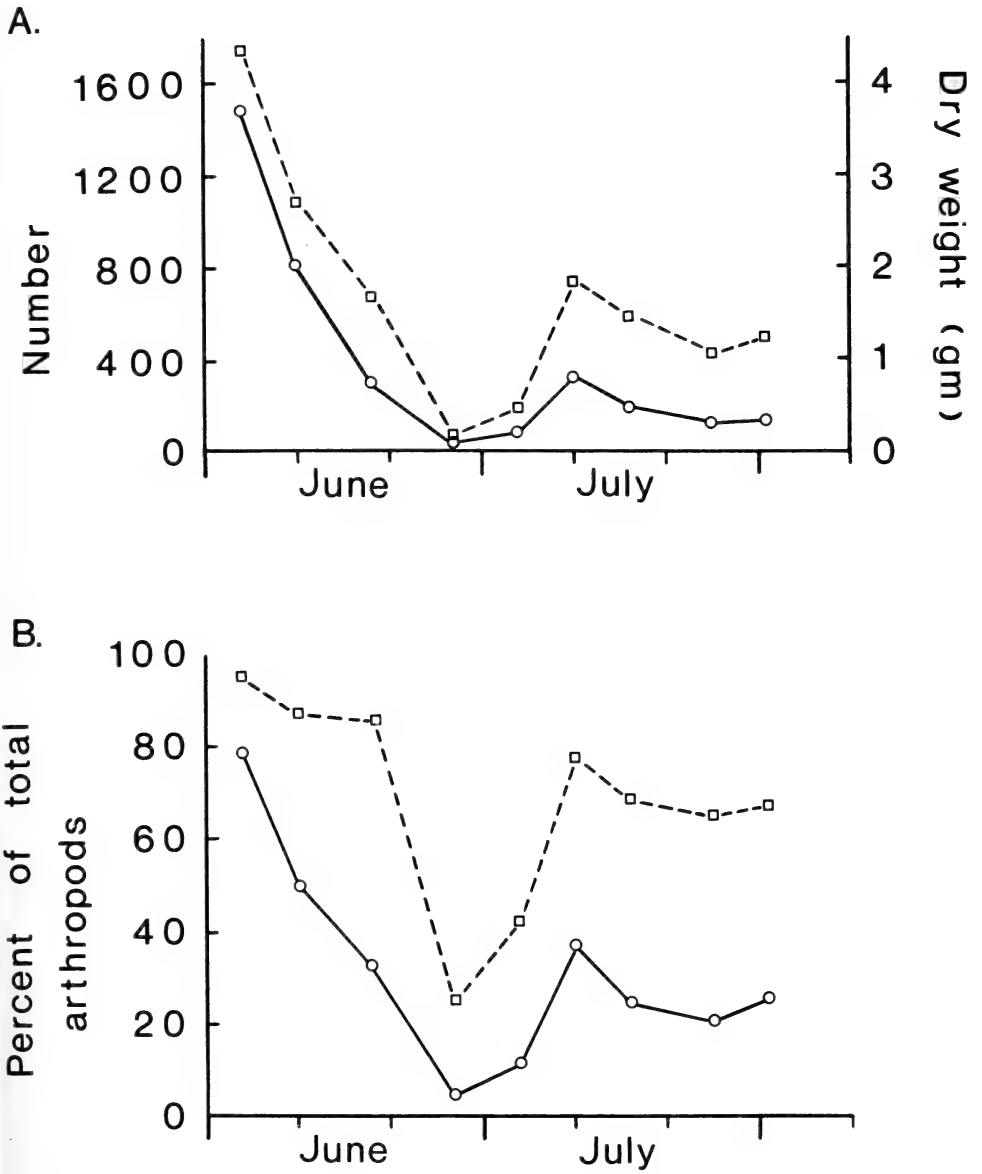

FIGURE 2A. Number (————) and dry weight (— — — — —) of *T. borealis* recorded from plot A; B, percent number (————) and percent dry weight (— — — —) *T. borealis* of the total arthropod fauna from plot A.

RELATIVE RESPONSE TO COLOURED SUBSTRATES BY OVIPOSITING BLACKFLIES (DIPTERA: SIMULIIDAE). III. OVIPOSITION BY *SIMULIUM (PSILOZIA) VITTATUM* ZETTERSTEDT[1]

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Abstract

When six coloured and four neutral test strips were floated over a medium-brown coloured background of a stream bed in Algonquin Park, Ontario, females of *Simulium vittatum* Zett. oviposited more on yellow than on green, purple, blue, orange, and red strips, and more on white than on dark or light grey or black strips. The response to coloured strips resulted in an attractance pattern with a peak at the yellow; this response varied inversely with two reflectance ratios: 325-450 mμ/450-700 mμ and 450-500 mμ/500-550 mμ which show the relative proportion of purple-blue and green-yellow radiations respectively from each strip. The response to neutral strips varied directly with their luminous reflectance and inversely with the intensity ratio 325-450 mμ/450-700 mμ. This species comprised approximately 8% of eight simuliid species trapped at the test site.

* * * * * *

Introduction

Previous studies have shown that two species of simuliids oviposit selectively on certain coloured substrates in nature (Golini and Davies, 1975a,b). The preference for certain colours during oviposition by both *Simulium verecundum* S. & J. and *Simulium ornatum* Mg., was found to be modified by the background reflectance of the bottom of the stream on which the strips were floated and by whether gravid females were trapped by sticky strips as they landed, or oviposited freely. This study analyzes the response of gravid females of *Simulium vittatum* Zetterstedt as they oviposited on non-sticky, coloured strips exposed over a medium-brown stream bed background.

Materials and Methods

The procedure used in these experiments was described in detail previously (Golini and Davies, 1975a). Tests with *S. vittatum* were made from 15 July to 12 August 1966 in Algonquin Park, Ontario. Each of the ten coloured strips measured 2.5 cm by 25 cm. A spectral analysis of these strips (Table I) showed that the six colours: purple, blue, green, yellow, orange and red, differed essentially in hue, while their luminous reflectances were relatively similar. The four neutral strips: black, dark grey, light grey and white differed essentially in their luminous reflectance. The six colours were floated side by side, 12 cm apart, on the water surface of a narrow shallow stream draining a beaver pond and having an average current of 50 cm/sec. The four neutral strips were floated together 3 m upstream from the coloured strips.

Gravid female simuliids oviposited on the non-sticky strips foating over the medium-brown coloured background of the gravel stream bed. The ratio of the reflectance of the stream background to that of the white test strip was about 1:4. The relative quantity of eggs was determined from the dry weight of eggs laid on

[1]The subgeneric status of this species was revised by Stone (1963).

TABLE I. Spectral reflectances taken from 12 samples of coloured oviposition strips. Values are expressed as percent reflectance as compared to a standard sample of magnesium carbonate, which has an absolute reflectance of about 98% over most of the visible range.

Colour	Wavelengths (mμ)									Average mμ			Ratios	
	325	350	400	450	500	550	600	650	700	325-700	325-450	450-700	325-450 / 450-700	450-500[a] / 500-550
Black	4.5	4.1	3.5	3.4	3.2	3.0	3.1	4.0	3.5	3.6	3.9	3.3	1.2	1.06
Dark Grey	5.2	5.0	15.8	16.0	14.8	13.0	12.0	11.6	11.1	11.7	10.3	13.3	0.78	1.07
Light Grey	5.5	5.1	31.0	39.5	36.0	34.0	32.2	31.7	29.9	27.1	19.4	34.5	0.56	1.08
White	6.1	6.0	35.2	90.9	90.0	89.6	88.9	90.0	90.2	63.8	34.0	90.0	0.38	1.01
Purple	7.2	7.0	29.9	42.8	34.9	29.0	31.9	37.8	47.0	30.0	21.3	36.2	0.59	1.23
Blue	6.8	6.3	26.1	47.9	63.6	44.1	28.0	23.1	26.2	31.0	20.7	39.1	0.53	1.05
Green	6.3	6.0	15.0	16.9	28.8	42.0	26.5	24.0	25.9	22.0	10.7	28.6	0.37	0.52
Yellow	5.0	4.8	12.0	12.1	21.1	46.5	58.2	65.0	71.0	32.8	8.1	46.6	0.17	0.41
Orange	5.1	5.0	10.0	10.0	13.9	20.1	44.0	58.3	62.0	24.6	7.4	34.2	0.22	0.63
Red	6.5	6.9	35.1	42.9	38.2	33.1	63.9	85.2	86.6	38.5	21.8	52.0	0.42	1.09
White + tf[b]	3.9	3.7	30.7	92.0	91.1	90.5	89.9	89.9	90.0	66.8	32.6	90.6	0.36	1.01
Yellow + tf	3.3	3.3	10.5	11.0	17.0	45.8	58.1	63.5	69.0	31.4	7.0	44.1	0.16	0.37

[a] Calculated using 25 mμ wavelength intervals
[b] tf = test strip coated with an even layer of Bird Tanglefoot (colourless and transparent)

each of the ten strips. The proportion of *S. vittatum* females among the species ovipositing was calculated from the number of simuliids trapped on one yellow sticky strip floated daily 3 m downstream from the test site.

Observations and Results

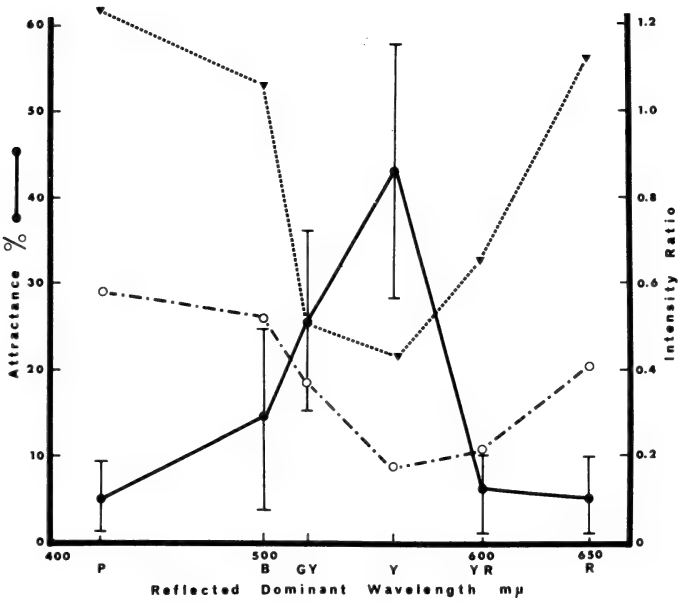
Eggs of *Simulium vittatum* Zett. and *Simulium decorum* Walker, unlike those of most other species of simuliids are usually laid in characteristic criss-crossing strings bound by a gelatinous matrix on leaves and other surfaces floating on or emerging from the water surface of streams and conjoining ponds (Emery, 1913; Jobbins-Pomeroy, 1916; Wu, 1931; Stone and Jamnback, 1955; Davies and Peterson, 1956; Davies *et al.,* 1962; author's data). Wu (1931) reports that the eggs of *S. vittatum* "are deposited in a string which curves or twists over itself and in which the eggs are laid in a single row, mostly side by side, but sometimes end to end. When oviposition is heavy and the egg mass becomes extensive and several-layered, the string arrangement may not be apparent, yet the mass still does not appear compact." During the present study many of these eggs were found on the walls of the sluiceway out of Lake Sasejewun, approximately 0.5 km from the experimental site. These eggs were also found in a single loose string arrangement on both the test strips and emergent vegetation associated with the larger egg masses of *Simulium verecundum* S. & J. (Golini and Davies, 1975a). These differences in the arrangement of the egg masses, which reflect differences in oviposition habits between these species, facilitated separation and assessment of the relative quantity of the eggs of *S. vittatum* and *S. decorum* from those of *S. verecundum.* Sample collections of ovipositing simuliids, taken at the test site during the 1966 to 1968 oviposition seasons (Table II), showed that the proportion of gravid females of *S. vittatum* to *S. decorum* was 80 to 1. Therefore, *S. vittatum* was considered to be the dominant species found ovipositing at the test site in the manner described above.

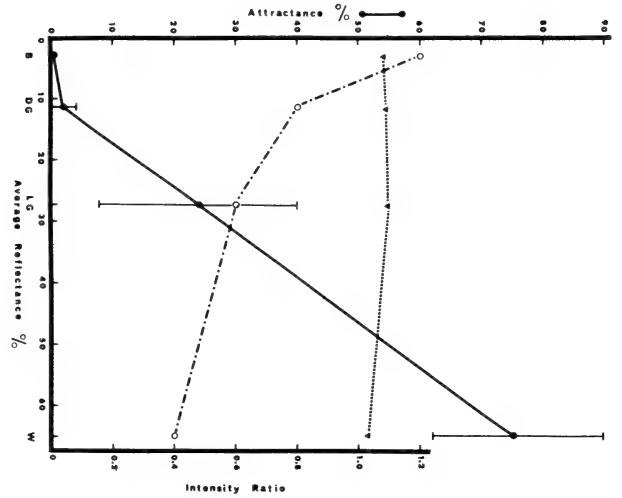
Occasionally, dead females of *S. vittatum* with a few mature eggs remaining in their abdomen were also found trapped in the gelatinous matrix of the egg masses. The mature egg is oval from dorsal view, triangular with rounded angles in cross-section, and the average number per female and dimensions agreed with those of previous studies (Wu, 1931; Davies and Peterson, 1956).

Jobbins-Pomeroy (1916) observed that the eggs of *S. vittatum* are unable to withstand desiccation for two days. Edwards (1920) suggested that simuliid species which produce thin-shelled eggs deposit their eggs enclosed in a jelly substance as an adaptation to survive in streams likely to become dry for long periods. However, the sticky gelatinous matrix which normally surrounds the egg of such species as *S. vittatum, S. verecundum* and *S. ornatum* seems to be even more important in binding the eggs to each other and to the oviposition substrate, as it was found in the present study.

Response to Light Reflected from Oviposition Strips

During the oviposition season, eleven tests were made with the six coloured strips. Frequently, the yellow strip received the largest number of eggs and it showed a relative attractance of 43% (Fig. 1). It was followed by green with 25.4%; blue, purple, orange and red showed a progressively decreasing attractance which descended sharply on either side of this yellow peak. Considering that the luminous reflectance of the six coloured strips was relatively similar (Table 1), the response of ovipositing *S. vittatum* females was found to be directly related to the reflectance ratios 325-450 mμ over 450-700 mμ, and 450-500 mμ over 500-550 mμ. These ratios represent the relative proportions of purple-blue and green-yellow radiations respectively reflected from each strip.





FIGURES 1-2. The relative attractance of coloured non-sticky test strips to ovipositing females of *Simulium vittatum* Zett., expressed as the mean percent of the dry weight of eggs laid on each strip (●————●). The standard error, S_x, of the means was calculated at 80% confidence limits. The strips were floated over the medium brown gravel stream bed background. The reflectance ratios 325-450 mμ/450-700 mμ (o——— ———o) and 450-500 mμ/500-550 mμ (▼——— ———▼) show the relative proportion of purple-blue and green-yellow radiations respectively reflected from each strip. Fig. 1. Response to six test strips of different hues (P = purple, B = blue, GY = green, Y = yellow, YR = orange, R = red) from 11 tests comprising 53.7 mg of eggs. Fig. 2. Response to four neutral test strips of different luminous reflectance (B = black, DG = dark grey, LG = light grey, W = white) from 7 tests comprising 12.2 mg of eggs.

Seven tests were made with the neutral strips. Most eggs were frequently found on the white strip which received an average of 76% of the total (Fig. 2). It was followed by light grey and dark grey which received approximately 23% and 1% of the total number of eggs respectively. Eggs were never found on the black strip. In assessing the relative attractance of the neutral strips, the response of *S. vittatum* was found related directly to luminous reflectance but inversely to the reflectance ratio of 325-450 mμ over 450-700 mμ (Fig. 2).

Discussion

Females of *Simulium vittatum* show a diel pattern of oviposition activity with a major presunset and a minor postsunrise peak (Davies and Peterson, 1956: Corbet, 1967). This species has been reported to oviposit normally by affixing its eggs to a solid surface, trailing leaves when present being preferred over rocks, cement or wood lapped by water. During high population density these females have been observed to drop their eggs freely into the water and even to submerge while ovipositing (*op. cit.*). However, numerous females of this species have been observed more frequently to oviposit in communal fashion on faces of dams below lake outlets (Davies and Peterson, 1956; author's data). These observations corroborate those of Stone and Jamnback (1955) who reported that "larvae are often so numerous that they appear like a black mossy covering on the dam face." During the present study *S. vittatum* comprised only 8.1% of the eight species found ovipositing at the experimental site (Table II), but it was the second most abundant species after *S. verecundum*. Hence, it is probable that *S. vittatum* or some of its polymorphic forms, oviposits only secondarily on trailing vegetation.

Although the possibility of *S. vittatum* being a species complex was suggested (Rothfels and Dunbar, 1953; Davies *et al.,* 1962), additional studies revealed not sibling speciation but a high degree of sympatric heterozygous variability in this species (Pasternak, 1964). *S. vittatum* was originally described by Zetterstedt in 1838 from material collected in Greenland and Iceland. Subsequent reports of its distribution showed that it is essentially a North American species ranging south even into Mexico (Emery, 1913; Jobbins-Pomeroy, 1916; Wu, 1931; Vargas, 1945; Sommerman, 1953; Stone and Jamnback, 1955; Davies *et al.* 1962; Pasternak, 1964). This indicates that this species has successfully adapted to many habitats, and that with high population densities sympatric polymorphic forms become increasingly more numerous. Consequently under these conditions differences in oviposition habits may become readily more apparent.

The response of ovipositing *S. vittatum* to strips of different hues was similar to that of *S. verecundum* under identical experimental conditions (Golini and Davies, 1975a). However, greater variability was observed in the response of *S. vittatum,* probably because fewer flies of this species were obtained. Nevertheless, the behavioural responses resulted in a normal distribution pattern with yellow being preferred over the other hues. For both of these species, and in a modified fashion for *S. ornatum,* yellow was the peak colour of this attractance pattern. Similarly, the response of *S. vittatum* to oviposit preferentially on strips with high luminous reflectance is similar to that of *S. verecundum* under identical conditions. For both of these species their predominant preference for white resulted when the flies oviposited freely on test strips floating over a medium-brown stream bed background. This response to the neutral strips varied directly with the average reflected light intensity but inversely with the intensity ratio 325-450 mμ over 450-700 mμ.

These behavioural responses, which show a significant preference for substrates of certain colours, represent the visual sensitivity of these simuliids at oviposition. In interpreting these results the assumption has been made that ovi-

TABLE II. Relative species abundance of gravid female simuliids trapped while landing on one yellow sticky oviposition strip floating on a stream in Algonquin Park, Ontario, during 1966-1968 seasons.

Simuliid species	Number of gravid females												
	July 1966				June 1967		May	June 1968					
	2-9	10-18	19-26	27-31	4-6	8-10	27-30	3-5	6-9	10-15	16-19	Total	%
Prosimulium fuscum S. & D.	0	0	0	0	2	0	0	0	0	0	0	2	0.2
Cnephia mutata (Mall.)	0	0	0	0	2	0	1	2	0	0	0	5	0.4
Simulium aureum (Fries)	4	3	1	1	0	0	0	0	0	0	0	9	0.8
Simulium decorum Walk.	0	0	0	0	0	1	0	0	0	0	0	1	0.1
Simulium tuberosum (Lundstr.)	13	11	0	1	2	0	0	0	0	0	0	27	2.4
Simulium vittatum Zett.	23	8	2	1	1	1	1	5	12	31	7	92	8.1
Simulium venustum Say	11	9	0	0	3	3	5	3	4	0	0	38	3.4
Simulium verecundum S. & J.	107	138	83	79	40	19	94	113	188	75	20	956	84.6
Total number of flies	158	169	86	82	50	24	101*	123	204	106	27	1130	
Number of tests	4	4	2	3	3	3	4	3	4	4	4		

* This includes 86 gravid females collected in about 20 minutes on the evening of May 28 as they were ovipositing on a blade of grass, *Glyceria striata* (Lam.) trailing on the water surface of the stream.

positing simuliids in the field are responding visually to coloured oviposition strips, since the reflected light was the obvious variable that initially was amenable to analysis. It is probable that these females were responding in a lesser degree to olfactory and/or tactile stimuli emanating from the various colour pigments. Evidence presented previously (Golini and Davies, 1975 a,b) has shown that this visual response is affected by certain factors. The physiological state of the females, background reflectance of the stream bed and restriction of final choice of the coloured substrate (by using sticky rather than non-sticky strips) were found to be the main modifying factors. These responses to colour at oviposition are opposite of those shown by *S. venustum* Say when biting (Davies, 1972).

These results indicate that the response of some simuliid species under natural conditions is much more adaptive than may have been supposed, and that their stereotyped bahaviour, although genetically determined, is nevertheless relative, rather than absolute, with respect to environmental stimuli. In addition, these results suggest that a green-yellow or a white substrate floated over an intermediate reflecting stream background provides optimum conditions for sampling or trapping certain simuliid populations during oviposition in the field.

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CONOPIDAE AND SARCOPHAGIDAE (DIPTERA) AS PARASITES OF ADULT BOMBINAE (HYMENOPTERA) IN ONTARIO

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Abstract

Larvae of conopids and sarcophagids were present in 12.7% of the workers of bumble bees collected off flowers in July and August, but these flies were encountered less frequently in queens and males. The incidence of *Physocephala* (Conopidae) in bees from nests, and some details on the biology of these parasitic flies are recorded. The relative abundance of *Physocephala* spp., and the distribution of the four species present in Ontario are given.

* * * * * *

Introduction

Species of *Physocephala* and *Zodion* (Conopidae), *Sarcophaga sarracenioides* Ald., *Boettcharia litorosa* (Reinhard) and *Helicobia morionella* (Ald.) (Sarcophagidae) are known to be internal parasites of *Bombus* Latr., in North America (Ryckman, 1953; Smith, 1966). Robertson (1929), Webb (1961), Hobbs (1965, 1966) and Freeman (1966) have given a few records of flower visitation and some hosts for *P. tibialis* (Say), and *P. texana* (Will.). However to date, there are no records on the incidence of fly larvae in adult bumble bees in North America. Little has been recorded on the distribution and abundance of the four species of *Physocephala* known to occur in Ontario (Macfarlane, 1974). *Zodion obliquefasciatus* (Macq.) has been recorded as a parasite of the alkali bee (*Nomia melandri* Ckll.) as well as bumble bees (Freeman, 1966). In general, less seems to be known of the biology of the three sarcophagids reared from bumble bees (Hallock, 1940).

Materials and Methods

Fifty-two queens, 2,170 overwintered queens, 360 workers, and 450 males were captured in 1972 and 1973 on flowers in the vicinity of Guelph, Ontario, from mid-April until mid-October. These bees and a further 56 new queens, 57

workers and 71 males from nests were examined for parasites. Also, 70 queens of *Bombus* were obserevd in nests and any queen found dead in the nest was dissected.

Adults of *Physocephala* from Ontario from the Canadian National Collection, Ottawa, the Royal Ontario Museum, Toronto, and the University of Guelph, Guelph, were examined to obtain data on the distribution and abundance of these flies in Ontario.

Results

Four adults of *Physocephala tibialis* have been collected from Pt. Pelee, Rondeau Park, St. Thomas, and Dundas between June 24 and September 9. Fourteen specimens of *P. marginata* (Say) were recorded from Guelph, Arkell, Holly, Midland, Hepworth, Wingham, Belleville, Marmora, Chaffeys Lock, Perth Rd. (Frontenac Co.), and Ottawa between July 3 and September 3. During this study three adults of *P. marginata* were collected off blueweed and white sweet clover and a male was seen on August 18 darting at a worker of *B. affinis* Cress. Twenty-one specimens of *P. texana,* recorded from Pt. Pelee, Orangeville, Primrose, Hepworth, Toronto, Ottawa and Sault Ste. Marie, were taken between June 30 and July 20. Two hundred and three adults of *P. furcillata* (Will.), were recorded from Ontario between June 6 and September 3. Adults were most common in collections made between July 10-24 and they were collected off milkweed, goldenrod, burdock, white sweet clover, and dogbane. The 130 males and 36 females of this species were found throughout southern Ontario and as far north as Fort Colonge, Beechgrove, Rainy River, Pinewood, Finland, Minahico, Onesided Lake, Kenora, Minaki, Cedar Lake, Vermillion Bay, Dryden, Lake Nipigon, White Lake, Nellie Lake, Porquis Jct., and Temagami.

Only 5 of 2,358 queen bumble bees examined were found to be affected by either conopid or small sarcophagid larvae. Two queens, *B. americanorum* (F.) and *B. borealis* (Kirby), which had initiated nests, died between July 23 and 28. These queens and a queen of *B. rufocintus* Cress. collected on July 12 had *Physocephala* in their abdomens. A third-instar larva of *Physocephala* was present in 1 of the 28 *B. rufocintus* queens collected off flowers, but none of the other 739 overwintered queens of *B. fervidus* (F.), *B. griseocollis* (DeG.) *B. americanorum,* or *B. borealis* was affected by fly larvae. Two new queens of *B. griseocollis* collected in August, were found to have one sarcophagid larva in each.

A larva of *Physocephala* and one of a sarcophagid were present simultaneously in each of two workers of *B. bimaculatus* Cress., collected off flowers, but otherwise only one larva was found per host bee. Conopid larvae from bees taken on flowers were mainly in the last or second last instar. Species of *Physocephala* and *Zodion* were the most common parasites of *Bombus* workers. A larva of *Zodion* sp. was present in one worker of *B. fervidus* collected on July 15 and one of *B. vagans* Sm. on August 23. Most larvae of *Physocephala* were collected between July 15 and August 27; 20 in July and 11 in August. The first larvae were found on July 12 and the last on October 9. The incidence of parasitism by *Physocephala* varied considerably depending on the host species, the caste, and the month (Table I). Their larvae were most common in workers during July and August (mean parasitism 10.1%), but were less common in males (2.3% parasitism). During September and October they were less common in workers and males. Sarcophagid larvae were frequently collected in August (10 of the 12 specimens) but were first recorded on July 20 with the last being taken on October 8. Unlike the larvae of *Physocephala,* which were attached to the abdominal air sacs by their posterior spiracles, the sarcophagid larvae were free in the haemolymph, and were in the early instars.

TABLE I. Seasonal parasitism of worker (W) and male (M) Bombinae by Diptera in southern Ontario, 1972-1973.

Species of *Bombus* and *Psithyrus*	No. of bees examined in July and Aug.				Percentage of field bees in July-Aug. with larvae of				No. of bees examined in Sept. and Oct.				Percentages of field bees in Sept.-Oct. with Conopid larvae	
	Nests†		Field		Conopids		Sarcophagids		Nests†		Field			
	W	M	W	M	W	M	W	M	W	M	W	M	W	M
B. impatiens Cress.	0	0	28	6	7.8	0	3.9	0	40	7	31	153	0	0
B. affinis Cress.	0	0	42	8	9.5	0	0	0	1	59	17	101	5.9	0
B. vagans Sm.	1	0	32	9	6.3	0	0	0	5	0	5	48	0	0
B. fervidus (F.)	5	3	49	13	14.2	0	8.2	0	0	0	9	27	0	2.7
B. americanorum (F.)	0	0	44	0	11.4	0	0	0	3	0	0	0	—	—
B. perplexus Cress.	0	0	41	5	7.1	0	0	0						
B. bimaculatus Cress.	0	0	35	24	20.0	4.2	5.8	0						
B. griseocollis (DeG.)	0	0	17	0	0	0	17.6	0						
B. terricola Kirby	2	0	10	4	0	0	0	0	0	0	0	8	—	0
P. citrinus (Sm.)	*	12	*	0	—	0	0	0	*	0	*	25	—	0
TOTAL	8	15	298	87	10.0	1.2	3.3	0	49	66	62	363	1.5	0.3

† None of the bees from nests was parasitized.
* No worker caste.

Dead workers and males from 17 of 44 nests contained 48 larvae and pupae of *Physocephala,* 28 of these parasites were collected in August and 17 more by September 20. The species of bees affected were *B. fervidus* (8 nests), *B. vagans* (6 nests), *B. impatiens* Cress., *B. terricola* Kby., and *B. affinis* (1 nest each). The incidence of parasitism in workers and males was considerably lower in large nests than in small nests. For example, in a large nest of *B. affinis* 5 of the 1,910 workers and males contained pupae of this fly, whereas in a small nest of *B. vagans* 3 of the 5 workers were affected. In the same species of bumble bees the incidence of parasitism was also lower in larger nests than in small nests. The incidence in other nests of *B. vagans* which produced 21-27, 48, and 133 workers and males was 7.5-9.5%, 9.3%, and 5.3% respectively. It was recorded from 10.3%, 6.3%, 5.0%, 2.0%, 1.9%, and 1.4% of the workers and males in nests of *B. fervidus* which varied in size from 16-209 workers and males. However, none of the 57 live workers of *Bombus* and *Psythirus,* from nests, was affected by fly parasites (Table I). All of the dead workers and males in some nests had *Physocephala* in their abdomens.

Adults of *Physocephala marginata* and *P. furcillata* emerged from workers of *B. fervidus* and *B. vagans* respectively in late July. These flies pupated in August and September and overwintered in the abdomens of dead bees.

Adults of *Pediobius williamsoni* (Girault) (Eulophidae, Hymenoptera) were reared from pupae of *Physocephala* within the abdomen of *B. fervidus.* The *Physocephala* were probably parasitized as pupae or last-instar larvae, when the bees had died within the nest.

Discussion

Females of the species of *Physocephala* in Ontario emerge too late in the season to parasitize bumble-bee queens except for a few of the last ones to leave their overwintering quarters. Although the larvae of these parasites were common in worker bees, there was a paucity of adult flies in collections. *Physocephala* females were most abundant in July and August before most of the male bumble bees emerged. Consequently, larvae of these flies were less common in males than in workers during August. Although different species of *Physocephala* are present in Europe, their incidence is similar to that in North America. They are also the most common parasites of *Bombus* workers (Postner, 1951; Pouvreau, 1974).

Of the three species of sarcophagids known to parasitize bumble bees in North America only *Sarcophaga sarracenioides* has been recorded from Ontario (Stone *et al.* 1965). Future studies may show that other species are involved.

The effect of parasitic flies on the longevity of workers of *Bombus* has not been studied. The sarcophagid, *Senotaina tricuspis* Meig., recorded from bumble-bee workers in Europe (Boiko, 1948), has been reported to reduce the longevity of honey bee workers by 25% (Simintzis, 1958; Alekseenko and Mazhar, 1961).

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LABORATORY AND FIELD STUDIES ON THE EFFECTIVENESS OF POSTPLANTING INSECTICIDE TREATMENTS IN CONTROLLING THE DARKSIDED AND REDBACKED CUTWORMS ATTACKING TOBACCO[1]

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Abstract

The object of this study was to evaluate postplanting treatments of different formulations of selected insecticides for controlling darksided and redbacked cutworms attacking tobacco in eastern Canada. Based on results of earlier studies

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and additional laboratory tests on 11 experimental insecticides, chlorpyrifos, leptophos. N-2596 (*S*-(*p*-chlorophenyl)) *O*-ethyl ethylphosphonodithioate), and WL 24073 (*O*-[2-chloro-1-(2,5-dichlorophenyl) vinyl] *O*-methyl ethylphosphonothioate) were selected for evaluation as postplanting treatments under field conditions using microplots infested with laboratory-reared larvae. Carbaryl was used as a standard for purposes of comparison. Tests over two seasons indicated that the four insecticides gave excellent cutworm control at 0.56 to 1.12 and were superior to carbaryl at 2.24 Kg AI/ha. Carbaryl WP and N-2596 EC were not phytotoxic. Chlorpyrifos and leptophos were phytotoxic in one year under conditions of high moisture followed by low temperature, with EC more so than WP formulations. WL 24073 EC caused moderate to severe phytotoxicity. No residues of N-2596, chlorpyrifos, chlorpyrifos-oxon, leptophos or leptophos-oxon were detected in tobacco sampled at harvest.

* * * * * *

Introduction

Cutworms are important pests of tobacco in eastern Canada with the darksided cutworm, *Euxoa messoria* (Harris) and the redbacked cutworm *E. ochrogaster* (Guenée) being two of the more important. The former predominates in Ontario, Quebec, and Nova Scotia where tobacco is grown in rotation with rye (Cheng, 1971; Harris and Svec, 1968; Martel, 1973; Specht 1972), while the latter is the major species attacking tobacco grown in Prince Edward Island (Read, 1972). Organochlorine insecticides provided effective control of both species, but their use is being phased out as quickly as effective, less persistent insecticides can be developed. In Ontario, laboratory and field studies have indicated that several insecticides, particularly chlorpyrifos, leptophos and Stauffer N2596 are effective against the darksided cutworm (Cheng, 1970; 1971; 1973; Harris and Svec, 1968; 1970; Harris *et al.* 1968; 1969; 1971; 1973). Chlorpyrifos and leptophos are registered and recommended for use as preplanting rye or broadcast soil applications. Laboratory and field studies have also indicated that the redbacked cutworm is susceptible to these insecticides (Harris and Svec, 1973; McDonald, 1972) and chlorpyrifos and leptophos are registered and recommended for redbacked cutworm control on some vegetable and cereal crops.

Although preplanting treatments will provide effective control of cutworms attacking tobacco if properly applied and timed, there are also occasions when postplanting treatments may be required, e.g. in instances where the grower has not utilized preventive controls as cutworms have not been a problem before, or where cutworms migrate into tobacco fields from adjacent headlands or nearby rye fields. It was the object of this study to evaluate postplanting treatments of different formulations of selected insecticides for controlling darksided and redbacked cutworms attacking tobacco in eastern Canada.

Methods and Materials

All tests were done using 3rd to 4th stage larvae, obtained from cultures of both species of cutworms maintained at the London laboratory. The rearing and testing techniques have been described in detail in previous papers (Harris and Svec, 1973; Harris *et al.* 1958, 1973) and therefore will be summarized. Cutworm larvae were reared under controlled laboratory conditions. Diapause eggs stored at 0 ± 1°C were placed on the surface of air-dry sand in a 4-litre jar and incubated at 26 ± 1°C. On hatching the young larvae were provided with bundles of fresh clover for food. Third to 4th stage larvae were fed on Chinese cabbage.

Laboratory tests with insecticides

Although the contact toxicity of a number of insecticides to both species of cutworms had been determined earlier (Harris and Svec, 1968; 1970; 1973; Harris *et al.,* 1973; McDonald, 1972), other experimental compounds had since been submitted for evaluation. The direct contact toxicity of 11 insecticides relative to chlorpyrifos and leptophos was assessed using technical grade materials (>90% purity) dissolved in 19:1 acetone:olive oil (v/v) and applied from a Potter spray tower. Chemical designations of experimental materials without accepted common names are as follows: AC 64475: 2-(Diethoxyphosphonylimino)-1,3-dithietane; Bay MEB 6046: 3,4-Dichloro-*a*-(trichloromethyl) benzenemethanol acetate; Dowco 275: Phosphorothioic acid: *0,0*-diethyl-*0*-(6-fluoro-2-pyridyl) ester; Nia 33297: 3-phenoxybenzyl (+) *cis-trans*-3-(2,2-dichlorovinyl)-2,2-dimethylcyclopropanecarboxylate; SD 8832: *0*-2-chlorovinyl *0*-ethyl diethylphosphoramidate; WL 24073: *0*-[2-chloro-1-(2,5-dichlorophenyl) vinyl] *0*-methyl ethylphosphonothioate; WL 25735: *0*-[2-chloro-1-(2,5-dichlorophenyl) vinyl] *0*-methyl methylphosphonothioate; WL 26738: *0*-[1-(2,4-dichlorophenyl) vinyl] *0*-methyl ethylphosphonothioate.

Each screening test consisted of a control (solvent only) and four insecticide concentrations. Duplicates, each containing 10 3rd stage larvae were tested at each concentration. The treated insects were placed in containers containing a layer of moist sand, provided with food, and placed at 27±1°C, 60±5% RH, and 24 hr photoperiod for 42 hr when mortality counts were made. Other laboratory tests were done to assess the effectiveness of two of the more promising direct contact insecticides as soil treatments using procedures described previously (Harris *et al.,* 1973). This involved application of EC formulations of the insecticides to the surface of field moist and air-dry Plainfield sand contained in metal trays 43 cm sq x 10 cm deep. Laboratory-reared cutworms were introduced, food provided and mortality counts made after 48 hr. Chlorpyrifos was included for comparative purposes. In all laboratory tests with technical or formulated materials, results were corrected for natural mortality (Abbott, 1925) which never exceeded 10%.

Field tests with insecticides

Tests were conducted in microplots over two seasons using techniques similar to those outlined elsewhere (Harris *et al.,* 1971; 1973). Insecticides tested included those which were effective as preplanting treatments as referred to above (chlorpyrifos, leptophos, N-2596 (*S*-(*p*-chlorophenyl) *0*-ethyl ethylphosphonodithioate) and WL 24073 which had shown promise in the present series of laboratory tests. In both years carbaryl was included for comparative purposes. The microplots were filled with light mineral soil in the fall of 1971 and seeded to rye. In April the rye was turned under by hand spading to simulate ploughing. Dates of establishment of the tests and taking records for each year were as follows:

Year	Tobacco Transplants set out	Cutworms added (AM) and insecticides applied (PM)	Damage assessed	Phytotoxicity assessed
1972	May 23	June 6	June 12	June 27
1973	May 25	June 25	July 1	July 16

Three rows of tobacco plants (5/row) were planted in each plot. The centre row was used for determination of residues at harvest and thus was protected from

cutworm attack by placing a circular plastic barrier around each plot for the duration of the larval stage. In 1972 tests were conducted using both redbacked and darksided cutworms. This was done by dividing each plot into halves by placing a galvanized iron strip set 15 cm into the ground and projecting 10 cm above the surface across each plot. Each subplot was infested with 5 cutworms/plant, i.e. 25 redbacked cutworms were placed in one half of the plot, 25 darksided cutworms in the other. In the 1973 test, set out at a later date in June to parallel the period in which the redbacked and darksided cutworm attack tobacco in Quebec, only the darksided cutworm was used (2 larvae/plant, i.e. 20 larvae/plot). In both years insecticide treatments, in duplicate, were applied as over-the-row (20-25 cm spread) applications in 182 L water using an Oxford Precision Sprayer. A rating system for both efficacy and phytotoxicity was adopted: 0 = no damage; 1 = light; 2 = moderate; 3 = severe; 4 = very severe. In both years tobacco was harvested in the last week of August and representative samples taken as required for residue analysis. Techniques of extraction, clean-up and GLC analysis have been described in detail elsewhere (Harris *et al.*, 1973).

Results and Discussion

In laboratory tests on the darksided cutworm Nia 33297 was more toxic by direct contact than either chlorpyrifos or leptophos (Table I). WL 24073, AC 64475, and WL 25735 were slightly less effective. The seven other insecticides showed little promise. The order of toxicity of the insecticides to the redbacked cutworm was similar, although this species did appear to be slightly more susceptible to insecticides in general than the darksided cutworm (Table I).

TABLE I. Direct contact toxicity of 11 insecticides relative to chlorpyrifos and leptophos to 3rd stage larvae of the darksided and redbacked cutworms.

Insecticide	42 hr avg. corr. % mortality at indicated % insecticide solution							
	Darksided cutworm				Redbacked cutworm			
	0.001	0.01	0.1	1.0	0.001	0.01	0.1	1.0
Nia 33297	0	100	100	—	15	95	100	—
Chlorpyrifos	0	0	93	100	0	18	100	100
Leptophos	0	0	90	100	0	0	100	100
WL 24073	0	0	70	100	0	5	90	100
AC 64475	0	0	65	100	3	10	73	100
WL 25735	0	0	30	100	0	5	90	100
Mecarphon	0	0	10	100	0	0	0	100
Dowco 275	0	0	5	65	0	0	0	100
WL 26738	0	0	0	55	0	0	5	80
Chlormephos	0	0	0	50	0	0	0	35
SD 8832	0	0	0	20	0	0	0	5
Bay MEB 6046	0	0	5	0	0	0	0	40
Oxamyl	0	0	0	0	0	5	0	0

Effective cutworm control is usually obtained with insecticides having dual action, i.e. effective on both soil and foliage. Other studies (unpublished data) have indicated that technical WL 24073 and WL 25735 show good activity in soil, while Nia 33297 and AC 64475 are only fair and thus were not included in subsequent tests.

To obtain further information prior to field tests, EC formulations of WL 24073 and WL 25735 applied as soil treatments were tested in the laboratory at practical levels of application. WL 24073 was effective relative to chlorpyrifos in

moist sand, but was less active in dry sand (Table II). WL 25735 showed moderately good activity against the darksided cutworm but was not as effective as either WL 24073 or chlorpyrifos in moist or air-dry soil.

TABLE II. Laboratory assessment of the toxicity of EC formulations of two insecticides relative to chlorpyrifos applied as surface applications to moist and air-dry Plainfield sand to 4th stage darksided cutworms.

Insecticide	% water	48 hr avg. corr. % mortality at indicated Kg AI/ha			
		0.28	0.56	1.12	2.24
Chlorpyrifos	6.0	100	100	100	
	0.5		100		
WL 24073	6.0	100	100	100	
	0.5		10	75	100
WL 25735	6.0	65	100	100	
	0.5		70	75	95

As noted above, earlier studies showed that chlorpyrifos, leptophos, and N2596 applied as preplanting treatments provide effective cutworm control and thus they were used in the 1972 field tests to assess their value as postplanting treatments. Chlorpyrifos EC and WP and N-2596 EC gave excellent control of both species of cutworms at 1.12 and 2.24 Kg AI/ha (Table III). Leptophos, while less effective was adequate. All three were more effective than carbaryl. Conditions of moderate soil moisture and temperature in the first week after treatment were ideal for effective cutworm control. Neither N-2596 EC nor carbaryl WP were phytotoxic. However, both chlorpyrifos and leptophos EC were moderately phytotoxic at 1.12 Kg AI/ha and severely phytotoxic at 2.24 Kg AI/ha (Table III). WP formulations of both insecticides were less phytotoxic. Phytotoxicity assessments were complicated by cold weather in the second week of June culminating in a severe frost on June 12. Symptoms of phytotoxicity resulting from insecticide applications often appear under stress conditions, e.g. cold, wet weather. In 1973, WL 24073 was also included in the field studies and lower rates of chlorpyrifos and N-2596 were tested. Leptophos was tested at the lower of the two rates used in 1972 since this appeared to be the minimum rate which would provide effective control. Emphasis was also placed on comparing the efficacy of different formulations. Regardless of formulation all four insecticides were effective at 0.56 to 1.12 Kg AI/ha and were superior to carbaryl (Table III). Climatic conditions in the week after treatment were again ideal for effective cutworm control. WL 24073 caused moderate to severe phytotoxicity; none of the other insecticides were phytotoxic. Subsequent analyses of samples of tobacco taken at harvest in 1972 and/or 1973 indicated no residues of N-2596, chlorpyrifos or chlorpyrifos-oxon at 0.56 or 1.12, leptophos or leptophos-oxon at 1.12, or carbaryl at 2.24 Kg AI/ha within the limits of sensitivity of the analytical methods (Table III).

The results indicate that N-2596, chlorpyrifos and leptophos will be effective as over-the-row postplanting treatments for control of the darksided and redbacked cutworms attacking tobacco, and will be superior to carbaryl. Under stress conditions chlorpyrifos and leptophos may be phytotoxic. Use of WP formulations of these materials would tend to minimize this effect.

TABLE III. Effectiveness of four insecticides relative to carbaryl as postplanting treatments for controlling the darksided and redbacked cutworms attacking tobacco grown in light mineral soil.

Insecticide	Formulation	Kg AI/ha	Damage Rating[1] Efficacy[2] (6 days post-treatment)	Phytotoxicity (21 days post-treatment)	Residues (ppm[3]) on tobacco at harvest
			1972		
N-2596	EC	1.12	0.	0.	< 0.001
		2.24	0.	0.	N/S[4]
Chlorprifos	EC	1.12	0.	2.	< 0.002;-oxon < 0.02
		2.24	0.	4.	N/S
	WP	1.12	0.	1.	< 0.002;-oxon < 0.02
		2.24	0.	2.	N/S
Leptophos	EC	1.12	1.	2.	N/S
		2.24	.5	4.	N/S
	WP	1.12	.5	1.	N/S
		2.24	1.	2.	N/S
Carbaryl	WP	2.24	2.	0.	< 0.08
Control	—	—	4.	0.	N/D[5]
			1973		
N-2596	EC	0.56	0.	0.	< 0.001
		1.12	0.	0.	< 0.001
Chlorpyrifos	EC	.56	0.	0.	< 0.002;-oxon < 0.02
	WP	.56	0.	0.	< 0.002;-oxon < 0.02
	G	1.12	0.	0.	< 0.002;-oxon < 0.02
WL 24073	EC	.56	.5	2.	N/S
		1.12	0.	4.	N/S
Leptophos	EC	1.12	0.	0.	< 0.01;-oxon < 0.03
	WP	1.12	0.	0.	< 0.01;-oxon < 0.03
Carbaryl	WP	2.24	1.	0.	N/S
Control	—	—	2.	0.	N/D

[1]0 = no damage; 1 = Light; 2 = Moderate; 3 = Severe; 4 = Very severe.

[2]Efficacy assessments in 1972 for both darksided and redbacked cutworms yielded identical results; in 1973 only darksided cutworms were used in the tests.

[3]ppm based on fresh weight of crop.

[4]N/S — not sampled.

[5]N/D — none detected.

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EFFICACY, PHYTOTOXICITY, AND PERSISTENCE OF INSECTICIDES USED AS PRE- AND POSTPLANTING TREATMENTS FOR CONTROL OF CUTWORMS ATTACKING VEGETABLES IN ONTARIO[1]

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Abstract

A study was undertaken to obtain sufficient data on efficacy, phytotoxicity and persistence of several insecticides showing promise for control of cutworms attacking vegetable crops grown on mineral soils in southwestern Ontario to

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enable registration. Chlorpyrifos, leptophos, Stauffer N2596 (*S*-(*p*-chlorophenyl) *0*-ethyl ethylphophonodithioate), WL 24073 (*0*-[2-chloro-1-(2,5-dichlorophenyl) vinyl] *0*-methyl ethylphosphonothioate) and carbaryl were tested for effectiveness against the darksided cutworm, *Euxoa messoria* (Harris) as pre- and postplanting treatments. Crops included peppers, cucumbers, tomatoes, potatoes, cabbage, chinese cabbage, broccoli, brussels sprouts, cauliflower and rutabaga. Chlorpyrifos, leptophos and N2596 were effective at 1.12-2.24 kg AI/ha as preplanting broadcast applications to the soil surface or incorporated into the top 2.5 cm of soil. Preplanting treatments of chlorpyrifos and leptophos caused no phytotoxicity to peppers, cucumbers, tomatoes or potatoes and only the latter contained detectable residues of chlorpyrifos, leptophos and/or their degradation products at harvest. Postplanting row treatments of chlorpyrifos, leptophos, N2596 and WL 24073 were effective at 0.56 to 2.24 kg AI/ha depending on the insecticide and the crop. None of the insecticides was phytotoxic to peppers, tomatoes or potatoes. In one test leptophos and carbaryl caused slight, and WL 24073 severe, damage to cucumbers. In another test chlorpyrifos and leptophos caused no phytotoxicity to any of the crops. Residues of these 2 insecticides or their degradation products were detected only on chinese cabbage. The results indicate that chlorpyrifos, leptophos and N2596 will be suitable replacements for the more persistent organochlorine insecticides for control of cutworms attacking vegetable crops.

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Cutworms are important pests of many agricultural crops in Ontario. Organochlorine insecticides were effective, but agricultural uses of the cyclodiene insecticides in Ontario were eliminated in 1969 and DDT uses were restricted. These included cutworm control on tobacco and vegetables. Other recommended insecticides, e.g. carbaryl and trichlorfon, while effective against some cutworm species such as the variegated cutworm, *Peridroma saucia* (Hübner) (Harris *et al.,* 1962), did not adequately control soil-inhabiting species such as the darksided cutworm, *Euxoa messoria* (Harris) (Harris *et al.,* 1969; 1974). The latter was a major problem on tobacco and DDT use for this purpose was retained under permit until satisfactory alternatives could be developed. Several years research resulted in development of some insecticides e.g. chlorpyrifos and leptophos that were effective as pre- and/or postplanting treatments. Pertinent literature has been summarized (Harris *et al.,* 1974).

In 1970 DDT failed to effectively control soil-inhabiting cutworms attacking vegetables in the main marsh areas of the Province. Carrots and onions were most severely damaged, largely by the redbacked cutworm *E. ochrogaster* (Guenée). Laboratory and field studies indicated that chlorpyrifos and leptophos were effective (Harris and Svec, 1973; McDonald, 1972) and they were registered and recommended in Ontario for control of the cutworms attacking carrots, onions and celery grown on organic soils. Horticultural crops are also grown extensively in southwestern Ontario on mineral soils, and in some areas, particularly adjacent to tobacco-growing areas, reports of darksided and redbacked cutworm damage increased. While earlier efficacy studies indicated that chlorpyrifos and leptophos would be effective and persistence of residues of chlorpyrifos and leptophos in some vegetables had been documented (Braun *et al.,* 1975a, b; Harris *et al.* 1973b) further registrations were contingent on obtaining data on insecticide efficacy against cutworms in mineral soils, on phytotoxicity and on persistence of residues on the various crops subject to cutworm attack. This report summarizes results of a cooperative study undertaken in 1973-74 to meet these objectives.

Methods and Materials

The program involved both Agriculture Canada (Research Institute, London, Ontario) and the Ontario Ministry of Agriculture and Food (Horticultural Ex-

periment Station, Simcoe and the Provincial Pesticide Residue Testing Laboratory, Guelph, Ontario). Field studies were conducted at London using microplots, and Simcoe using larger scale field trials. The soil types were Plainfield sand (London) and Berrien sandy loam (Simcoe). Normal practices of cultivation and fertilization were followed in both microplot and larger scale field trials. In the microplot tests, artificial cutworm populations were introduced. Fourth stage, laboratory-reared cutworms were used. Preplanting pesticide treatments were applied as broadcast applications either to the soil surface or incorporated into the top 2.5 cm soil. Postplanting treatments were applied as a 20-25 cm band over the row. Pesticide formulations used were: chlorpyrifos, 40% emulsifiable concentrate (EC) and 25% wettable powder (WP), leptophos, 27% EC and 45% WP; Stauffer N2596 (*S*-(*p*-chlorophenyl) *O*-ethyl ethylphosphonodithioate) 40% EC; Shell WL 24073 (*O*-[2-chloro-1-(2,5-dichlorophenyl) vinyl] *O*-methyl ethylphosphonothioate) 10% EC; carbaryl 85% WP and diphenamid 80% WP. Applications were made with an Oxford Precision Sprayer (London) or a Chapin Sprayer (Simcoe) using 444 liter water/ha unless otherwise specified. Emphasis was placed on peppers, cucumbers, tomatoes and potatoes since most cutworm damage from 1971-73 was associated with these crops. Less extensive tests were done on crucifers.

1) **Peppers, cucumbers, tomatoes and potatoes**

a) *Preplanting treatments*—Two experiments were done. In one, primarily for assessment of insecticide efficacy, 16 plots, each 0.9 x 4.6 m were established at Simcoe. Duplicate broadcast treatments of chlorpyrifos, leptophos and Stauffer N2596 EC at 1.12 kg AI/ha both singly and in combination with diphenamid at 2.24 kg AI/ha (for combined insect-weed control) were applied May 21 and incorporated immediately. Control plots were included. In the event that a natural cutworm infestation did not occur, two portable microplots comprising fiberglas circles 0.6 m in diam x 15 cm deep were set into the ground to a depth of 5 cm in each plot. Each microplot was infested with 20 larvae, lettuce leaves were provided as food and each microplot was covered with a screen. Cutworm mortality was assessed 72 hr after treatment. The plots were subsequently seeded with tomatoes (Veebrite) for assessment of damage resulting from natural cutworm populations and of phytotoxicity.

The second study at Simcoe was done primarily to obtain data on phytotoxicity and persistence of residues of chlorpyrifos and leptophos. Twelve plots, each 4.6 x 6.1 m were established, 3 each for potatoes, peppers, cucumbers and tomatoes. Chlorpyrifos and leptophos EC were applied at 1.12 and 2.24 kg AI/ha respectively while the third plot was used as a control. Treatment and planting (3 rows/plot) dates were: potatoes (Chieftain) May 5 and 14; peppers (Staddon's Select); cucumbers (Pioneer); and tomatoes (Veebrite) May 30-31 and June 4. Plant damage from the natural cutworm population was rated 2, 4 and 6 days after germination or planting on the basis of: 0 — no damage; 1 — Light ($<$ 25% leaf damage); 2 — Moderate (26-50%); 3 — Severe (51-75%); 4 — Very Severe ($>$ 75% leaf damage or plants cut off at stem). Peppers, cucumbers, and tomatoes were harvested July 18, August 1 and 8 respectively, and potatoes August 1 and 10. Random samples (454 g) of fruit were collected and analyzed at the Provincial Pesticide Residue Testing Laboratory at Guelph for residues of chlorpyrifos (limit of detection 0.005 ppm), chlorpyrifos-oxon (0.002 ppm), 3,5,6-trichloro-2-pyridinol (0.001 ppm), leptophos (0.005 ppm), leptophos-oxon (0.002 ppm), and 4-bromo-2,5-dichlorophenol (0.001 ppm) as described elsewhere (Braun 1974).

b) *Postplanting treatments*—Four experiments were done: 2 microplot studies at London and 2 larger scale tests at Simcoe. The microplot procedure has been outlined in detail elsewhere (Harris *et al.,* 1971; 1973a). Since earlier studies,

referred to above established that several insecticides were effective as preplanting treatments, emphasis was placed on obtaining information on their effectiveness, phytotoxicity and persistence as postplanting row treatments. In the 1st experiment at London potatoes (Chieftain) were seeded May 7, 2 rows of 5 plants/plot. Peppers (2 x 5/plot) and tomatoes (1 x 5/plot) were transplanted and cucumbers (2 x 5/plot) seeded May 31. Several hours prior to insecticidal treatment the plots were infested with cutworms 2/plant. Four experimental insecticides were tested: chlorpyrifos WP at 0.56, leptophos WP at 1.12, N2596 at 0.56 and Shell WL 24073 at 1.12 kg AI/ha. Carbaryl at 2.24 kg AI/ha was included as a standard. When available WP were used for postplanting treatments in preference to EC formulations since the former are usually less phytotoxic. Treatments, in duplicate, were applied June 5-8 in late afternoon as row applications. Cutworm damage was rated as in a) 2, 4 and 6 days and phytotoxicity 7, 14, and 21 days after treatment. Cucumbers and peppers were harvested July 23 and 25 respectively, tomatoes and potatoes August 8 and 30 respectively. The fruit was sampled for determination of chlorpyrifos (limit of detection 0.003 ppm), chlorpyrifos-oxon (0.06 ppm), leptophos (0.005 ppm), leptophos-oxon (0.05 ppm) and N2596 (0.001 ppm) as described elsewhere (Harris *et al.*, 1973a).

The 2nd study at London involved determination of host plant preferences of the darksided and redbacked cutworms. Portable microplots described in a) were installed in the rows of various vegetables grown at the Research Institute Field Station. Each microplot encompassed 2 plants. Cutworms were introduced, 5/plant and the plots covered with screens to prevent birds from destroying the larvae. Plant damage was assessed after 72 hr.

The 3rd study at Simcoe, was primarily for assessment of insecticide efficacy. Eight 0.9 x 4.6 m plots were seeded May 21 with tomatoes (Veebrite). After germination, portable microplots were installed in the rows, 2/plot, and each was infested with 20 cutworms. Chlorpyrifos and leptophos WP and N2596 were applied June 7 at 1.68, 2.24, and 1.68 kg AI/ha respectively as row sprays. Treatments were duplicated and controls were included. After treatment the plots were covered with screens. Cutworm mortality and plant damage were assessed 72 hr later.

The 4th experiment also at Simcoe was primarily to assess insecticide phytotoxicity as postplanting treatments and persistence of the residues. Four large plots 19.8 x 18.3 m were established. Potatoes (Chieftain) were planted May 11, peppers, tomatoes and cucumbers June 11. After planting each plot was subdivided into 4 - 4.6 wide x 18.3 m long. Each subplot contained 3 rows of plants. In the event that natural cutworm infestations did not occur, portable microplots, each containing 10 larvae were established in the pepper and tomato plots for assessment of insecticide efficacy. Chlorpyrifos WP at 0.56 and 1.12 and leptophos WP at 1.12 and 2.24 kg AI/ha were applied as row applications. Peppers, tomatoes and potatoes were treated June 8, cucumbers June 22. After treatment the microplots were covered with screens. Cutworm mortality and plant damage were assessed after 72 hr. Damage from natural cutworm infestations was rated 7, 14, and 21 days after treatment. Peppers were harvested July 18 and August 1, cucumbers August 1, tomatoes August 8 and 20, and potatoes August 10. Repsentative samples of the fruit were analyzed for residues at the Provincial Pesticide Residue Testing Laboratory at Guelph as described above.

c) *Phytotoxicity tests*—Four plots, each 12.2 x 18.3 m were established at Simcoe, one each for peppers, cucumbers, tomatoes and potatoes. Six varieties of each crop (Table I) were planted with 2 rows of each variety. Potatoes were planted May 11, peppers and tomatoes were transplanted June 1, and cucumbers seeded June 13. EC and WP formulations of chlorpyrifos and leptophos were

TABLE I. Varieties of crops used in phytotoxicity trials (Simcoe, Ontario).

Peppers	Cucumbers	Tomatoes	Potatoes
Canape	Bounty	Campbell 28	Cobbler
Early California Wonder	Early Pick	Heinz 1350	Kennebec
Keystone Hybrid 1933	Pickmore	Heinz 1706	Netted Gem
Keystone Hybrid 2668	Pioneer	Heinz 6919	Norland
Midway	Premier	Moira	Sebago
Yolo Wonder	Spartan Jack	V 729	Wauseon

applied at 1.12 and 2.28 kg AI/ha respectively. Peppers were treated June 13, cucumbers June 25, tomatoes May 30-31, and potatoes June 14. Applications were made crossways to the rows, with each application covering a strip 3.1 m wide x 18.3 m long. Phytotoxicity was rated twice weekly as described above.

2) **Crucifers**

a) *Preplanting treatments*—Insecticide efficacy was assessed in microplots at London using direct seeded cabbage as the indicator crop as described in 1b). Each plot was infested with 50 cutworms April 29. Chlorpyrifos, leptophos and N2596 EC, 1.12 kg AI/ha, were applied a few hr later. Treatments were in duplicate; controls were included. Cutworm mortality was assessed 72 hr later. The plots were seeded 7 days after treatment. Plant damage by cutworms was assessed June 7.

b) *Postplanting treatments and phytotoxicity tests*—Two experiments were done. Insecticide efficacy was assessed in microplots at London using direct seeded cabbage, as described in 1b) above. The plots were seeded May 10 and infested with 50 cutworms/plot May 30. Chlorpyrifos WP at 1.12, leptophos WP at 2.24 and N2596 at 1.12 kg AI/ha were applied as row applications, later on May 30 in 888 liters water/ha. Treatments were in duplicate; controls were included. Cutworm mortality was assessed 72 hr later and plant damage from cutworm attack, June 6.

The 2nd study at Simcoe, was done to obtain information on phytotoxicity and residues. The procedure was similar to that outlined in 1b). Six crops (one variety of each) were included: cabbage (King Cole); chinese cabbage (Spring Time); broccoli (Green Comet); rutabaga (Laurentian); brussels sprouts (Jade Cross); and cauliflower (Clou). All were seeded June 12. Chlorpyrifos EC and WP at 1.12 and leptophos EC and WP at 2.24 kg AI/ha were applied. Natural cutworm damage was rated 2, 4 and 6 days and phytotoxicity 7, 14 and 21 days after treatment. Cabbage was harvested August 30, chinese cabbage August 3 and 20, and all the other crops on August 20. Representative samples were collected and analyzed for residues at the Provincial Pesticide Residue Testing Laboratory in Guelph.

Results

1) **Peppers, cucumbers, tomatoes and potatoes**

a) *Preplanting treatments*—Both studies done at Simcoe yielded good results. In the 1st study chlorpyrifos and N2596 were both effective against the darksided cutworm at 1.12 kg AI/ha either alone or in combination with diphenamid (Table II). Leptophos at 1.12 kg AI/ha alone and in combination with diphenamid was not as effective. Damage to the tomatoes from naturally occurring cutworm populations was not sufficiently high to warrant assessment.

TABLE II. Mortality[1] of darksided cutworms following pre- and postplanting applications of 3 insecticides to direct-seeded tomatoes (Simcoe, Ontario).

Insecticide/herbicide	Formulation	kg AI/ha	72 hr avg. % cutworm mortality
Preplanting treatment[2,3]			
Chlorpyrifos	EC	1.12	100
Chlorpyrifos + diphenamid	EC + WP	1.12 + 2.24	100
N2596	EC	1.12	96
N2596 + diphenamid	EC + WP	1.12 + 2.24	90
Leptophos	EC	1.12	56
Leptophos + diphenamid	EC + WP	1.12 + 2.24	69
Control	—	—	0
Postplanting treatment[4]			
Chlorpyrifos	WP	1.68	100
Leptophos	WP	2.24	88
N2596	EC	1.68	63
Control	—	0	0

[1]Based on mortality of cutworms in portable microplots installed in the larger plots.
[2]Insecticides tested alone and in combination with diphenamid for weed control.
[3]Broadcast application incorporated into top 2.5 cm soil.
[4]Twenty to 25 cm band application over the row.

In the 2nd experiment, lack of a natural cutworm infestation precluded assessments for insecticide efficacy. Preplanting treatments of chlorypifos at 1.12 and leptophos at 2.24 kg AI/ha were not phytotoxic to any of the crops. No detectable residues of chlorpyrifos, leptophos or their degradation products were found in peppers, cucumbers or tomatoes at harvest. The initial samples (August 1) of potatoes contained average levels of 0.18 ppm chlorpyrifos, a trace of chlorpyrifos-oxon and 0.14 ppm 3,5,6-trichloro-2-pyridinol. In the subsequent sampling (August 10) residues of chlorpyrifos and 3,5,6-trichloro-2-pyridinol each averaged 0.02 ppm. Residues of leptophos averaged < 0.01 ppm in the potatoes at first harvest; no residues of leptophos-oxon or 4-bromo-2,5-dichlorophenol were detected. No residues of leptophos or its degradation products were detected in potatoes from the second harvest.

b) *Postplanting treatments*—In the 1st of 2 microplot studies at London, chlorpyrifos at 0.56 and WL 24073 at 1.12 kg AI/ha gave good control of cut-

TABLE III. Effectiveness of 5 insecticides applied as postplanting treatments[1] in controlling the darksided cutworm attacking peppers (Microplot tests, London, Ontario).

Insecticide	Formulation	Rate of application kg AI/ha	Damage Rating[2] Days after treatment		
			2	4	6
Chlorpyrifos	WP	0.56	0	0	0.5
WL 24073	EC	1.12	0.5	0.5	0.5
N2596	EC	0.56	1.0	1.0	1.0
Leptophos	WP	1.12	1.0	1.0	1.0
Carbaryl	WP	2.24	1.0	1.0	1.0
Control	—	—	1.5	1.5	2.5

[1]20-25 cm band application over the row.
[2]0 — no damage to 4 — very severe damage.

worms attacking peppers (Table III). N2596, leptophos and carbaryl at 0.56, 1.12 and 2.24 kg AI/ha respectively were less effective with the cutworms causing light damage. Cutworm feeding was atypical in this experiment being confined to the leaves, possibly because of conditions of high soil moisture. Results obtained with the 3 other crops included in the study were confusing in that, although the microplots had been infested with 2 cutworms/plant, no damage was apparent on tomatoes, cucumbers or potatoes in either control or treated plots. Chlorpyrifos, leptophos and carbaryl WP and WL 24073 and N2596 were not phytotoxic to peppers, tomatoes or potatoes at the application rates used. Leptophos and carbaryl caused light phytotoxicity (rating = 0.5) and WL 24073 very severe phytotoxicity (rating = 4.0) to cucumbers. No residues of chlorpyrifos, chlorpyrifos-oxon, leptophos, leptophos-oxon or N2596 were detected on peppers, cucumbers, tomatoes, or potatoes at harvest.

The darksided cutworm has been assumed to be the major species of cutworm attacking vegetables grown in light mineral soils in Ontario as larvae collected from infested pepper, tomato and potato fields in recent years have usually been identified as this species when reared through to adults. Results of the previous study suggested that the darksided cutworm has distinct host plant preferences. Identification of cutworm larvae is difficult and with the numerous reports of cutworm damage to vegetables in recent years, only a limited number of collections have been reared for identification. The possibility that a related species. e.g., the redbacked cutworm might also be involved was therefore considered. The 2nd microplot study done at London indicated that the redbacked cutworm had a slightly broader range of preferences and tended to be more destructive than the darksided cutworm (Table IV). The results obtained with the darksided cutworm

TABLE IV. Vegetable host plant preferences of the darksided and redbacked cutworms (Microplot Tests, London, Ontario).

Host plant	Damage rating[1]	
	Darksided cutworm	Redbacked cutworm
Carrot (Baby Finger)	4	4
Parsnip (Hollow Crown)	4	4
Red Beet	3	4
Pea (Alaska)	3	2
Spanish Onion	2	4
Sweet Corn (Silver Queen)	2	3
Lettuce	2	2
Bean (Gold Crop)	2	2
Pepper	2	N/T[2]
Celery	1	2
Leek	1	0
Tomato (seedlings)	4	N/T
Tomato (transplants)	0	N/T
Cucumber	0	N/T
Potato	0	2

[1]Damage ratings made 48 hr after infesting plots with 4th stage larvae; 0 — no damage to 4 — very severe damage.
[2]N/T = not tested.

confirmed the observations made in the previous experiment, i.e. that it showed preference for peppers over potatoes, cucumbers, and tomato transplants. Yet when seedling tomatoes were tested, darksided cutworm larvae caused severe damage to the plants. Food preferences of the darksided cutworm may be dependent not only on the crop but also on stage of plant development. This observation

is further substantiated by comparing results obtained on potatoes in these experiments with observations made in infested potato fields in southwestern Ontario. In our studies the darksided cutworm did not feed on potatoes. Yet larvae causing severe damage in three commercial potato fields in southwestern Ontario in 1973, when reared to adults, were identified as the darksided cutworm.

In the 3rd study, at Simcoe, tests were done on the 3 insecticides showing the most promise in the microplot studies at London, i.e. chlorpyrifos, leptophos, and N2596 and direct seeded tomatoes used as the indicator crop. Chlorpyrifos at 1.68 kg AI/ha provided excellent cutworm control as a postplanting treatment (Table II). Leptophos at 2.24 and N2596 at 1.68 kg AI/ha were less effective. The cutworms caused severe damage in the control microplots, slight damage in the leptophos and N2596 plots and no damage in the chlorpyrifos plots.

The 4th study, also at Simcoe, paralleled the microplot study at London on peppers, cucumbers, tomatoes, and potatoes but only chlorpyrifos and leptophos were tested. Efficacy assessments using portable microplots were done only on peppers and tomatoes. Chlorpyrifos WP at 0.56 and 1.12 kg AI/ha provided effective control of the darksided cutworm on peppers (damage rating = 0) as compared to the control (damage rating = 1.5). The larvae did not feed on the tomato transplants in either the control or treated microplots. No significant natural cutworm infestation occurred in any of the plots. No significant residues of chlorpyrifos or its degradation products were found on any of the crops at harvest or of leptophos or its degradation products on peppers, cucumbers or potatoes. Trace amounts of leptophos were found on tomatoes at first harvest (August 8) at the 2.24 kg/ha application rate; at the second sampling (August 20) no residues were detected.

c) *Phytotoxicity tests*—Neither EC nor WP formulations of chlorpyrifos at 1.12 or leptophos at 2.24 kg AI/ha caused significant phytotoxicity to any of the 6 varieties (Table I) of the 4 crops tested at Simcoe.

2) **Crucifers**

a) *Preplanting treatments*—In microplot studies at London, preplanting broadcast soil surface applications of chlorpyrifos, leptophos and N2596 at 1.12 kg AI/ha gave excellent control of darksided cutworms attacking direct-seeded cabbage (Table V). Seventy-two hr mortality counts indicated that leptophos was either less effective or slower in its action. However, in terms of plant damage all 3 were effective whereas the cutworms destroyed all plants in the control plots (Table V).

b) *Postplanting treatments*—The efficacy studies, in microplots at London, indicated that row treatments of chlorpyrifos at 1.12 and leptophos at 2.24 kg AI/ha caused 96-97% cutworm mortality in 72 hr (Table V). Only 3 per cent of the plants were destroyed (Table V). N2596 at 1.12 kg AI/ha was less effective.

In the field experiment at Simcoe lack of a natural cutworm population precluded efficacy assessments. Neither formulation of chlorpyrifos at 1.12 or leptophos at 2.24 kg AI/ha was phytotoxic to cabbage, chinese cabbage, broccoli, rutabaga, brussels sprouts, or cauliflower. No residues of chlorpyrifos, leptophos or their degradation products were detected on any of the crops at harvest, other than leptophos or chinese cabbage. At first harvest (August 3) 0.02 ppm leptophos was found on plants treated with the WP formulation. A more extensive sample taken August 28 on both the EC and WP treatments showed 0.17 ppm leptophos and $<$ 0.01 ppm 4-bromo-2,5-dichlorophenol resulting from the EC treatment, and 0.64 ppm leptophos, $<$ 0.01 ppm leptophos-oxon, and 0.01 ppm 4-bromo-2,5-dichlorophenol from the WP treatment.

TABLE V. Mortality of darksided cutworms and percent damage to direct-seeded cabbage following preplanting or postplanting applications of 3 insecticides (Microplot tests, London, Ontario).

Insecticide	Formulation	kg AI/ha	72 hr avg. % cutworm mortality	Avg. % plants destroyed
Preplanting treatment[1]				
Chlorpyrifos	EC	1.12	100	0
N2596	EC	1.12	100	0
Leptophos	EC	1.12	75	0
Control	—	—	0	100
Postplanting treatment[2]				
Chlorpyrifos	WP	1.12	97	3
Leptophos	WP	2.24	96	3
N2596	EC	1.12	84	13
Control	—	0	0	100

[1]Broadcast soil surface application.
[2]Twenty to 25 cm band application over the row.

Discussion

There are 3 possible approaches to controlling cutworms attacking vegetable crops grown on light mineral soil: preplanting broadcast treatment to the cover crop grown in rotation with vegetables; preplanting broadcast soil treatment; and postplanting row treatment. The method of control adopted depends on cropping practices and species of cutworms attacking the crops.

In southwestern Ontario rye and to a lesser extent wheat are commonly grown in rotation with the major crop particularly in areas devoted primarily to tobacco production. The darksided cutworm, the most important species at present, overwinters in these fields as the egg, hatches in early spring and feeds on the rye foliage. Chlorpyrifos or leptophos applied to the rye foliage in late April or early May at 0.56 to 1.12 kg AI/ha provide effective control of the darksided cutworm attacking tobacco (Cheng, 1971, 1973; Harris *et al.*, 1969, 1971, 1973a) and this approach would be equally effective in controlling cutworms attacking vegetables grown in rotation with rye or other cereal crops.

In instances where there is no cover crop, a preplanting soil application of chlorpyrifos, leptophos or N2596 is effective at 1.12 to 2.24 kg AI/ha against the darksided cutworm attacking tobacco as a broadcast application to the soil surface or incorporated into the top 2.5 to 5.0 cm of soil (Cheng, 1971, 1973; Harris *et al.* 1968, 1971). This study indicates that any of these insecticides used as a preplanting soil treatment also would effectively control the darksided cutworm attacking vegetables (Tables II and V) and could be used in combination with a preplanting herbicide application (Table II). Since these insecticides are equally toxic to the redbacked cutworm (Harris and Svec, 1973; Harris *et al.*, 1974; McDonald, 1972) their use as preplanting soil treatments in areas where this species is a problem would also be feasible.

Postplanting treatments are required in instances where: growers have not previously encountered cutworm problems and thus have not used preventative controls; where cutworms migrate into vegetable fields from adjacent rye fields in

late May or early June; or where another species of cutworm, e.g. the black cutworm, *Agrotis ipsilon* (Hufnagel) appears after planting. Chlorpyrifos, leptophos and N2596 are all effective as postplanting treatments against the darksided and redbacked cutworms attacking tobacco grown on mineral soils (Harris *et al.,* 1974) and against the redbacked and black cutworms attacking vegetables grown on organic soils (Harris and Svec, 1973; Harris *et al.,* 1973b). The present study indicates that these materials also will be effective against cutworms attacking vegetables grown on mineral soils at rates of 0.56 to 2.24 kg AI/ha depending on the insecticide and crop (Tables II, III, V). Chlorpyrifos appeared to be more effective as a postplanting treatment than leptophos or N2596. In contrast to preplanting applications, speed of insecticide action is important with postplanting treatments, i.e. the slower the action, the more plant damage will occur. Chlorpyrifos appeared to act more quickly than the other two insecticides. Phytotoxicity was not generally a problem other than with cucumbers although use of WP rather than EC formulations, would probably be advisable. No detectable residues of chlorpyrifos or its degradation products were found at harvest on any of the 10 crops subjected to postplanting treatments and residues of leptophos and its degradation products were found only in chinese cabbage. Studies with leptophos on 13 other vegetable crops also indicated that residues were not present in significant amounts at harvest when this insecticide was used for cutworm control in the early season (Braun *et al.,* 1975a; Harris *et al.,* 1973b). Similar findings have been reported with lettuce, onions and carrots treated with chlorpyrifos and leptophos where treatments were made at planting time followed by 3 postplanting applications spaced at 15- to 16-day intervals (Braun *et al.* 1975b).

The results indicate that chlorpyrifos, leptophos, and N2596 will be suitable replacements for the more persistent organochlorine insecticides for control of cutworms attacking vegetable crops.

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EFFECTS OF GRANULAR SYSTEMIC INSECTICIDES ON POPULATIONS OF THE CORN LEAF APHID AND YIELDS OF FIELD CORN IN SOUTHWESTERN ONTARIO

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Abstract

Several granular systemic insecticides which were effective against rootworms were examined for their effect on levels of infestation and injury by the corn leaf aphid, *Rhopalosiphum maidis* (Fitch), in field corn. In three of four years disulfoton at 1 lb AI/acre decreased aphid infestations and yields were significantly greater than in untreated plots. Aldicarb and Counter at 1 lb AI/acre significantly increased yields in the one year they were tested. Carbofuran and phorate at the above rate did not affect grain yield.

* * * * * *

Introduction

Foott and Timmins (1973) found that moderate to severe infestations of the corn leaf aphid, *Rhopalosiphum maidis* (Fitch), could cause large yield reductions in field corn, particularly if plants were under moisture stress. Most of the injury from aphid feeding occurred before and during pollination when the aphids were on the tassel. To be effective, aphicides must be applied before pollination. However, since tassels are hidden by the upright whorl leaves until shortly before pollination, most growers are unaware of the extent of aphid populations and insecticides are seldom applied.

Corn growers often apply granular systemic insecticides to the soil for control of the northern corn rootworm, *Diabrotica longicornis* (Say). The effects of these materials on other pests of corn in southwestern Ontario have not been studied. This paper reports the results of a 4-year study of the effects of several granular insecticides on populations of the corn leaf aphid and yield of field corn.

Materials and Methods

The investigation was conducted in plots of field corn at Harrow, Ontario from 1969 to 1972 inclusive. Seeds of the single cross variety WF9 X M14 were planted 10 in. apart in 40 in. rows. A good stand was guaranteed by planting two seeds per hill and later thinning to one plant. All tillers were removed. A treatment plot was one row of 33 to 37 corn plants. Six such treatment plots were applied each year in a randomized complete block design replicated three to five times.

Granular systemic insecticides were applied as a side dressing on each side of the rows in furrows 2 in. deep and 2 in. from the plants. Unless otherwise stated, the insecticides were applied soon after the plants had emerged and were thinned to one plant per hill. Similar furrows were also made along untreated rows of plants and left open for the same length of time as in the treated rows.

The populations of live aphids on the tassel were estimated at pollination and categorized as: 0, nil aphids; 1, up to 50 aphids; 2, 50 to approximately 400; 3, many hundreds on parts of the tassel; 4, many hundreds on most of the tassel; 5, many hundreds on all of the tassel and whorl leaves.

All plots were examined periodically and plants that were dwarfed or spindly before the initiation of aphid infestations, smutted, damaged by wind or machinery, off-type, possessing more than one ear, or were the end plants in a row were excluded from the analysis.

The ears were individually bagged at harvest and placed in a drying room until the moisture level was lowered to approximately 6 or 7%. The kernels were then removed with a hand-operated sheller and weighed.

The insecticides applied and the rates of application for each of the four years are shown in Table I. The late application of phorate in 1970 and 1971 refers to an application that was delayed until the plants were approximately 20 in. high.

Results and Discussion

Aphid populations were low in 1969, with most of the infestations occurring in the 0 and 1 categories (Table I). A 2.43 in rain accompanied by severe winds which occurred when the tassels on many plants were partially exposed probably had a deleterious effect on the aphids. Yields in the aldicarb plots were significantly greater ($P = 5\%$) than those in the untreated and carbofuran plots. The other materials had no effect on yield.

Populations of aphids in 1970 were larger than those recorded in 1969. Whereas only 9.6% of the plants had a 2 or higher rating in 1969, 36.2% of the plants were in this category in 1970 (Table I). All treated plots had greater yields than the untreated plots, but only the 1 and 2 lb AI/acre rates of disulfoton were significantly different at the 5% level. A rainfall of 4.91 in. during July, almost double the long-term average of 2.63 in., provided ample moisture and probably minimized yield reductions due to aphids in untreated plots. There was no advantage in delaying the application of phorate. Aphid infestations and yields in plots treated when the plants were approximately 20 in. high were similar to those in plots treated soon after plant emergence.

TABLE I. Levels of *R. maidis* infestations and mean yields per plant when plots of field corn were treated with granular systemic insecticides, 1969-1972.

Insecticide	Rate (lb AI/acre)	No. of plants per level of aphid infestation on tassel[1]						Mean yield of shelled corn per plant (g)[2]
		0	1	2	3	4	5	
1969								
aldicarb 10% G	1	118	42	2	0	0	0	172.8 a
disulfoton 15% G	2	133	30	1	0	0	0	169.9 ab
disulfoton 15% G	1	84	68	13	0	0	0	169.7 ab
phorate 10% G	1	52	81	24	5	1	0	169.4 ab
carbofuran 10% G	1	62	78	20	2	0	0	165.6 bc
untreated		37	98	19	7	0	0	164.0 bc
1970								
disulfoton 15% G	2	63	26	5	1	0	0	158.1 a
disulfoton 15% G	1	33	34	20	1	1	0	154.6 ab
phorate 10% G (late application)	1	4	47	39	3	3	0	149.8 abc
carbofuran 10% G	1	3	49	33	5	4	0	147.7 bc
phorate 10% G	1	11	54	25	3	2	0	145.3 bc
untreated		2	32	45	7	5	1	142.9 c
1971								
disulfoton 15% G	2	0	0	24	58	5	0	158.1 a
disulfoton 15% G	1	0	0	12	66	12	0	157.7 a
phorate 10% G (late application)	1	0	0	11	56	16	0	156.5 a
phorate 10% G	1	0	0	5	47	38	2	130.5 b
carbofuran 10% G	1	0	0	5	70	12	1	130.3 b
untreated		0	0	4	44	36	2	123.8 b
1972								
disulfoton 15% G	2	69	50	6	0	0	0	193.0 a
disulfoton 15% G	1	25	75	25	0	0	0	181.5 ab
Counter 10% G	1	3	45	80	0	0	0	178.3 ab
carbofuran 10% G	3	9	91	26	0	0	0	177.0 ab
carbofuran 10% G	1	2	55	66	1	0	0	166.5 bc
untreated		0	10	107	4	5	0	160.3 c

[1]Definitions of aphid infestations: 0, no live aphids; 1, up to 50 aphids; 2, 50 to 400; 3, many hundreds on part of tassel; 4, many hundreds on most of tassel; 5, many hundreds on all of the tassel and whorl leaves.
[2]Means not followed by a common letter are statistically different at the 5% level (Duncan's multiple range test).

The greater effectiveness of the disulfoton treatments in controlling aphids was confirmed by comparing aphid infestations at the beginning and at the peak of pollination. Whereas the majority of the plants which were rated 2 or greater in disulfoton-treated plots were rated 1 or less on the second evaluation, nearly all plants in the other plots retained the original rating. Dead aphids were frequently observed on plants in disulfoton-treated plots.

The largest aphid infestations occurred in 1971. Every plant examined during the pollination period had at least a 2 rating, with the majority being 3 or higher (Table I). Yields for the two rates of disulfoton and the phorate (late application) treatment were significantly higher (P = 5%) than those in the untreated, carbofuran and early-treated phorate plots. There is no explanation for the observation that aphid infestations in the disulfoton 1 lb AI/acre and

carbofuran plots were similar, but yields significantly different. A determination of the mean number of kernels per ear and kernel weight for each treatment showed that yield reductions were due mainly to reduced numbers of kernels (Table II). This is further evidence that most injury from aphid feeding occurs before and during pollination.

TABLE II. Average numbers of kernels per ear and weight/1000 kernels of field corn treated with granular systemic insecticides, Harrow, Ontario, 1971.

Insecticide	Rate (lb AI/acre)	Mean no. kernels/ear[1]	Mean weight of 1000 kernels (g)[1]
disulfoton 15% G	2	687.6 a	232.7 a
disulfoton 15% G	1	673.2 a	233.2 a
phorate 10% G (late application)	1	643.8 ab	235.1 a
carbofuran 10% G	1	568.4 bc	235.0 a
phorate 10% G	1	553.8 bc	239.2 a
untreated		530.6 c	238.2 a

[1]Means not followed by a common letter are statistically different at the 1% level (Duncan's multiple range test).

As in 1970, large numbers of dead aphids were observed on plants in the disulfoton plots during the pollination period (Fig. 1). Most of the living aphids on these plants were early instars, an indication that several days of feeding were necessary for mortality. Aphid mortality was also observed in some of the other treated plots, but it ranged from very low to moderate.

In 1972, 42.4% of the plants had a 2 or higher rating at pollination (Table I). The July precipitation was 2.57 in., almost equal to the long-term average of 2.63 in. Although 69 of the plants in the disulfoton 2 lb AI/acre plots had no live aphids at pollination, dead aphids were observed on many of them. Dead aphids were also present on some of the plants in the disulfoton 1 lb AI/acre plots that had no live aphids, but to a lesser extent than in the 2 lb AI/acre treatment. Yields in the disulfoton 2 lb AI/acre plots were significantly higher ($P = 1\%$) than those in carbofuran 1 lb AI/acre and untreated plots. Yields in the disulfoton 1 lb AI/acre, Counter 1 lb AI/acre and carbofuran 3 lb AI/acre plots were significantly higher ($P = 5\%$) than those in the untreated plots.

Precipitation probably was an important factor in the three years that disulfoton provided significantly higher yields. For example, a rainfall of 2.03 in. in the four days preceding pollination in 1970 apparently increased the uptake of disulfoton and caused a surge in aphid mortality during pollination. In 1971, the recorded precipitation in the 22 days preceding pollination was only 0.26 in. This lack of moisture likely restricted the absorption of insecticides and permitted large infestations of aphids to develop. A rainfall of 0.42 in. at the start of pollination resulted in a sudden increase in the uptake of disulfoton, as evidenced by the large numbers of dead aphids observed during pollination. In 1972, infestations were eliminated on many plants in the disulfoton-treated plots before records were taken at pollination. The only apparent explanation for this mortality was that 1.08 in. of rain fell in the week preceding pollination.

The greater effectiveness of disulfoton could result from its relatively low water solubility. Whereas materials with a higher water solubility could be absorbed by plants or leached from the root area early in the season, disulfoton might be retained in larger amounts near the roots for uptake during mid-season rains.

FIGURE 1. Dead *R. maidis* on a corn plant in a plot treated with disulfoton at 1 lb AI/acre, Harrow, Ontario,1971.

Conclusions

Three of the insecticides tested, carbofuran, disulfoton and phorate are currently registered for control of the northern corn rootworm at a maximum rate of 1 lb AI/acre. I conclude that in some years growers who use disulfoton would also prevent significant yield losses due to aphids. This material would be most effective when moderate rainfall occurs in the 7 to 10 days preceding pollination, the period during which there is often a very rapid increase in aphid populations. There was no evidence that carbofuran or phorate at the approved rates prevented yield reductions due to aphids. Carbofuran at 3 lb AI/acre was required to produce significant increases in yield over untreated plots. Aldicarb and Counter, not presently registered for use on corn in Ontario, reduced injury in the one year they were tested.

Acknowledgment

The technical assistance of Mr. P. R. Timmins is gratefully acknowledged.

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DYNAMICS OF CUTWORM POPULATIONS ON TOBACCO CROPS IN SOUTH-WESTERN ONTARIO
I. A PRELIMINARY SIMULATION MODEL FOR THE CROP-PEST SYSTEM

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Abstract

The development of general systems theory provides an integrative approach to the solution of complex biological problems. Systems modelling techniques are applied to the management of insect pests of tobacco in south-western Ontario, with the immediate objective being to elucidate the basic structure of the system. The tobacco culture and major insect pests, especially *Euxoa messoria* (Harris), are reviewed, and a three-tiered model is formulated containing an inner (entomological) tier, a medial (tobacco culture) tier, and an outer (agro-policy) tier. The dynamics and advantages of simulation models are discussed.

* * * * * *

Introduction

General systems theory, an integrative approach to scientific problems, was developed in the 1930's by von Bertalanffy, an Austrian biologist who spent much of his adult life teaching in Canadian universities. His concepts were quickly adopted by engineers, military strategists, industrial and commercial planners and grew during the 1940's and 1950's into a highly diverse body of theory, and a yet more diverse set of applications (Miles, 1973). In the last two decades, the application of system theory to complex problems has become a particularly powerful technique due to the introduction of the computer as both an analytical and simulation tool.

We feel that biology, both theoretical and applied, has lagged behind in these developments. This was in spite of the origin of general system theory in biology and the fact that problems in ecosystem management are often admirably suited to computer simulation and modelling. It is particularly surprising in view of the early work done by K. E. F. Watt (1959; 1963; 1964) while working with the Department of Forestry, and the more recent outstanding work of C. S. Holling and his group at the University of British Columbia (e.g. Holling and Goldberg, 1971; Walters and Bunnell, 1971). In the United States, England, and other countries there have been a number of recent successes in analyzing theoretical aspects of ecosystems (e.g. Jeffers, 1972) and such aspects of ecosystem management as pest control (Conway and Murdie, 1972; Wood, 1971; Haynes, 1973) and conservation (Milner, 1972; Goodall, 1969).

The project reported on in this communication is a joint project between two teams, one from Agriculture Canada and one from Queen's University. The purpose of the project is to apply the systems modelling techniques of Forrester (1968) to a pest management situation. The final goal is to produce a sufficiently predictive simulation model for effective, cost-saving agricultural management in the region. The system under study is the interface between the tobacco crop and its insect pest load within the tobacco culture of south-western Ontario.

The objective of this paper is to elucidate the basic structure of the system and to suggest an inchoate dynamic model of potential predictive value. The paper

is preliminary in nature in that it deals with the morphology of the systems model without specifying the nature of the various dynamic interactions.

The "real-world" system

The major chronic pest species, responsible for most of the insect challenge to tobacco crops in south-western Ontario, is the darksided cutworm, *Euxoa messoria* (Harris) (Cheng, 1971). Other species, of occasional importance, are the aphid *Myzus persicae* (Sulzer), the root maggots *Hylemya florilega* (Zetterstedt) and *H. platura* (Meigen), the tomato hornworm *Manduca quinquemaculata* (Haworth), and a number of other cutworms. For the time being we have decided to concentrate our attention on the darksided cutworm.

The interaction of the cutworm with the tobacco crop is very strongly affected by the tobacco culture practices of the region. Figure 1 represents this interaction. The region can be divided into three land use categories: tobacco, rye (the usual rotation crop for tobacco), as well as other crops and non-crop acreage. The tobacco-rye crop rotation utilizes only a limited fraction of the total acreage; this fraction is partly determined by suitability of field conditions and partly by a tobacco quota system. The tobacco harvest is followed by a fall seeding of a rye crop. The rye is either harvested or plowed under the next year, being followed by a second rye crop which is plowed under the spring after that, in preparation for tobacco planting.

Figure 1 superimposes onto the land use diagram a series of population curves for *E. messoria*. The adults of this insect fly in late summer, and disperse randomly throughout the region. Any deviation from randomness in oviposition is the result of female choice, and not directly related to human control practices. We therefore assume randomness of oviposition and winter egg survival until field data prove otherwise. The immature stages develop in all three land use conditions, and are chemically controlled only in those fields where tobacco is about to be planted.

It is obvious that the actual number, or density, of the pest population, in any given field or in the region as a whole, is determined from year to year by a very complex set of interacting factors (e.g. Bucher and Cheng, 1971). In addition to the culture practices and control measures, we must include a number of biological factors, such as predator and parasite populations, habitat suitability, competitors, and the regularity of each of these. Furthermore, non-biological factors, such as weather conditions may be of crucial importance. Unfortunately, the potential population regulation-factors have not been adequately described, and their effectiveness and mutual interactions are virtually unknown.

General Morphology of the Model

Figure 2 is a flow diagram showing the essential constituents of the system and their main interactions. The salient feature of this model is its three-tiered structure. We will discuss the importance of this feature below.

The inner (entomological) tier consists of the four pest populations and a complex array of predators, parasites and pathogens; the dynamic interactions among these components are indicated symbolically.

The medial (tobacco culture) tier includes the various crops, the tobacco culture practices (including pest control), and the ecology of the region. The outer tier contains a variety of factors that form part of the total social, cultural, and agro-policy matrix of the region and beyond.

The model must accurately predict future pest problems. Therefore, it is important that all factors which affect the population densities of the pest species,

directly or with a short time lag, be identified, monitored and included in an inner operative tier of the model. Those factors that affect the essential variables (the predicted pest populations) only indirectly, with a relatively long lag period, can be placed in an outer tier, where adjustments can be made annually, rather than continually.

For example, if the ecology of the region deteriorates considerably as a result of a new pest management technique, this will eventually feed back to the control measures, thereby affecting the pest population dynamics. This pathway will take considerable time. Research and political activities will elicit government activity, and via legislation or extension services, subsequent year's control measures will be affected. Thus, the time lag is of sufficient magnitude so as not to invalidate a January prediction of April pest population sizes due to government action initiated after the release of the prediction.

The Dynamics of the Model

It is important to recognize that merely working out the exact dynamic interactions within the inner tier will not suffice. These strictly biological interactions will form the nucleus of the dynamic model, but the validity and usefulness of the model would be greatly enhanced if realistic dynamic inputs from the medial tier, and beyond, were incorporated. A dynamic simulation model has three separate utilities. Firstly, when the development of the model proceeds hand-in-hand with data collecting, wasteful collection of unnecessary data may be avoided. The model will indicate high priority experiments and sampling areas. Secondly, once fully tested and running, such a model can rapidly and realistically integrate field data collected in the framework of a monitoring service, quickly producing advance warning of pest problems. Finally, a good dynamic simulation model will be able to simulate the effects of any control measures and culture practices which may be considered.

In conclusion, dynamic system modelling of agricultural systems has the following advantages:

1. Complex agricultural systems, where several pests are being controlled simultaneously, and where alternative complex culture practices are available, face the system's manager (e.g. farmer) with problems for which no intuitive solutions are optimal. The development of a simulation model will allow the manager to arrive at optimal policy decisions rapidly.
2. Inputs from various sources, such as marketing boards, government extension services, monitoring surveys, meteorological stations and the pesticide industry, can be meaningfully combined only in a systems model.
3. Optimization of biological control practices, maximal chemical control, minimal cost and minimal environmental impact may be achieved through the use of simulation models.
4. The usefulness of a model depends on how realistic it is in simulating a real-world system. Some real-world variables are not important, in that changes in these variables have little impact on the system as a whole. The system is then termed "insensitive" to such variables. Those variables to which the system is sensitive are crucial. A model will allow us to identify such important variables and will, therefore, guide us in further field research.

This paper has attempted to briefly introduce a typical agricultural system and to present a typical systems methodology for dealing with the problems inherent in such a system. We anticipate at a later date to be able to communicate with the entomological community of Ontario in more detail both the structural components of the system and the particular simulation models.

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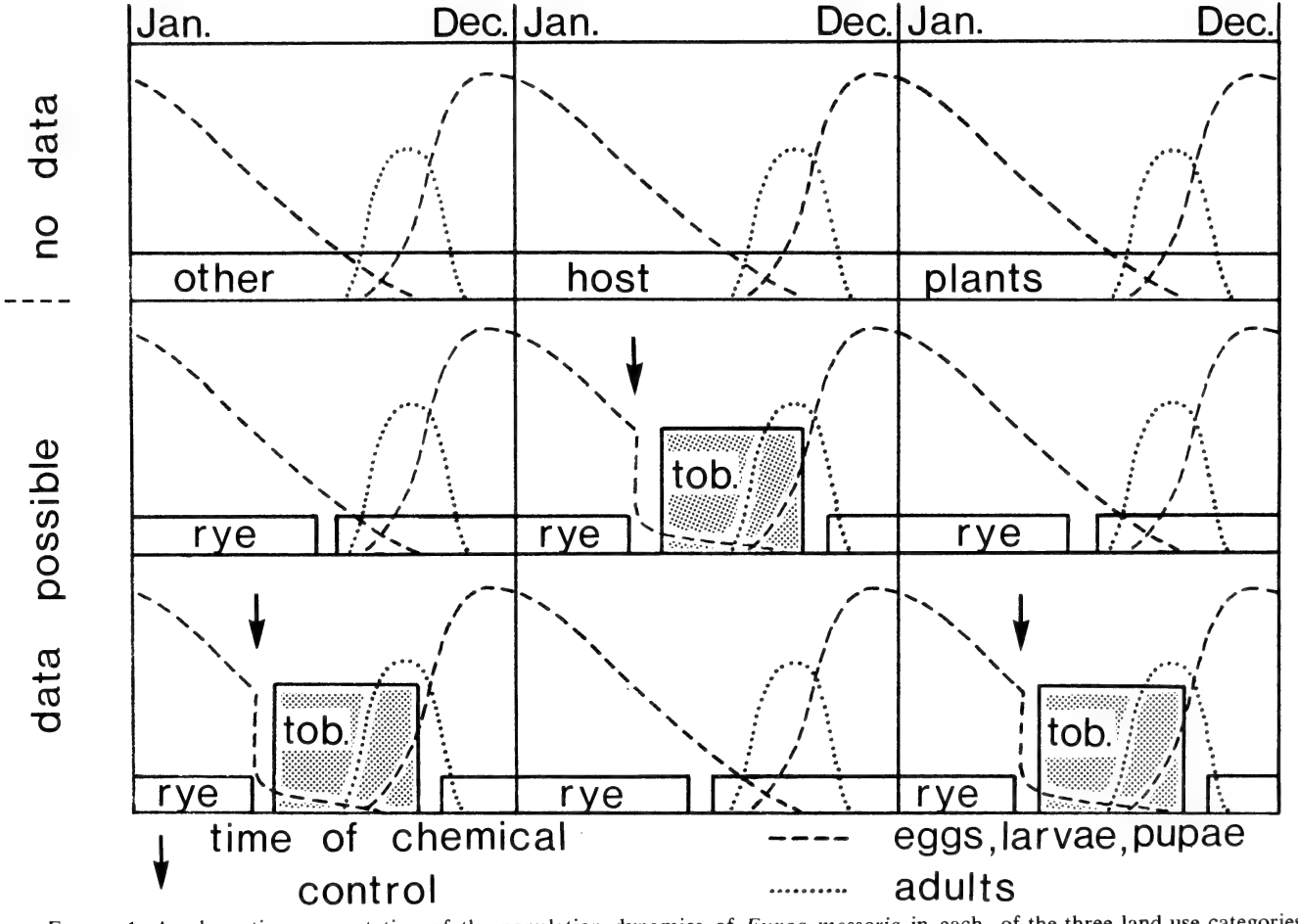

FIGURE 1. A schematic representation of the population dynamics of *Euxoa messoria* in each of the three land use categories.

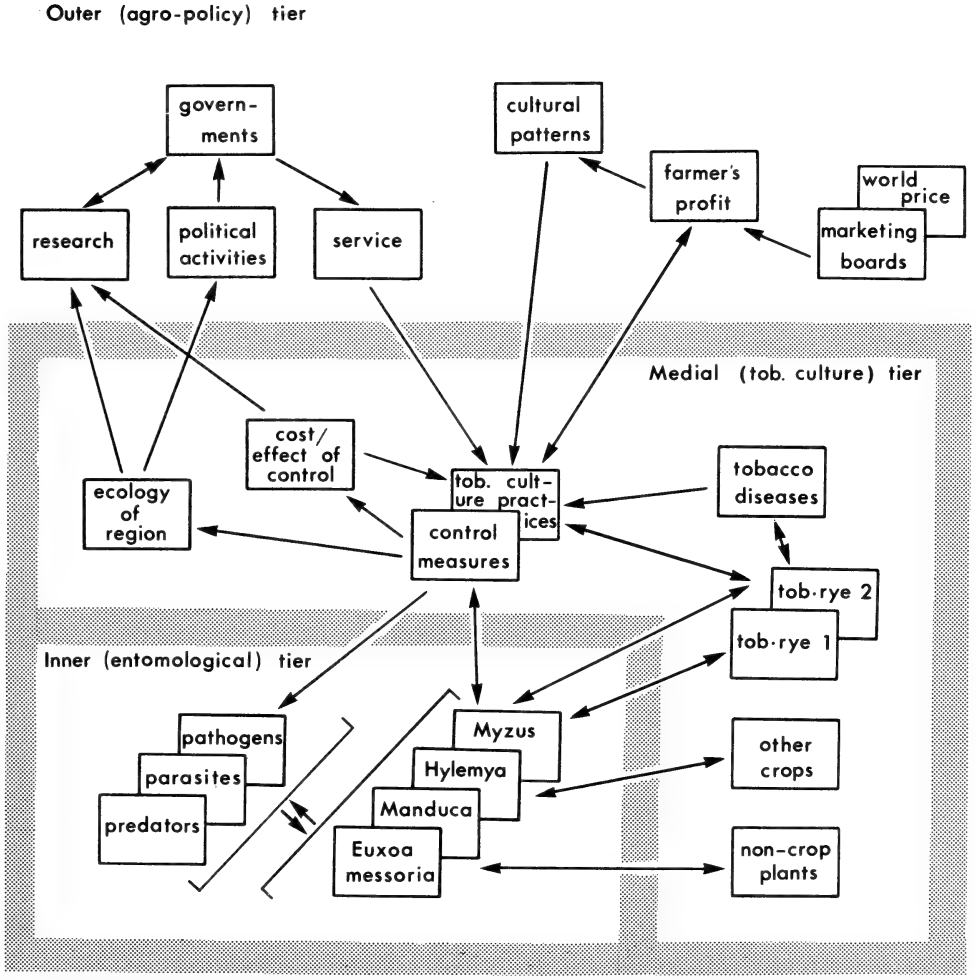

FIGURE 2. The three-tiered model of the tobacco culture system in south-western Ontario.

ADULT EMERGENCE, OVIPOSITION AND LODGING DAMAGE OF NORTHERN CORN ROOTWORM (COLEOPTERA: CHRYSOMELIDAE) UNDER THREE TILLAGE SYSTEMS

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Abstract

The number of rootworm eggs extracted and the number of adults that emerged from zero, minimum and full tillage fields were not significantly different. However, 50% emergence occurred 5 days earlier and the number of lodged plants was significantly higher in the full tillage field.

* * * * * *

Introduction

Northern corn rootworm (NCR), *Diabrotica longicornis* (Say), is a pest of corn in southern Ontario (Ont. Ministry Agric. and Food 1974) and may become more important as tillage practices change. There is disagreement on the influence of tillage on rootworm populations (Matteson *et al.* 1965, Musick and Collins 1971, Preuss *et al.* 1968, Calkins and Kirk 1969, Chiang 1973). We compare emergence of NCR, the amount of lodging, and the number of rootworm eggs in the soil in corn fields under three tillage regimes in southwestern Ontario in 1974.

Materials and Methods

Adjacent fields with zero, minimum or full tillage cultivation were located at the Ont. Ministry of Agric. and Food Research Station, Elora, Ont. The soil was Guelph loam with a slope of 0-0.6%. The schedule of operations performed on these fields had not changed since 1970 (Table I). Each field contained 4 blocks (56 x 30 m) with a 3 m strip between blocks and fields.

The number of adults that emerged was determined using cages (Musick and Fairchild 1970); 3 cages/block, 12/treatment. Observations were made at ca. weekly intervals from 31 July to 28 Oct. Each cage contained 2-5 plants and the data were expressed as adults/plant.

Lodged plants in 30.5 m of row were counted in 4 locations in each block on 30 Sept. Plants, deviating from the vertical position, had root damage and were classified as lodged.

Eggs were counted from 4 random soil cores (15.2 cm deep x 1.9 cm) in each block on 16 Oct., 1974. All soil cores were collected within 2.5 cm of a corn stalk. Eggs were extracted from this soil following Matteson (1966) with modifications. We used a 250 ml flask and a 2.5 cm magnet.

Data were transformed using $\sqrt{x + 0.5}$ prior to statistical analysis. Differences reported are those significant at the 5% level unless otherwise stated.

Results and Discussion

Adult rootworms were noted first in the emergence cages on 7 Aug. and the last count was made on 16 Oct. (Fig. 1). Although the number of adults collected in the 3 tillage systems were not statistically different, log-probit analysis determined that the time required for 50% emergence was different (Table II). Time

TABLE I. Management schedule of cornfields from 1970 to 1974 at the Ont. Ministry of Agric. and Food Res. Sta., Elora, Ont.[1]

Operation	Zero Tillage	Minimum Tillage	Full Tillage
Fertilize[2,3]	←———	Within a week before planting	———→
Plant[2,4]	←———	Late May to early June	———→
Atrazine[5]	←———	Before corn emerged	———→
Harvest	←———	Late Oct. to early Nov.	———→
Chop (corn stalks)	Not done	Fall, after harvest	———→
Plough	Not done	Not done	Fall, after chopping, to a depth of 15-25 cm
Disc	Not done	Fall, after chopping, to a depth of 5-15 cm	Spring, before planting, to a depth of 5-15 cm
Harrow (drag)	Not done	Not done	Spring, after discing

[1]In part from Rollo, 1974. Ecology of the slugs *Deroceras reticulatum, D. laeve* and *Arion fasciatus* in Ontario corn fields. M.S. Thesis. Univ. of Guelph, 173 pp.
[2]Operation was performed on the same day in each field.
[3]300 lb/acre of ammonium nitrate were broadcast on each field.
[4]Each field was planted with United 106 in 30 in rows; 200 lb/acre of 5:20:20 fertilizer were banded with the planter. Seed treated with diazinon, lindane and Captan.®
[5]All fields were sprayed with 3 lb, 80% atrazine in 1.5 gal light mineral oil per acre.

TABLE II. Emergence of northern corn rootworm; lodging of corn plants; and numbers of eggs in 3 tillage systems at Elora, Ont., 1974.

Tillage system	Total nos. emerged/plant/cage	Time of 50% emergence[1] x ± S.D.	Avg no. lodged plants/treatment	Avg no. eggs/core
Full	488.9	30.4 ± 1.5	86.75	2.50
Minimum	410.9	35.5 ± 1.5	16.75	6.38
Zero	548.7	35.0 ± 1.5	26.44	3.31

[1]Expressed as days after 30 July.

of 50% emergence was 5 days earlier (8 Sept.) in the full tillage field than in the zero and minimum tillage fields (3 Sept.). Preuss *et al.* (1968), in their study of western corn rootworm, *Diabrotica virgifera* LeConte, reported a 3-day delay in the time of emergence from the minimum (till-plant) compared to the full tillage (conventional tillage) system. The slopes of the regression lines representing the rate of NCR emergence from the 3 systems in this study were not different (ca. 5.4). Duncan's new multiple range test showed that there were more lodged plants in the full tillage fields ($P < .01$) than in the zero and minimum tillage fields. Lodging in the zero and minimum tillage fields was not different. The number of rootworm eggs was not different in the 3 tillage fields (Table II).

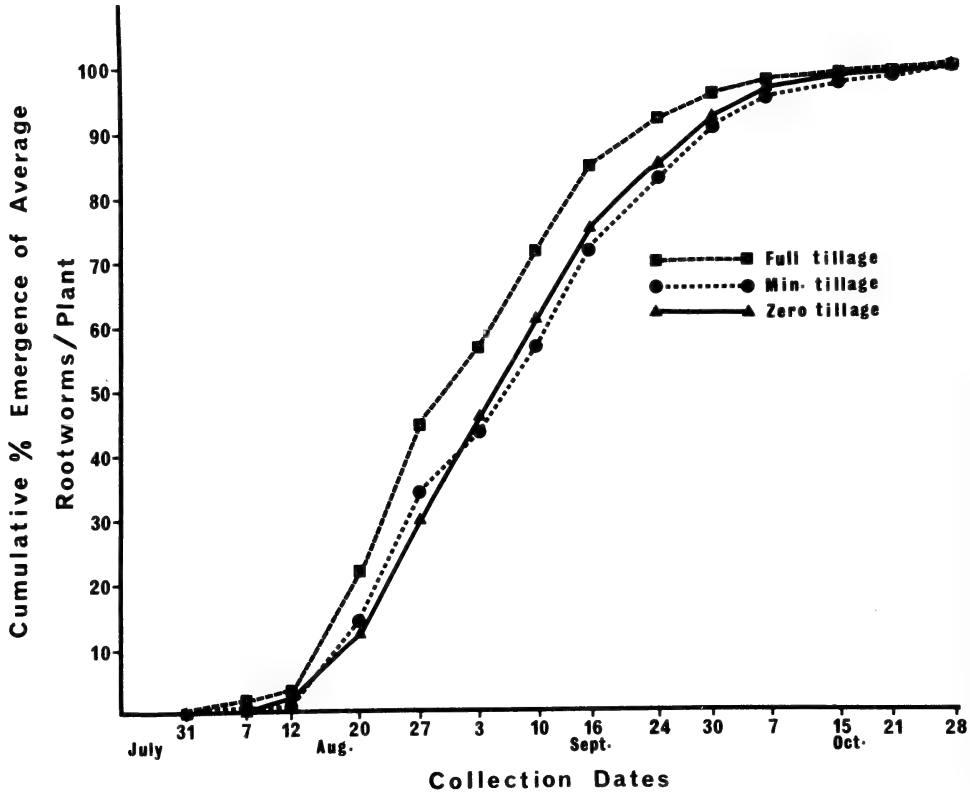

FIGURE 1. Cumulative % of emergence of northern corn rootworm/cage in 3 tillage systems.

Early rootworm emergence in the full tillage field indicated a faster rate of egg and larval development than in the other fields (Chiang and Sisson, 1968). This may account for the higher incidence of lodging in this tillage system. Further research is needed for verification. Ultimately, labour costs and crop yields will determine the tillage practice most economical for corn production in a particular area.

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SAMPLING METHODS FOR THE SLUGS, *DEROCERAS RETICULATUM* (MÜLLER), *D. LAEVE* (MÜLLER), AND *ARION FASCIATUS* NILSSON IN ONTARIO CORN FIELDS

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Abstract

The recovery of slugs and their eggs by hand-washing soil through sieves is time consuming and, because slugs are aggregated in distribution, many samples must be processed to adequately estimate the population. A faster mechanical process using wringer-type washing machines was developed for processing samples from corn fields. Soil samples were placed inside double wire baskets which hung inside the tubs of the modified washing machines. Several samples could be processed with one washer within 8 hours and there was no difference in the efficiency of egg recovery between machine and manual washing. The recovery of healthy eggs was 93-98% and 53% of diseased or dead eggs were recovered. Newly emerged slugs were destroyed by washing. A flooding procedure prior to machine washing recovered these slugs and also softened the soil so less time was required in the washing machines. All aspects of the sample collection, flooding and washing of samples are described.

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Introduction

Procedures and problems of estimating insect populations have been outlined by Southwood (1966). Procedures for sampling slug populations were discussed by South (1964), Hunter (1968), and Runham and Hunter (1970). Soil samp-

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ling was the only accurate method of assessing slug populations (Hunter, 1968). The distribution of slugs is sparse, aggregated, and changes vertically with the weather (Stephenson, 1968; Runham and Hunter, 1970), and hence many samples must be processed to obtain reliable estimates. No method has been developed which efficiently recovers both eggs and newly emerged or small slugs. A faster, more efficient sampling procedure is described below.

Materials and Methods

Full-, minimum-, and zero-tillage corn fields were sampled at the Elora Research Station near Elora, Ontario. Sampling areas were 30 plots of either 570 or 950 m^2 in each of the three tillage areas. Corn plants were removed along the plot boundaries and stratified random samples were taken in each plot with a sampling tool similar to that used by Brydon (1966). The sampler (Fig. 1A) was larger and of heavier construction than Brydon's to increase the sample area to 572cm^2 and to provide durability. South (1964) used 12 samples, 929cm^2 to obtain a 95% confidence limit of 0.75-1.25 ($\bar{x}$ 1.0 slug/sample). He also found from two tests with 4 inch cores (81cm^2) that 59 and 194 samples were required for comparable accuracy. Intermediate sample sizes have not been tested so we used 572cm^2 but took 60 samples per month. This represented 5.6m^2 of soil and was the maximum possible because of concomitant research.

Corn stalks were cut off at the base and discarded before taking a sample and any slugs and eggs in the surface litter were collected. The core sampler was inserted by standing on it and rocking it in a circular motion until the adjustable depth stop indicated a 10cm depth. This depth was selected because most *Deroceras reticulatum* (Müller) and eggs occur in the first 10 cm of soil (Carrick, 1942; Arias and Crowell, 1963; South, 1965; Hunter, 1966). We sampled to a depth of 31cm in December 1973 and confirmed that 90.2% of *Deroceras* eggs ($n = 869$) were in the first 10cm of soil.

The major disadvantage of core samplers of this type is that specimens are injured when soil is forced from the core (Thomas, 1944; Southwood, 1966). To overcome this difficulty, the soil was first loosened with a trowel and then gently pushed into an opaque plastic bag. Any soil which was not lifted by the sampler, was removed with the trowel. The trowel was especially important on dry or stoney soil because the core sampler did not completely remove the sample in these soils. Plastic bags were sealed, labelled, and transported to the laboratory and processed or refrigerated. Samples from greater depths were obtained by reinserting the sampler into the same hole and driving it down further.

Flooding Procedure

Small or newly emerged slugs are poorly recovered by washing and for this reason a flooding procedure similar to that of South (1964) was added to the extraction routine in 1973. Flooding chambers (Fig. 1B) were constructed from polystyrene containers, 20cm in diameter and 18.5cm deep. Three holes, 3cm in diameter, were melted in the bottom of the containers with a piece of hot pipe and a similar hole was made in the lid. These holes were covered with a 60-mesh brass screen to confine the slugs, but allow water to enter through the bottom and air to escape through the top. Circulation of water under the container was obtained by attaching legs, made from petri dishes.

Samples were divided between two such containers to allow slugs to reach the upper surface more easily. The flooding was accomplished in two inflatable plastic swimming pools, 1.2m in diameter and 30cm deep, each of which held 22 flooding chambers. Chambers were initially flooded to a depth of 2.5cm for one

day and then the water level was raised 7.5cm every 3 days until the water was level with the soil surface. Slugs were recovered when they crawled to the soil surface. Flooding the soil for about one week did not reduce the recovery of eggs in subsequent soil washing. In the laboratory eggs of all three species completed development while submerged (Table I).

TABLE I. Percentage hatch and average time to hatch of eggs of *Deroceras reticulatum, D. laeve,* and *Arion fasciatus* submerged in distilled water in a diurnally fluctuating temperature of 15-20° C.

Species	Number of eggs	Number hatched	Percentage hatched	Days to Hatch	
				Mean	Range
Deroceras reticulatum	62	13	21.0	17.3	13-24
Deroceras laeve	22	21	95.5	25.4	23-28
Arion fasciatus	73	36	49.3	49.2	32.5-86.5

Mechanical Soil Washing (Wet Sieving)

Preliminary samples were washed consecutively through wire screen (0.6cm openings), and 10- and 20-mesh sieves (Fig. 1D). However, this was time-consuming and sieves often clogged and material splashed out. A mechanical process using agitator-type washing machines was used in 1973 (Fig. 2). Pumps were disconnected from the drainage systems, and a 5cm pipe installed if the original drainage system was smaller than 5cm. Machines were placed on a stand so they would drain into a settling tank to remove the silt from the runoff (Fig. 2A). A plastic bag, attached to the drainage pipe eliminated splashing. The soil sample was placed in a double basket that hung on the rim of the tub (Fig. 2B). The inner basket was 15cm in diameter and 18cm high and constructed of wire screen with 0.6cm openings (¼" hardware cloth). The outer basket was ca. 17cm in diameter and 21cm deep and constructed of wire screen with 1.2cm openings (½" hardware cloth). This outer basket was lined with 32-mesh Saran® screen which was sewn onto the sides and bottom of the wire basket with twine. Pieces of 3mm wire were fastened to both the inner and the outer basket to hook them onto the rim of the tub of the washer. Tape was used to cover the sharp edges of the wire baskets (Fig. 2C).

Four or five double baskets were used in each tub, depending on the agitating power of the machine. The baskets would hold the 5,720cm^3 samples after some soil was washed through the screen by spraying water through the sides of the baskets. After baskets were loaded with samples, the agitator tank was rinsed and the drainage pipe was closed, either by a valve or by lifting the drainage pipe above the level of water in the tub. In addition a plug was inserted into the drain to prevent clogging. Three to four hours after filling with water and starting the agitator, the water was changed and silt that collected on the samples was washed off by spraying through the sides of the baskets. Although this was not always necessary, it shortened the washing time. The time required to wash soil from the baskets depended on the clay- and organic-matter content of the soil, and the agitating efficiency of individual machines. Soil from a full-tillage field washed faster than that from the zero-tillage field and samples which were flooded as described, washed faster than those which were not.

Six to eight hours after loading, the machine was drained and any remaining soil was removed by spraying the sides of the baskets. The inner baskets were removed, and the larger debris discarded. A large proportion of the organic material, which otherwise impeded recovery of slugs and eggs, was removed by

agitating the outer basket in a pail of water and by sieving off material that floated. Before discarding, this material was examined for adhering slugs and eggs which otherwise sink.

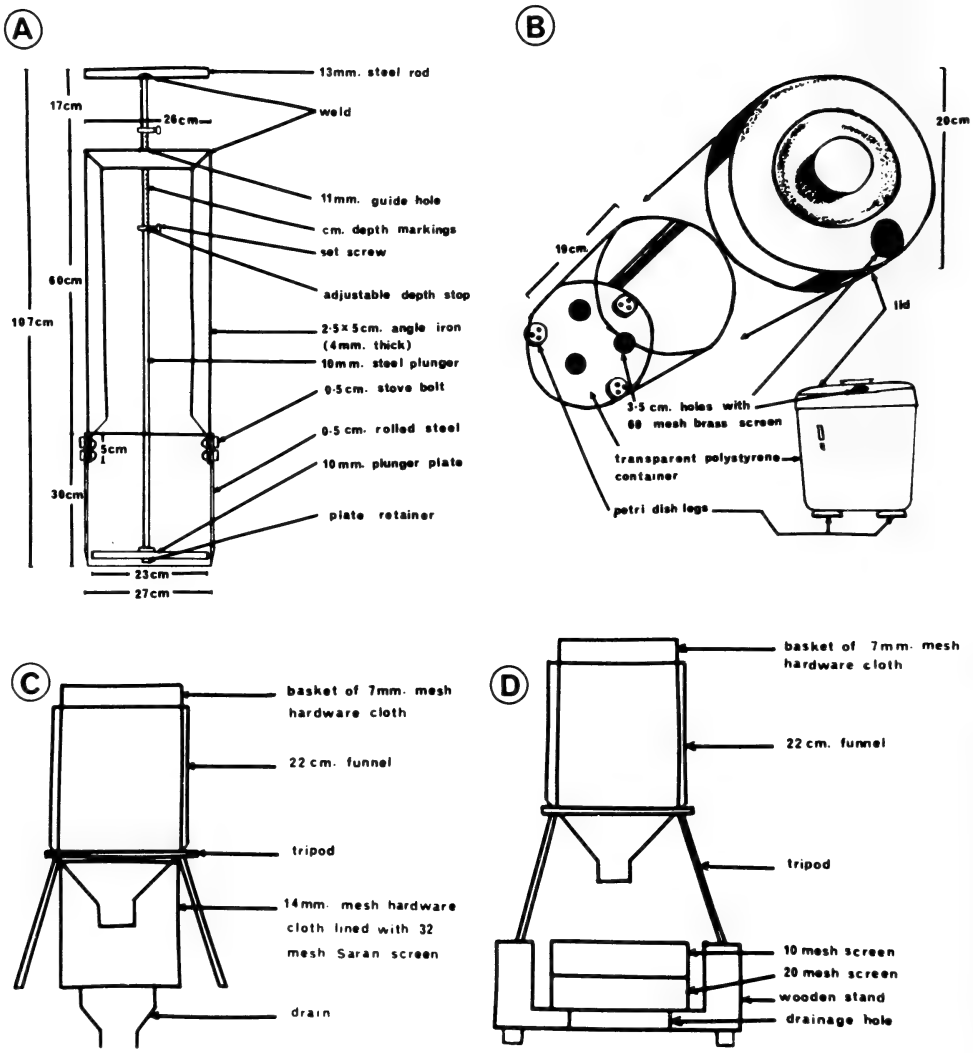

FIGURE 1. Equipment for sampling populations of *Arion fasciatus* and *Deroceras* spp; A. Construction details of a core sampler, area 572cm²; B. Construction details of a chamber to flood soil samples; C and D. Apparatus used to recover eggs from soil by hand washing.

A supplementary soil-washing system was used to process samples more quickly. Soil was washed through wire screen of 0.6cm openings into a basket similar to the outer basket described for the washing machine (Fig. 1C). Water was sprayed through the screened sides of the basket to reduce the force of the water and prevent damage to slugs and eggs. The basket design prevented clogging and splashing, which was a problem with conventional sieves.

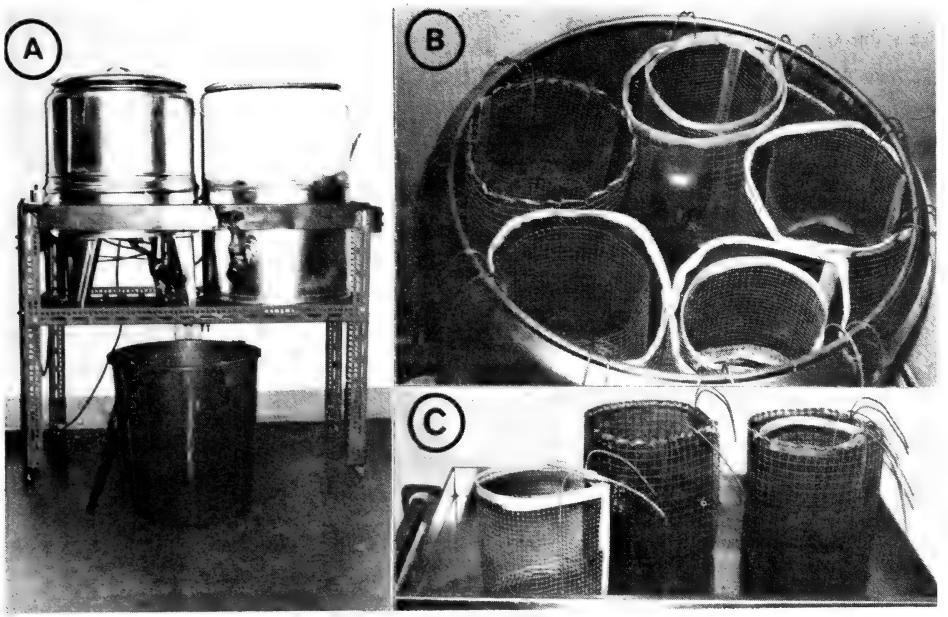

FIGURE 2. Equipment for machine washing soil for recovery of *Arion fasciatus* and *Deroceras* spp; A. Washing machines with large drains installed, stand and settling tank; B. Arrangement of sample baskets in place within the tub of a washing machine; C. Unassembled inner and outer baskets and, on the right, an assembled basket.

Recovery of Eggs

The outer basket was allowed to drain, and was then agitated in a pail of 25% magnesium sulphate. The eggs and slugs floated in this solution and were separated from the inorganic materials. Hatching of eggs recovered in this way was 16.9% (n = 347). Whenever earthworms failed to float due to dilution of the magnesium sulphate, the solution was replaced. A sieve was used to gather floating material and transfer it into a 30-mesh sieve in a pan of water. Eggs of *Deroceras* spp. are spherical and transparent and were easily seen by holding the sieve up to the light. Eggs were removed with a large-mouthed eye dropper. After a search, the sieve was agitated, swirled in the water and searched four more times to avoid missing eggs.

Results and Discussion

The efficiency of both manual and machine washing of soil for recovering eggs of *Deroceras* spp., *Arion fasciatus* Nilsson and *A. hortensis* Ferussac, was tested during July and August when eggs in the samples were rare. Eggs of *D. reticulatum* and *Deroceras laeve* (Müller) are indistinguishable and were not considered separately. Known numbers of eggs of the various species as well as 30 dead eggs of *Deroceras* spp., recognizable by their yellow colour, were added to soil samples.

These samples were flooded as described above and then extracted by machine or manual washing. There was no difference in efficiency between machine or manual washing and pooled percentage recoveries are shown in Table II. *A. fasciatus* were 97% recovered and *A. hortensis,* a related species that did not occur in the corn field, were 93% recovered. Hunter (1968) recovered only 15.4%

(n = 13) of *A. hortensis* eggs by washing soil through sieves with a jet of water. Dead eggs are particularly fragile and 50% of these were recovered thus verifying the high efficiency of extraction of healthy eggs.

TABLE II. Percentage recovery of slug eggs by washing soil.

Species	Number of Eggs: Introduced	Recovered	% Recovery
Deroceras spp.			
Healthy	235	229	97.4
Dead	30	16	53.3
A. fasciatus	143	140	97.9
A. hortensis	65	61	93.8

The total number of eggs of *Deroceras* spp. recovered monthly from 60 samples by washing is presented in Figure 3A and the recovery of slugs is shown in Figure 3B. The fall in numbers of slugs during summer (Fig. 3B) was due to their vertical movement below the sampling depth as the soil dried. The appearance of large numbers of slugs after heavy rains and their reappearance in October and early November confirmed this. Because *D. reticulatum* overwintered in the corn field only as eggs, and because the slugs emerging from these did not breed until September (Rollo, 1974), the population of this species can be estimated by concentrated sampling in the spring and fall when most slugs are near the surface. Eggs are also adequately estimated at this time because no eggs are laid until

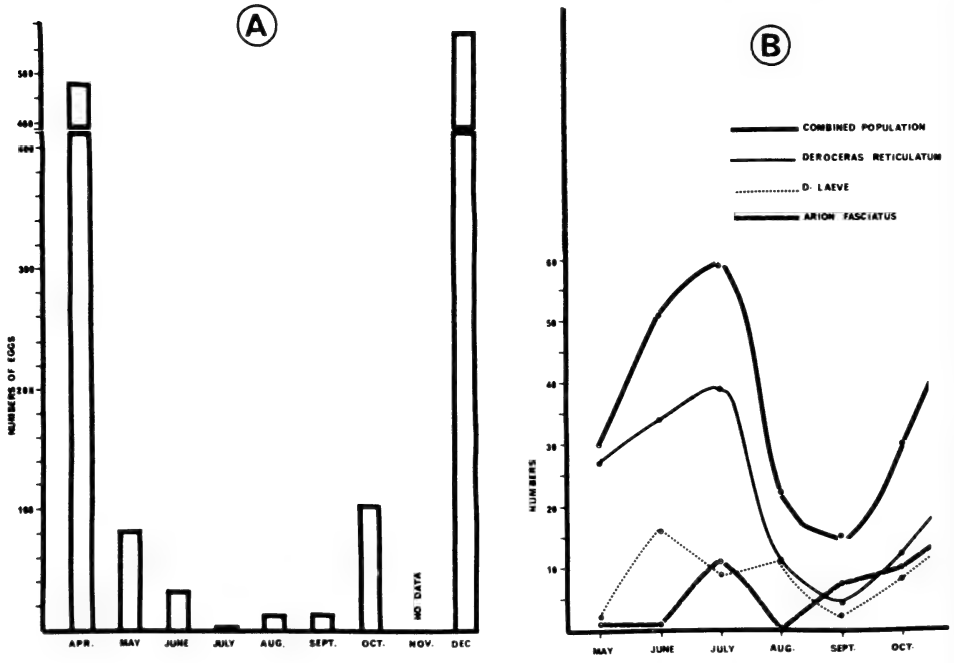

FIGURE 3. Recovery of slugs from a zero-tillage corn field in 1973 near Elora, Ont.; A. Number of eggs of *Deroceras* spp. per month from 60 soil samples, each of 572cm²; B. Numbers of *Deroceras reticulatum, D. laeve* and *Arion fasciatus* per month.

September. (Eggs found during summer were always *D. laeve* (Fig. 3A). In uncultivated areas where plant canopies hold an insulating layer of snow, or in more moderate climates, all stages overwinter and sampling must be carried out throughout the season. The presence of adults in the spring indicates which situation prevails.

D. laeve and *A. fasciatus* are not killed by low winter temperatures and must be sampled throughout the season in all habitats. A 10cm depth was not adequate for *A. fasciatus* and a depth of at least 30cm is recommended. The low density of this species did not make this worthwhile in the present study. No eggs of *A. fasciatus* were recovered, whereas immatures were commonly found from August onwards. This indicated that the eggs were laid below 10cm deep. Most *A. fasciatus* were near the surface during late October and early November and this is the best time to sample if sampling 30cm deep is not possible. *D. laeve* remained closer to the surface throughout the year than did the other species, and as a result sampling at the 10cm level made *D. laeve* and *D. reticulatum* appear equally numerous in August (Fig. 3B). In the spring and fall when slugs are numerous and near the surface greater sampling efficiency can be obtained with 10cm deep samples but a few 30cm deep are recommended. During summer when slugs are deeper, we recommend sampling 30cm deep.

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ADDITIONAL RECORDS OF ENSIFERA (GRYLLOPTERA) IN ONTARIO

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Abstract

Vickery and Kevan (1967) listed all known records of orthopteroid insects in Ontario. Subsequent records for the Ensifera, Order Grylloptera, are listed, together with appropriate comments on distribution.

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Vickery and Kevan (1967) published lists of records for the orthopteroid insects in Ontario, including all of the known records. Johnstone (1971) listed two more species, *Microcentrum rhombifolium* (Saussure) and a species of *Neoconocephalus* which was listed as *N. crepitans* (Scudder), both of which were new to the Canadian fauna. Both of these species were collected at Point Pelee, Essex Co., in 1970, but D. M. Wood (pers. comm. 1972) had collected them at the same locality some years earlier. The name *crepitans* was used for this species of *Neoconocephalus* by Cantrall (1968) and others, but recently (Walker *et al.* 1973) *crepitans* was placed in synonymy under *robustus* Scudder. Although a sibling species was discovered and described, *N. bivocatus* T. Walker, Whitesell and Alexander (Walker *et. al., op. cit.*) this taxon does not occur in Canada and *Neoconocephalus robustus* (Scudder 1862) is the name to be applied to specimens from Canada previously recorded as *N. crepitans*.

This paper includes records of captures since 1967, mainly by Kerr, Morris and associates at Erindale College, University of Toronto. Also included are records made by personnel of the Lyman Entomological Museum and Research Laboratory, Macdonald College, McGill University, although these are mainly incidental as emphasis was placed on collection of Acridoidea (Orthoptera) during this time. The specimens are in the collections of the two institutions unless another repository is specified.

ORDER GRYLLOPTERA

SUBORDER ENSIFERA

SUPERFAMILY GRYLLACRIDOIDEA

Family Rhaphidophoridae

Subfamily Rhaphidophorinae

Ceuthophilus meridionalis Scudder.

Brant Co., 1.7 miles (2.74 km) E. of Paris, 1 ♀, 6-VII-74.

SUPERFAMILY GRYLLOIDEA

Family Gryllidae

Subfamily Nemobiinae

Allonemobius fasciatus (DeGeer).

Bog near Nellie Lake, Hwy 11, N.E. Timmins, 1♂, 2 ♀ ♀, several juveniles, 15-VIII-74.

All of the species of nemobiine crickets were listed by Vickery and Kevan (1967) in the genus *Nemobius*. Vickery and Johnstone (1970, 1973) revised the North American (more specifically Canadian) species, which are now placed as follows: *Allonemobius* - *A. fasciatus* (DeGeer), *A. allardi* (Alexander and Thomas), *A. griseus griseus* (E. M. Walker), *A. maculatus* (Blatchley); *Neonemobius* - *N. palustris* (Blatchley); *Eunemobius* - *E. carolinus carolinus* (Scudder).

Family Oecanthidae

Subfamily Oecanthinae

Oecanthus fultoni T. J. Walker

Bob's Lake (Sharbot Lake), 1♂, 1-IX-73; 1♂, 3-IX-73.

Oecanthus quadripunctatus Beutenmüller.

Bob's Lake (Sharbot Lake) 2♂♂, 3-IX-73; Brampton, 1 ♂, 20-VII-74.

Oecanthus nigricornis F. Walker

Erindale, 1 ♂, 14-X-70.

SUPERFAMILY TETTIGONIOIDEA

Family Tettigoniidae

Subfamily Decticinae

Atlanticus sp.

St. Williams, 1♂, 21-IX-72; 2 ♀ ♀, 25-VIII-73; 3 ♀ ♀, 22-VIII-74; Simcoe (Green's Corners), 1 ♀, 30-VIII-74.

This genus is in need of revision and until this is done identifications are uncertain as the species apparently are quite variable. The males in the above series have tegmina which project only slightly beyond the pronotum and would key to *Atlanticus davisi* Rehn & Hebard in the key of Rentz and Birchim (1968). However, it seems likely that they are neither *A. davisi* nor *A. testaceus* (Scudder) (pers. comm., 1974, David Rentz, Academy of Natural Sciences, Philadelphia). They may belong to an undescribed species but their placement must await a revision of the genus which is now being undertaken at Erindale College. *A. testaceus* is the only species of *Atlanticus* previously recorded from Canada. We have re-examined the specimens previously reported (Vickery and Kevan 1967) and find that the specimens from Arner have long tegmina and are *A. testaceus* whereas the specimens from Turkey Point are closer to those in the above series.

Metrioptera (*Sphagniana*) *sphagnorum* F. Walker

Ignace, 2♂♂, 7 ♀ ♀, VII-73; Firesteel R. (Upsala), 2 ♂ ♂, VII-70, 5 ♂ ♂, 17-VII-71; Beaver Creek (Upsala), 1 ♂, 20-VII-70; Trewartha L. (English River, 2 ♀ ♀, 20-VIII-70; 4 ♂ ♂, 18-VIII-71; 2 ♂ ♂, 22-VIII-73; Raith,

10♂♂, 10-VIII-68; 8 ♂ ♂, 18-VIII-71; Valora, 1 ♀, 23-VII-73; 1 ♀, 26-VII-73; 10 ♂ ♂, 1 ♀, 28-VII-73; Nellie Lake (Iroquois Falls) bog, Hwy 11, N.E. Timmins, 1 ♂, 6-VIII-72; 4♂♂, 25-VII-74; 3 ♂ ♂, 14-VIII-74; 4 ♂ ♂, 15-VIII-74.

The Nellie Lake record is a considerable eastward extension of the known range of this species. Kevan *et al.* (1963) indicated that *M.* (*S.*) *sphagnorum* might occur in northern Quebec. The present record makes this appear more logical. A search of the area from Noranda to La Sarre, Quebec, should reveal whether or not it does occur so far east.

Metrioptera (*Roeseliana*) *roeselii* (Hgb.)

Alexandria, 5 ♂ ♂, 5 ♀ ♀, 16-VII-73; Carillon Prov. Pk., 2 juveniles, 23-VI-73; Gananoque, 2♂♂, VII-68; Black Lake (near Peterborough), 1 ♂, 9-VIII-71; Seeleys 'Bay, 8 ♂ ♂, 4 ♀ ♀, 20-VI-72; Leo Lake Rd and Hwy 15 (near Seeley's Bay), 1 ♂, 8 ♀ ♀, 20-VI-72; Vineland, 4 ♂ ♂, 5 ♀ ♀, 9-VII-72; 2♀♀, 28-VI-73; 2 ♂ ♂, 31-VII-74; Beamsville, 1 ♂, 22-VII-72; 1 ♂, 2-VIII-74; 1 ♂, 8-VIII-74; St. Catharines, 4 ♂ ♂, 1 ♀, 31-VII-74; Jordan, 2♂♂, 1 ♀, 31-VII-74; Fonthill, 2 ♂ ♂, 31-VII-74; Welland, 3 ♀ ♀, 31-VII-74; Grimsby Beach, 2♂♂, 7-VIII-74; Silverdale, 2 ♂ ♂, 31-VIII-74; Blossom Park, Ottawa (sight record, 1973).

Vickery and Kevan (1967) predicted a westerly spread of this species into and across southern Ontario. This has occurred and is continuing. However, it also spread south and westward in New York State and entered Ontario by way of the Niagara Peninsula. At the present time, the two invasions from east and south have not met but this should occur within the next five years. There is some indication that *M. roeselii* may displace *Orchelimum gladiator,* which apparently occupies the same habitat type.

Family Conocephalidae

Subfamily Copiphorinae

Neoconocephalus robustus (Scudder) was reported from Point Pelee as *N. crepitans* (Scudder) by Johnstone (1971). The present distribution in Ontario of *N. lyristes* (Rehn and Hebard), which had been reported by several authors (Walker 1902, - as *Conocephalus nebrascensis,* and Urquhart 1941, among others) is not known. It had been reported from Grimsby, Sarnia, and St. Clair River (see Vickery and Kevan 1967) but has not been collected in recent years, even at these localities.

Neoconocephalus ensiger (Harris)

Barry's Bay, 4-X-72; Pembroke, 4-X-72; Petawawa, 4-X-72, (all three records by stridulation, not by capture); Bothwell 1 ♂, 15-VIII-73; Erindale, 1 ♂, 29-VII-70; 1 ♂, 29-VII-73; Brant Co., 1.7 mi. E. Paris, 8 ♂ ♂, 6-VIII-74 (stridulation of one brown male recorded).

Subfamily Conocephalinae

Orchelimum gladiator Bruner

Burwash, 1 ♂, 8-VIII-68; Rutter, 3 ♂ ♂, 8-VIII-68; Elizabethville, 17♂♂, 8-29-VIII-69; Estaire, 1 ♂, 3-VIII-70; Nepewassi Lake (Estaire), 1 ♂, 8-VIII-71; Tilbury North, 1 ♂, 3-IX-71; Simcoe, 2 ♂ ♂, 12-VIII-71; Scotland, 1 ♂, 12-VIII-71; Huttonville, 1 ♂, 9-VIII-73; Walpole I., 3 ♂ ♂, 15-VIII-73; Wolfe I. (Kingston), 1 ♂, 3 ♀ ♀, 24-VII-73; near Sudbury (in the shadow of the Copper Cliff smelter), 2 ♂ ♂, 1 ♀, 24-VII-74; Muriel Lake Killarney), 1 ♂, 10-VIII-74, Brant Co., 1.7 mi. E. Paris, 6 ♂ ♂, 6-VIII-74. This species occurs farther north than was previously known.

Orchelimum vulgare Harris

Elizabethville, 58 ♂♂, 5-IX-65 to 14-VIII-73; Jeanette's Creek, 1 ♂, 25-VIII-70; New Glasgow (Elgin Co.), 1 ♂, 24-VIII-70; Walpole I., 1 ♂, 3-IX-71; 2 ♂♂, 15-VIII-73; Long Point, 1 ♂, 12-VIII-71; Erindale, 1 ♂, 14-VIII-73; Point Pelee, 14♂♂, 6♀♀, 23-VIII-70; Brampton, 1 ♂, 14-VIII-73.

O. vulgare, as well as the other species of *Orchelimum* which follow, does not range nearly so far north as does *O. gladiator.*

Orchelimum volantum McNeill

Long Point, 4 ♂♂, 12-VIII-71; Point Pelee, 4 ♂♂, 1 ♀, 23-VIII-70.

Orchelimum nigripes Scudder

Merlin (Kent Co.), 1 ♂, 24-VIII-70; Jeanettes' Creek, 2 ♂♂, 25-VIII-70; Rondeau, 1 ♂, 24-VIII-70; Tilbury Creek (Kent), 3 ♂♂, 25-VIII-70; Point Pelee, 18♂♂, 13♀♀, 23-VIII-70; Tilbury North (Essex), 1 ♀, 3-IX-71; Holiday Beach Prov. Park, 1 ♂, 1 juvenile, 7-VIII-74.

Orchelimum delicatum Bruner

Tilbury North (Essex) 1 ♂, 3-IX-71; Rondeau, 2 ♂♂, 24-VIII-70; Long Point, 2♂♂, 2♀♀, 12-VIII-71; Walpole I., 1 ♂,15-VIII-73.

Orchelimum campestre Blatchley

Jeanette's Creek, 4 ♂♂, 1 ♀, 25-VIII-70; Long Point, 1 ♂, 12-VIII-71; Port Britain (Durham Co.), 1 ♂, 29-VIII-73.

The Port Britain specimen is macropterous and was the only one found. It was probably a migrant and it appears unlikely that this species is established at this locality, since it is much farther east (on Lake Ontario) than other records which are confined to Essex County.

Conocephalus fasciatus (DeGeer)

Upsala, 2♂♂, 1 ♀, 20-VII-70; Estaire, 2 ♂♂, 1 ♀, 3-VIII-70; Erindale, 1 ♂, 11-VIII-70; English River, 2♂♂, 17-VIII-71; Firesteel R. (Upsala), 1 ♂, 3-VIII-72; Brant Co., 1.7 mi. E. Paris, 1 ♀, 6-VIII-74; Algonquin Park, Hemlock Bluffs bog, 2 ♂♂, 1 ♀, 17-VIII-74.

Conocephalus brevipennis (Scudder)

Rondeau, 1 ♂, 24-VIII-70.

Conocephalus nigropleurum (Bruner)

Long Point, 1 ♂, 12-VIII-71; Walpole I., 1 ♂, 15-VIII-73.

Family Phaneropteridae

Subfamily Phaneropterinae

Scudderia pistillata Brunner

Streetsville, 1 ♂, 31-VII-70; Erindale, 1 ♂, 29-VII-70; Walpole I., 1 ♂, 15-VIII-70; Algonquin Park, Hemlock Bluffs bog, 1 ♂, 1 ♀, 20-VIII-73; 1 ♂, 17-VIII-74.

Scudderia curvicauda (DeGeer)

Elizabethville, 1 ♂, 24-VII-72; Simcoe, 1 ♀, 15-VIII-73; 1 ♂, 3-IX-73.

Scudderia septentionalis (Audinet-Serville)

Simcoe, 1 ♂, 15-VIII-73; 1 ♂, 5-IX-73; St. Williams, 2♂♂, 22-VIII-74; Bronte Park, near Burlington, 1 ♂, 2-VIII-73 (C.N.C., Ottawa); Hamilton, 4♂♂, 10-VIII-60 (Coll. D. M. Wood, R.O.M., Toronto).

Previously recorded only from Guelph, this species was quite numerous at Simcoe (Green's Corners) and St. Williams. It occurs earlier than other species of *Scudderia* and does not persist much later than the end of August. None were found at Simcoe on 30-VIII-74, although it had been common there earlier that month.

Scudderia texensis Saussure and Pictet

Erindale, 1 ♂, 29-VII-70; 1 ♂, 27-VIII-70; Oakville, 1 ♂, 17-IX-70; 1 ♀, 29-VIII-72.

Amblycorypha oblongifolia (DeGeer)

Beamsville, 1 ♂, 15-VIII-73; 4♂♂, 20-VIII-74; St. Williams, 2 ♂ ♂, 25-VIII-73; Simcoe, 1 ♀, 30-VIII-74.

Microcentrum rhombifolium (Saussure) was reported from Point Pelee by Johnstone (1971).

Subfamily Pseudophyllinae

Pterophylla camellifolia camellifolia (Fabricius)

St. Williams, 1 ♂, 25-VIII-73; 2♂♂, 22-VIII-74; Bothwell (recording of stridulation of ♂), 15-VIII-73.

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NUTRITIVE VALUE OF PINE FOLIAGE FOR SOME DIPRIONID SAWFLIES

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Abstract

Quantitative investigations of food consumption and utilization were undertaken to determine the nutritive value of foliage from four species of pine—jack pine (*Pinus banksiana* Lamb.), red pine (*P. resinosa* Ait.), Scots pine (*P. sylvestris* L.) and eastern white pine (*P. strobus* L.)— for four sawfly species—*Neodiprion sertifer* (Geoff.), *N. nigroscutum* (Midd.), *N. lecontei* (Fitch) and *Diprion similis* (Htg.) These investigations were accompanied by an attempt to relate the nutritional suitability of the foliage to some of its constituents including dry matter, nitrogen and fibre. Differences in nutritive value among the pine species as judged by weight gain were reflected in the ability of the larvae to convert digested food to body tissues and to utilize nitrogen. Differences in the quantity of dry matter and nitrogen in the food were not related to any of the indices of food utilization. Figures for fibre content showed a high negative correlation with values for the approximate digestibility of dry matter but no relationship with any of the other indices.

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Des études quantitatives sur la consommation et l'utisation des aliments par quatre Tenthrédes, *Neodiprion sertifer, N. nigroscutum, N. lecontei* et *Diprion similis,* ont été entreprises pour déterminer la valeur nutritive des aiguilles provenant de quatre essences de Pins, *Pinus banksiana, P. resinosa, P. sylvestris* et *P. strobus.* L'auteur a également tenté de faire des corrélations entre la valeur nutritive des aiguilles et certains de ses constituants, notamment le poids des aiguilles séchées, et la teneur d'azote et de fibres de celles-ci. On a déterminé les différences de la valeur nutritive des essences en mesurant l'augmentation en poids des larves; la capacité des larves à convertir en tissus les aliments digérés et leur capacité d'assimiler l'azote démontraient également ces différences. On n'a pu pas rapporter de lien entre les différences de la quantité des deux constituants (aiguilles séchées et l'azote) aux indices d'assimilation nutritive. Quant aux données obtenues sur le contenu fibreux des aiguilles, l'auteur signale une corrélation négative élevée avec la digestibilité approximative des aiguilles séchées, mais aucun rapport avec aucun des autres indices.

Introduction

Forest entomologists have noted that the physiological condition of host trees is an important environmental factor influencing the abundance of forest insects. For defoliating insects, the evidence suggests that attack is greatest on poor sites and several studies have indicated that the application of organic or mineral fertilizers leads to reduced larval populations and reduced fecundity (Stark 1965). The response has been attributed to alterations in the nourishment provided by the host-free foliage through changes in the levels of nutrient components such as nitrogen (Büttner 1961) or soluble sugar (Schwenke 1962; Otto and Hackbarth 1967). The changes in the leaf are likely complex, however, and other nutrients or chemical or physical factors may be implicated; thus, it is difficult to attribute variations in insect growth to any single component or even to groups of components. The difficulties are compounded by a lack of understanding of the

relative contribution of individual nutrients in a natural food to the nourishment of insects. In many phytophagous insects the role of nutrients in growth and development has been investigated by means of synthetic diets. Basic requirements and nutrient interactions in these diets have been determined by addition-deletion studies in which quantities of water, fibre, minerals, amino acids, etc., are varied. This investigation, however, has been confined to four pine-feeding diprionid sawflies, *Neodiprion sertifer* (Geoff.), *N. nigroscutum* Midd., *N. lecontei* (Fitch), and *Diprion similis* (Htg.) which have not yet been reared on artificial diets. Hence, examination of the significance of individual dietary constituents using the traditional methods was not possible.

Females of the four sawflies oviposit exclusively on species of the genus *Pinus,* displaying different preferences and degrees of specificity towards the various species (Coppel and Benjamin 1965, Becker and Benjamin 1967). Little information is available about larval growth on the different host trees, apart from studies on *N. sertifer* by Rose (1952) and on *D. similis* by Tsao and Hodson (1956). The developing larvae are able to feed on a variety of pines. Thus, the natural differences in foliage from different species of pine serve as an excellent starting point for investigations that aim to test and explain differences in nutritive value of foliage from various sources. The traditional indicators of the nutritive value of a particular food for a holometabolous insect are measurements of weight gain over a specified period of larval development, pupal weights, duration of development and mortality. With additional studies of food utilization a number of indices can be computed, including the efficiency of conversion of ingested (ECI) and digested food (ECD) to body, the approximate digestibility of dry matter (AD) which is a measure of the percentage of food utilized, the approximate digestibility of nitrogen (ADN) which measures the percentage of nitrogen utilized, and a consumption index (CI) which measures food consumption in terms of body size and rate of development (Waldbauer 1968). With these indices, it is possible to decide if differences in growth are due to alterations in food intake, variations in digestibility or efficiency of conversion of food, and to attempt to identify the factors that contribute to the nutritive value of a natural food. By means of such studies the quantitative contribution of individual nutrients of a natural food to the nourishment of the insect may also be determined. Therefore, quantitative studies were initiated to examine the utilization of dry matter and nitrogen by the four sawflies on foliage from four common species of pine: jack pine (*Pinus banksiana* Lamb.), red pine (*P. resinosa* Ait.), Scots pine (*P. sylvestris* L.) and white pine (*P. strobus* L.). In addition, an attempt has been made to relate the nutritional suitability of the leaves to the quantities of some of their constituents including dry matter, nitrogen and fibre.

This investigation was undertaken to provide guidelines and background information for further insect nutrition studies. The studies will aim to evaluate the growth of insects on host-tree foliage in which physiological changes may be induced by forestry practices relating to soil fertility.

Materials and Methods

Colonies of *N. sertifer* and *N. lecontei* in the third or fourth instar were collected from Scots pine and red pine respectively, in Sault Ste. Marie and were reared to the penultimate instar in the laboratory on the same specimens of foliage in 1-qt (1.14-litre) Mason jars. *Neodiprion nigroscutum,* collected originally from Chibougamau, Quebec, and *D. similis* from Simcoe County, Ontario had been reared for several generations in the laboratory on jack pine and Scots pine, respectively. The sources of foliage and the methods for measuring food utilization have been published elsewhere (Fogal and Kwain 1972a). The latter report analyzed

food utilization by *D. similis* which is a solitary feeder in the last instar; hence single larvae could be used. In preliminary experiments with *N. sertifer,* however, larvae began feeding very slowly when confined singly to a feeding tube, and some did not begin feeding even after 24 hr. When two larvae were confined in a tube they fed, usually in pairs, within 5 hr. With three or more larvae, at least one wandered. This sawfly has a gregarious habit of feeding even in the last instar, which fosters feeding initiation (Ghent 1960). *Neodiprion nigroscutum* and *N. lecontei* have the same habit. Therefore, in tests with the three gregarious species, two larvae were used.

The time of year at which each sawfly species was examined, the types of foliage tested, the initial number of single larvae or pairs of larvae, the mean initial weights of the larvae used to test each type of foliage and the final number of single larvae or pairs of larvae used to obtain the final dry weights are given in Table 1. Where the tests involved pairs of larvae, the final number excluded pairs in which a single larva had died during the feeding. Larvae which succumbed during the tests were routinely examined for the presence of nuclear polyhedrosis virus[1] which can afflict rearings of sawflies.

For nitrogen, fibre, lignin and cellulose determinations, dried foliage and faecal samples were milled to pass through a 20-mesh screen in a Wiley mill.

Nitrogen in the faeces, food and larvae was determined by a micro-Kjeldahl method (Horwitz 1970)[2]. Fibre, lignin and cellulose in the foliage were determined by a modification of an extraction procedure developed for agricultural feed stuffs (Van Soest 1963). The volume of extracting fluid and the duration of extraction required to attain a minimum fibre content were determined experimentally. No fat remained in the fibre after extraction, so that ether extraction prior to acid-detergent extraction was not required. In agricultural forages, drying at temperatures above 60° C gives high fibre and lignin values. A comparison of Scots pine foliage dried at 40° C for 48 hr or at 80° C for 16 hr and ground in the Wiley mill with fresh Scots pine ground to approximately the same consistency in liquid N_2 with a mortar and pestle gave the following results:

	Fresh ground	Dried at 40°C for 64 hr	Dried at 80°C for 16 hr
Fibre	33.3	33.2	32.9
Lignin	9.3	9.6	9.2

Drying has little effect on the fibre or lignin content of Scots pine foliage. Fibre and lignin in the foliage from other pine species are probably also unaffected by drying; therefore, all determinations were made on foliage and faeces dried at 80° C for 16 hr.

For each species of insect, the data on food consumption, development time, larval dry matter content, larval dry weight gain, the utilization indices, dry matter and nitrogen contents of the food were subjected to an analysis of variance and the results on the different foods were compared. Since the four sawflies were tested at successive times during the summer the dry matter and nitrogen contents

[1]Examined by J. Burke, Insect Pathology Research Institute, Sault Ste. Marie, Ontario.
[2]Nitrogen determinations by J. Ramakers, Great Lakes Forest Research Centre, Sault Ste. Marie, Ontario.

for each food were compared at successive times. Differences among mean values were tested at the 5 percent level of significance with Duncan's Multiple Range test (Steel and Torrie 1960). All percentages were transformed to the arc sine square root prior to analysis. Fibre, lignin and cellulose contents could not be analyzed statistically because foliage from test replicates had to be combined to provide sufficient plant material for chemical analyses.

Results

A. Growth and food consumption

Comparisons of the percentage survival, and the mean values for development time, percentage dry matter in freshly-molted final-instar larvae, and larval weight gain for the four sawflies on different species and age classes of host foliage are shown in the histograms of Fig. 1. It also includes mean values for the dry weight of food consumed.

In *N. sertifer* mortality occurred on all types of foliage tested. It could not be attributed to infection by nuclear polyhedrosis virus[3] which commonly afflicts rearings of this sawfly. Perhaps it is related to the nutritional quality of the foods, but more tests are required to make valid conclusions concerning this parameter. Food consumption on jack pine and white pine was significantly lower than on Scots pine and red pine. The duration of the instar was shortest on Scots pine and significantly longer on red pine and white pine; an intermediate duration was observed on jack pine. Differences in percentage of dry matter were not significant but dry matter weight gain was significantly higher on Scots pine than on red pine or white pine with an intermediate value for jack pine.

With *N. nigroscutum* mortality occurred only in larvae fed white pine leaves. This was likely due to starvation, because food intake was extremely low compared with that of larvae reared on the other species of foliage. No evidence of virus infection was noted. Apparently enough white pine foliage was consumed to allow the survivors to molt, but they lost weight. They also had dry matter contents significantly lower than those of larvae reared on the other species of leaves. Judged by development time and weight gain, Scots pine and red pine are relatively poor foods whereas jack pine is highly nutritious.

All larvae of *N. lecontei* that succumbed were infected with nuclear polyhedrosis virus, and this may have accounted for the higher mortality in this experiment. The fact that these larvae consumed almost twice as much food as did the larvae of *N. nigroscutum* is consistent with the increased duration of the penultimate instar. Food consumption was highest on current-year and one-year-old red pine, lowest on one-year-old jack pine and white pine, and intermediate on current-year jack pine and one-year-old Scots pine. The shortest development time was on one-year-old jack pine followed by that on current-year leaves of the same species. Development times did not vary significantly on the other foliage. The greatest percentage of dry matter was obtained on one-year-old red pine and the lowest on current-year red pine. With one-year-old foliage, weight gain was lowest on Scots pine and white pine, significantly higher on red pine and highest on jack pine. Weight gain on current-year red pine was significantly lower than on one-year-old foliage while weight gain on current-year jack pine was only slightly lower than that on one-year-old foliage.

In *D. similis* no evidence of polyhedra was found in dead larvae; thus, contamination with virus from the previous experiment with *N. lecontei* could not explain the mortality. *Diprion similis* is comparable to *N. lecontei* in total food

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[3]Examined by J. Burke, Insect Pathology Research Institute, Sault Ste. Marie, Ontario.

intake during the last feeding instar and small but significant differences occurred on different types of foliage. On red pine and both ages of Scots pine, food consumption was similar; on white pine and both jack pines it was significantly lower. The duration of development was similar to that of *N. lecontei*. On one-year-old-foliage, the lowest development times were on jack pine and Scots pine followed by white pine. The longest time was on red pine. The times on current-year jack pine and Scots pine were significanly longer than on the corresponding one-year-old leaves. Significant differences in percentage of dry matter were again observed. Larvae feeding on one-year-old foliage had highest weight gains on jack pine and Scots pine and significantly lower gains on red pine and white pine. Gains were significantly lower on jack pine and Scots pine current-year foliage than on the corresponding one-year-old foliage.

Weight gains on one-year-old foliage of jack pine were high for all of the sawflies. This, together with the lower development times, suggests that jack pine has high nutritive value for all of the sawflies tested. Scots pine is highly nutritious for *N. sertifer* and *D. similis* but has relatively low food value for *N. nigroscutum* and *N. lecontei*. Red pine foliage is low in food value for each sawfly except *N. lecontei* and white pine is a poor food for each sawfly. In comparison with one-year-old foliage, the current-year foliage has a low nutritive value in the tree species in which it was tested.

In comparing the order in which the various foods are ranked by weight gain, it is important to consider that the larvae were tested only in the last feeding instar and were fed on a single diet up to that time. This ensured that the average initial weight of groups of larvae used to test different foods would be the same. But the larvae may have become conditioned to the food in the early instars, affecting the performance in the penultimate instar. This possibility was tested with *D. similis* by comparing weight gains of penultimate instar larvae which had been reared on red pine or jack pine in the earlier instars. The order of the response to the four hosts was the same for larvae from both sources, but a proportion of the larvae transferred from the red pine had an extra molt (Fogal and Kwain 1972a). Extra instars may lead to erroneous estimates of weight gain in tests to determine host plant nutritive value. Because extra molts occurred only in tests where larvae were reared in early instars on a poor food, late-instar larvae to be used in tests such as these should be reared in early instars on a good food.

Differences in larval dry matter content were noted; the figures tended to be correlated with dry weight gains in tests with *N. sertifer* and *N. nigroscutum*. However, the correlation was not evident in tests with *N. lecontei* and *D. similis*. Differences in dry matter content were also noted in experiments on *Tenebrio molitor* Linn. reared on different diets (Davis and Sosulski 1973) and the use of dry weight measurements was recommended for precise comparisons of gains in weight in nutrition investigations with larvae of *Tenebrio*. It appears that a similar recommendation should be applied to sawflies as well.

Food intake measurements indicate that *N. nigroscutum* is strongly deterred from feeding on white pine, a factor that likely accounts for its poor growth on this food. Food intake on white pine was consistently low with the other sawflies, suggesting that white pine leaves have a physical or chemical deterrent or lack an appropriate stimulant affecting feeding of all these sawflies, but especially *N. nigroscutum*. This may explain poor weight gains on white pine, but on other host foliage, variations in weight gain are not related to food consumption.

B. Efficiency of utilization

Comparisons of the utilization indices for the four sawflies on different species and age classes of foliage are shown in the histograms of Fig. 2.

In *N. sertifer,* the efficiencies of conversion of digested food to body (ECD) reflect closely the pattern of weight gains on the four types of foliage (see Fig. 1). They were highest on Scots pine and lowest on white pine with intermediate values for jack pine and red pine. Digestibility figures for nitrogen (ADN) were all significantly different; the order from highest to lowest was jack pine, Scots pine, red pine and white pine. The digestibility of dry matter (AD) was high for jack pine and white pine, but low for Scots pine and red pine. It was negatively correlated with the consumption indices (CI) and food intakes. The efficiencies of utilization of food ingested (ECI) reflect the differences in digestibility as well as conversion of digested food, so that a food such as white pine, with a relatively low nutritive value as defined by weight gain, does not give the lowest ECI figure.

In *N. nigroscutum* the ECDs again reflect closely the pattern of weight gains among the foliage types but the differences among jack pine, Scots pine and red pine are not significant. On white pine the value was negative, reflecting the fact that some of the larvae in the test lost weight. Nitrogen utilization was highest on jack pine; lower values were obtained on Scots pine and red pine. On white pine the larvae showed a net loss of nitrogen. Dry matter digestibility was highest on jack pine and lowest on red pine with intermediate values for Scots pine and white pine. In contrast with *N. sertifer,* there was no relationship between digestibility figures and consumption indices. The consumption index was very low on white pine; on the other foods it was high and among them no differences were detected.

Data obtained with *N. lecontei* on one-year-old foliage showed a close relationship between the efficiency of conversion of digested food and the utilization of nitrogen. These in turn are related to the pattern of weight gains (Fig. 1). Digestibility of dry matter on the one-year-old foliage is highest with jack pine foliage and lowest with red pine. Scots pine and white pine are intermediate in value. The consumption indices are negatively correlated with these figures. Ingested jack pine is the most efficiently utilized food. It also has high nutritive value as judged by weight gain, and the conversion of the digested portion to body is highly efficient. In contrast, the digested portion of red pine is just as efficiently converted to body tissue, but because of a low dry matter digestibility the conversion of ingested food to body is low. The lower nutritive value of current-year foliage can be attributed to reduced efficiency of the conversion of digested food and lower nitrogen and dry matter digestibility. The consumption indices and food intake figures are somewhat higher on current-year foliage, suggesting that it is more palatable or that the increased food intake compensates for the lower digestibility.

Comparison of the ECD and ADN values for one-year-old foliage in the experiment with *D. similis* again reveals a high degree of correlation between them; they in turn are apparently correlated with weight gains. Red pine dry matter digestibility is the lowest and jack pine the highest, with intermediate values for Scots pine and white pine. An inverse relationship between the digestibility of dry matter and the consumption indices was not observed. The poorer performance on current-year foliage than on the corresponding one-year-old foliage is again due to poor digestibility of dry matter and nitrogen and to reduced efficiency of conversion to body substance. The consumption indices and the food intake figures indicate that jack pine current-year foliage may be less palatable than one-year-old foliage. No difference was evident between the two age classes of Scots pine.

Except for white pine fed to *N. nigroscutum,* all types of foliage are consumed and utilized by the penultimate-instar larvae of these sawflies, but to varying degrees. For each sawfly, differences are evident in the efficiency of conversion of digested food to body among the food types. A notable feature of these

differences is their close positive relationship with the patterns of weight gain and of nitrogen utilization. Apart from the figure for *N. nigroscutum* on white pine, the nitrogen digestibility figures for *N. lecontei* were generally lower than the values obtained with the other sawflies. Perhaps the virus infection influenced the utilization of nitrogen in *N. lecontei*. The variations in digestibility of dry matter tended to be inversely related to figures for the consumption indices in *N. sertifer* and *N. lecontei*. In *N. nigroscutum* and *D. similis,* however, a strong inverse relationship is not so evident. Perhaps palatability is an overriding factor determining food intake in *D. similis* and *N. nigroscutum*. *Neodiprion sertifer* and *N. lecontei* may not be so sensitive to feeding stimulants or deterrents and may adjust their food intake according to digestibility of the food.

Among the sawflies, the duration of the penultimate instar is shorter for *N. sertifer* and *N. nigroscutum* than it is for *N. lecontei* and *D. similis*. However, because food intake is much greater in the latter species the consumption indices are similar. The consumption indices compare very closely with those obtained with several other species of insects (Waldbauer 1968). When compared with fifth-instar *Prodenia eridania* (Cramer) feeding on a number of plants (Soo Hoo and Fraenkel 1966), however, the sawflies consume approximately ten times as much food while the weight gains are only twice as great. The similarity of the indices is explained by the longer duration of feeding in the sawflies. In comparison with other insects feeding on nonwoody plants (Waldbauer 1968) the sawflies are relatively inefficient in the utilization of their host food plants. The digestibility of the food is low and, in addition, the sawflies ability to convert digested food to body is low. Thus, the overall conversion of food to body as reflected by the ECI figures is inefficient. Low utilization indices have been obtained with other insects feeding on the leaves of woody plants (Lebedev and Savenkov 1932, Sattler 1939, and Soo Hoo and Fraenkel 1966). Leaves of trees eaten by *P. eridania,* a polyphagus feeder, are not digested as well or utilized as efficiently as leaves of nonwoody plants (Soo Hoo 1963), which suggests that the former are a poor quality food source.

C. Foliar dry matter, nitrogen and fibre content

Results of analyses of dry matter, nitrogen, crude fibre, lignin and cellulose are presented in Fig. 3. Since each sawfly was tested on samples of foliage at a different time during the course of one summer season the data are presented to show both the differences in the constituents of one-year-old foliage among pine species and changes with successive samplings. Data on current-year foliage are also included in the figure.

Dry matter: For each tree species, dry matter content in one-year-old foliage decreased significantly during the course of the summer. For samples fed to *N. sertifer,* differences among species were all significant; white pine was highest, followed by red pine, jack pine and Scots pine, respectively. In samples used for *N. nigroscutum,* no difference between white pine and red pine was detectable; jack pine was significantly lower and Scots pine lowest. In the test with *N. lecontei* the content in white pine was highest; the contents for red pine and Scots pine were both significantly lower but no differences were evident between the latter two species, or between jack pine and the other species. In *D. similis* food samples, white pine dry matter content was significantly higher than that of the other tree species; jack pine content was significantly higher than Scots pine, and no differences were detectable between red pine, Scots pine or jack pine. In all cases, dry matter content of current-year foliage was significantly lower than that found in corresponding species and samplings of one-year-old foliage.

Nitrogen: The analyses of variance indicated that differences in one-year-old foliage over the course of the summer were significant in jack pine, Scots pine

and red pine; no differences were evident in white pine samples. In jack pine the nitrogen content was the same for the first two samplings; it decreased in the third and increased in the samples fed to *D. similis*. In Scots pine, it decreased from the first to second samplings and then increased at subsequent sampling times. In red pine, the values were the same in the first two samplings and higher in the last two; no difference was detectable between the last two. In the test with *N. sertifer,* differences among the four pine species were all significant; white pine was highest, followed by jack pine, Scots pine and red pine. The same situation prevailed in the test with *N. nigroscutum*. In the test with *N. lecontei,* nitrogen content was highest in white pine and lowest in red pine; in jack and Scots pine the values were intermediate, being significantly different from the other two but not from each other. In the samples fed to *D. similis* white pine was highest, Scots pine was significantly lower, jack pine was intermediate between the two, but not different from either, and red pine had the lowest nitrogen content. The current-year foliage tended to have a lower nitrogen content than the one-year-old foliage but the difference was statistically significant in one case only, i.e., Scots pine in the test with *D. similis*.

Crude fibre: Crude fibre contents in one-year-old foliage were highest in red pine throughout the summer; lowest values were consistently found in jack pine. Scots pine and white pine, for the most part, fell between those extremes. Comparisons of successive samplings indicated a low fibre content for each pine species in the first samples fed to *N. sertifer*. In succeeding samples of Scots pine and jack pine the fibre remained constant at a higher level. In white pine it increased in the samples fed to *N. nigroscutum* and decreased in subsequent samples. In red pine it increased in the second and third samplings and decreased in the final sampling. Current-year foliage had consistently higher fibre content than did one-year-old foliage.

Lignin: One-year-old foliage tended to have the highest lignin content in red pine and the lowest in Scots pine with intermediate values for jack pine and white pine. For successive experiments, the pattern for each pine was low at first, increasing during the tests with *N. nigroscutum* and/or *N. lecontei,* and then decreasing or remaining constant. Lignin tended to be low in current-year foliage.

Cellulose: Cellulose contents were highest in Scots pine foliage throughout the summer. Lowest values were found in jack pine and white pine, with intermediate values in red pine. There was little change in the content in jack pine with successive times of sampling. In Scots pine the values were low in the first two tests and increased in the last two; in red pine the value was low in the first, while higher but similar values were found in the three succeeding samples; in white pine the value was low in the first, but increased in the next two samples and decreased in the last. In red pine and jack pine, cellulose was higher in current-year than in one-year-old foliage. The reverse was true for Scots pine.

No relationships between the foliar constituents and the utilization indices were immediately evident. Possible relationships were investigated by calculating a correlation coefficient for each component against each of the utilization indices. Data from all of the experiments were pooled and the results are shown in Table II. A high negative correlation coefficient was obtained between measurements of acid-detergent fibre and the approximate digestibility of dry matter (AD). All of the other coefficients are relatively low.

The lack of correlation between variations in the total nitrogen content of different pine foliage and indices of food utilization suggests that the nutritive value of foliage from the pine species tested may depend on subtle quantitative and qualitative relationships among the nitrogen-containing nutrients present in

the food; it is not determined by the total nitrogen present. This has been experimentally demonstrated in studies where nitrogen content is reduced by dilution with cellulose with no marked change in the quantity of nitrogen ingested or the percentage utilized (McGinnis and Kasting 1967). Indigestible bulk plays a significant role in determining the consumption and digestibility of a diet and the efficiency of conversion of ingested food; however, it may have little effect on the nutritive value as measured by weight gains or the efficiency of conversion of digested food to body substance. When cellulose is added to diets fed to *Melanoplus bivittatus* (Say) proportionately more food is consumed and digestibility figures are reduced. Even when the diet is diluted with up to 90 percent cellulose, the grasshoppers make normal weight gains, indicating that the availablity of nutrients from the diet is unaffected (*ibid.*). Perhaps indigestible components in a natural food behave in the same way. In pine foliage consumed by sawflies, neither cellulose nor lignin content alone could be correlated with approximate digestibility, but together, as crude fibre content, there is a high correlation.

Finally, comparison of previous- and current-year foliage fed to both *N. lecontei* and *D. similis* indicates that current-year foliage has a lower digestibility of dry matter and nitrogen and is poorly utilized. This is correlated with high fibre, low dry matter and low nitrogen content, suggesting a reduced availability of nutrients as a possible explanation of the reduced nutritive value on current-year foliage.

Discussion

Values for the digestibility of dry matter indicate that large percentages (78 to 88 percent) of pine foliage are not utilized by diprionid sawflies. Measurements of fibre indicate that it makes up only 33 to 44 percent of the dry matter. It may be that other constituents of the leaves are indigestible or that the AD values are grossly underestimated, or else a combination of both factors may explain low values. The resins and oils of the leaves may contribute to the indigestible portion of the food to a small degree; estimates of oleoresin content in pine foliage have been shown to approach 3 percent (Mirov 1967). However, the diprionid sawflies separate oil and resins from their food into esophageal diverticulae (Saint-Hilaire 1931), regurgitating the oily fluid when disturbed. Prevention of the passage of oleoresin in this way would tend to yield AD values higher than they should be. Thus, oleoresin can likely be discounted as contributing to the low AD values. Perhaps starch contributes to the indigestible portion of the dry matter; in red pine, it comprises as much as 14 percent of the dry matter of one-year-old leaves (Pomeroy *et al.* 1970) and could thus make a significant contribution to the indigestible portion of the food. It is possible that some or all of the remaining discrepancy between the amount of indigestible material and the quantity of utilized dry matter can be explained by an underestimate of the AD values. The presence of excretory products such as uric acid and peritrophic membrane in the faeces will lower the values. Uric acid in the faeces of sawflies (*N. sertifer*) is less than 1 percent of the dry matter (Janda 1961) and will not greatly affect the AD value. In contrast, the periotrophic membrane may have a significant effect. Brown (1937) has estimated that 20 percent of the excreta of *M. bivittatus* consists of peritrophic membrane. Taking this figure into account for *N. sertifer* on Scots pine would increase the AD from 17 to 30 percent. A number of factors obviously influence the AD values; nevertheless, the values obtained are highly correlated with the fibre contents of the foliage used in the feeding tests. This suggests that fibre is a significant factor contributing to differences in the digestibility of foliage from different species of pine.

Water accounts for a significant proportion of the fresh food but the amount of water utilized could not be calculated in our experiments because accurate

determinations of the fresh weight of the faeces were not made. Water evaporates quickly from the faeces and wet weights have to be determined from freshly dropped faecal pellets. A figure of 48.2 percent water content of fresh faecal pellets is reported for *Gilpinia hercyniae* feeding on white spruce (*Picea glauca* [Moench] Voss) leaves containing 57.3 percent water (Fogal and Kwain 1972b). The value for foliar water content is close to that of the pine foliage; if it is assumed that the water content in the faecal pellets of the pine-feeding sawflies approaches that of the faeces of the spruce sawfly an estimate of water utilization can be made. Food intake and faecal output figures for *N. sertifer* on jack pine indicate that 45 percent of the foliar water is utilized. There is a significant amount of excess water in the foliage and the small variations in water content among types of host foliage may not result in changes in nutritive value. This is supported by the observations that utilization indices are not correlated with dry matter content.

The values for approximate digestibility of nitrogen ranged from a low of 26 to a high of 47 percent. Thus, a significant proportion of the nitrogen is utilized, but these figures likely underestimate nitrogen digestibility because they do not take into account excretory nitrogen in the faeces. Values from Janda (1961) indicate that the faeces from the last-instar larvae of *N. sertifer* feeding on *P. strobus* contains 1.7 mg uric acid nitrogen per gram of faeces (0.17 percent of dry matter). Using this value the ADN value for *N. sertifer* feeding on *P. strobus* is raised from 38 to 48 percent. Perhaps a large part of the variation in the ADN figures is due to variations in the output of uric acid, with the low figures reflecting higher levels of uric acid output. Other excretory products and nitrogen in the peritrophic membrane also contribute to an incorrect ADN value but the extent of the error is unknown. A complete interpretation of the ADN values requires additional information, particularly quantitative information about the nitrogen constituents of the faeces.

For all tree species, the values for total nitrogen in the foliage are close to 1 percent and the differences have little effect on insect growth. However, nitrogen utilization on the different foods, as measured by the approximate digestibilities of nitrogen (ADNs) is related to larval weight gain and the efficiency of conversion of digested food (ECD). This suggests that factors affecting the utilization of nitrogen play a significant role in determining the nutritive value of a natural food for the sawflies.

Several factors may affect the utilization of nitrogen. Some of these factors are related to the physiological condition of the insect. For example, the ADN values for *N. lecontei* were generally lower than the values obtained with the other sawflies. Perhaps this is not a species difference but a reflection of the fact that some of the larvae were infected with virus. Factors related to food quality are likely important; the utilization of nitrogen may be affected by the degree to which other constituents of the leaves are utilized. A large share of nourishment is provided by simple sugars in *Prodenia eridania* Cram (Crowell 1941). Fat is utilized and makes a major contribution to the nourishment of three species of lepidoptera (Evans 1939b); and starch is utilized by some insects (Brown 1930, Evans 1939b) but not by others (Evans 1939a and b, Crowell 1941). Proportional relationships among utilizable nutrients are important in the nutrition of insects (House 1969). The utilization of nitrogen will be affected also by nitrogen quality. The deleterious effects of the ingestion of disproportionate amounts of amino acids in animals have been well documented (Harper *et al.* 1970).

For natural foods there is a limited amount of information available on the utilization of protein and amino acids by insects; data are available from a study on *Phalera bucephala* (Linn.) feeding on hazel (*Corylus* sp.) leaves (Evans

1939a) and another on *Prodenia eridania* feeding on cranberry bean leaves (Crowell 1941). The levels of total nitrogen, protein and amino acid nitrogen in the leaves used in the above studies and the utilization figures for each component are shown in Table III. The corresponding figures available for red pine and the diprionid sawflies are included in the table for comparison. In the *Phalera bucephala* study the total nitrogen in the leaves was divided into a water-insoluble residue (protein), containing most of the nitrogen, and into water-soluble constituents including amino acid nitrogen which is a very small portion of the total. Each component is utilized but amino acid utilization is apparently very small. However, this may be explained by high levels of excreted or unabsorbed amino acids in the faeces. Since the amino acid content in the food is so small, even small additions of amino acids from protein digestion will significantly reduce the digestibility figure. This contrasts with the values for *Prodenia eridania* feeding on cranberry bean leaves. In this case the amino acid nitrogen represents a significant proportion of nitrogen by comparison with the protein which, in this case, is the total insoluble nitrogen remaining in the residue after extraction with 80 percent ethanol. The figure for approximate digestibility of amino acids is much higher than for *Phalera bucephala.* This may not be a true value, because the figure for protein digestibility is extremely high and all of the amino acids released from the protein may not be absorbed. However, since the amino acid nitrogen represents such a large portion of the total it likely contributes significantly to the nourishment of the insect. The diprionid sawflies utilize total leaf nitrogen to a much smaller extent than does *P. bucephala.* The figures for the nitrogen components of the red pine leaves, except for total nitrogen, are taken from Pomeroy *et al.* (1970). They are a range of values obtained from June to September and correspond to the time during which the sawfly feeding tests were performed. The amino acid nitrogen is a very small portion of the total nitrogen (2 to 3 percent) whereas the buffer-soluble protein makes up about 30 percent. The values for percentage utilization of total nitrogen in red pine varied from 33 to 42 percent (higher when corrected for excretory nitrogen), depending on the sawfly. This suggests that all of the protein and amino acids are utilized; however, a significant portion of the nitrogen was not solubilized and some of it may also be utilizable. The small quantity of free amino acids in the foliar tissue likely contributes very little to the total nitrogen utilized. In this respect, therefore, red pine and hazel leaves are similar and the constituent amino acids contribute little to the nourishment of the insects by comparison with the protein component. This fact may have some important implications for attempting to utilize and explain the effects of alterations in dietary constituents induced by fertilization treatments. It suggests that changes in the free amino acid pool which can be induced by fertilization of trees with mineral nitrogen (Barnes and Bengston 1968) may not affect sawfly growth, unless large accumulations occur at potentially toxic levels, whereas, variations in the nutritional quality of the protein may have a significant effect on the insects.

Detailed studies on quantitative utilization coupled with measurements of the quantities of nutrient and non-nutrient substances in the diet can provide insights into the relative importance of various dietary substances. Such insights may be useful in predicting which components of the diet might be manipulated to greatest advantage to provide constraints on insect growth.

TABLE I. Dates of experiments, types of host foliage tested, number and initial weights of larvae used in the tests, and number of larvae used to determine final weights in a study of host plant utilization by four species of diprionid sawflies.

Sawfly species	Date of exp.	Host foliage tested	Initial no. of single or pairs of larvae	Mean initial dry wt of larvae (mg)	Final no. of single or pairs of larvae
Neodiprion sertifer[a]	June 22 to July 2	jack pine	10	10.7	8
		Scots pine	10	11.1	8
		red pine	10	10.7	7
		white pine	10	11.0	7
Neodiprion nigroscutum[a]	July 21 to July 28	jack pine	10	12.8	10
		Scots pine	10	13.3	10
		red pine	10	13.3	10
		white pine	10	12.8	5
Neodiprion lecontei[a]	Aug. 4 to Aug. 17	jack pine[c]	10	9.2	4
		jack pine	10	9.2	5
		Scots pine	10	9.4	7
		red pine[c]	10	9.4	7
		red pine	10	9.1	7
		white pine	10	9.3	7
Diprion similis[b]	Aug. 24 to Sept. 9	jack pine [c]	13	12.1	11
		jack pine	13	12.2	13
		Scots pine[c]	15	12.2	14
		Scots pine	15	12.0	14
		red pine	13	11.6	11
		white pine	13	12.1	12

[a] Paired larvae used in tests.
[b] Single larvae used in tests.
[c] Current-year foliage: All other foliage was one year old.

TABLE II. Correlation coefficients between chemical components of foliage (dry matter, acid-detergent fibre, acid-detergent lignin, cellulose, and nitrogen) and food utilization indices (AD, ECD, ECI, and CI). All host species and insect species combined.

Chemical component	Utilization Index			
	AD	ECD	ECI	CI
Dry matter	.248	—.202	—.129	—.490
Acid-detergent fibre	—.870	—.303	—.468	.357
Acid-detergent lignin	—.387	—.243	—.310	—.041
Cellulose	—.386	—.006	—.093	.392
Nitrogen	—.491	—.080	.045	—.460

TABLE III. Utilization (approximate digestibility) of total nitrogen, protein and amino acid nitrogen by *Phalera bucephala* on hazel, *Prodenia eridania* on cranberry bean, and diprionid sawflies on red pine plus the percentages of the components in the diets.

Nitrogen fractions	Approximate digestibility			Nitrogen content (% of dry wt)		
	Phalera bucephala[a]	*Prodenia eridania*[b]	Diprionid sawflies[c]	Hazel[a]	Cranberry bean[b]	Red pine
Total	73	—	33-42	1.37	—	0.83-1.07[c]
Protein	77	91	—	1.30	4.5	0.22-0.35[d]
Amino acid	15	77	—	0.005	1.2	0.01-0.02[d]
Unidentified	73	—	—	0.065	0.3	0.60-0.70[e]

[a] Evans, 1939a.
[b] Crowell, 1941.
[c] This investigation.
[d] Pomeroy *et al.*, 1970.
[e] Data from this investigation minus data from Pomeroy *et al.*

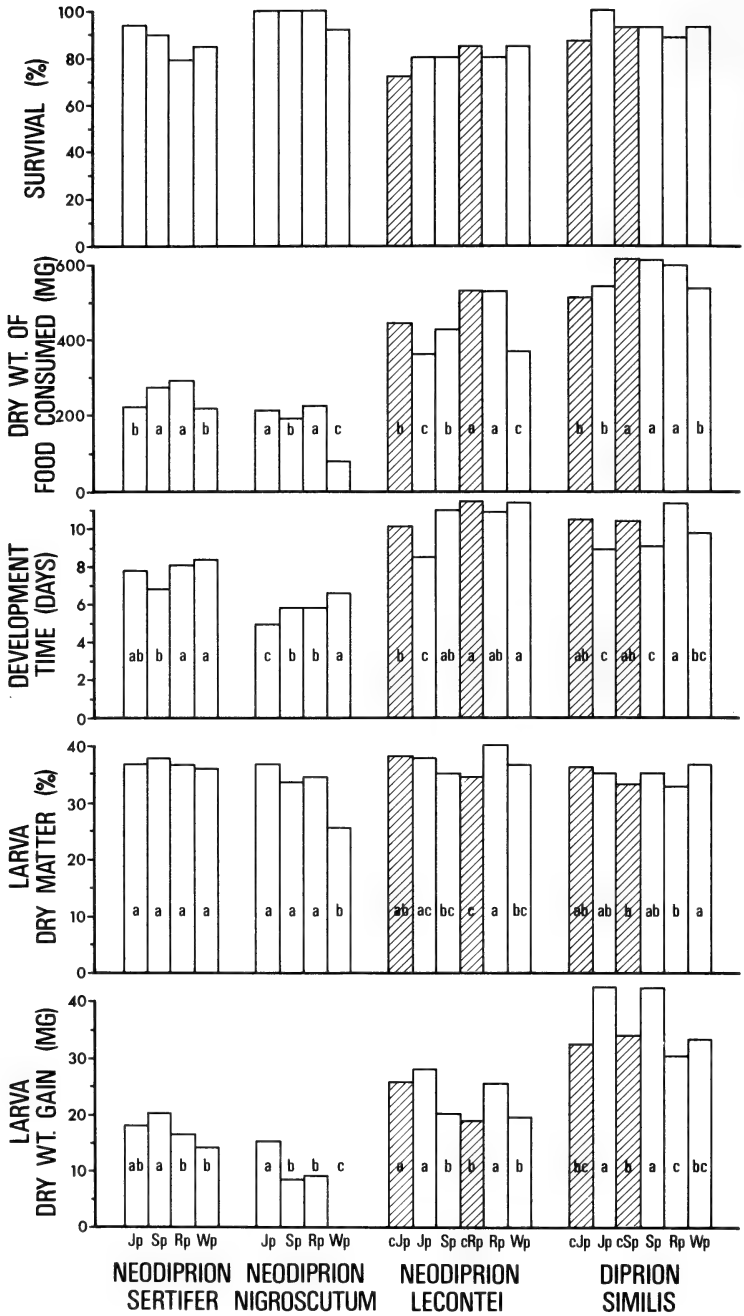

FIGURE 1. Histograms showing survival, mean food consumption, mean development time, mean dry matter contents of the last-instar larvae, and mean weight gain of the penultimate instar larvae of four sawflies, *N. sertifer, N. nigroscutum, N. lecontei* and *D. similis* on four species of pine foliage including one-year-old jack pine (Jp), Scots pine Sp), red pine (Rp), and white pine (Wp) and current-year jack pine (cJp), red pine (cRp), and Scots pine (cSp). Separate analyses of variance performed on data for each sawfly species. Statistical significance tested with Duncan's Multiple Range test at the 5 percent level. Bars bearing the same letter are not significantly different.

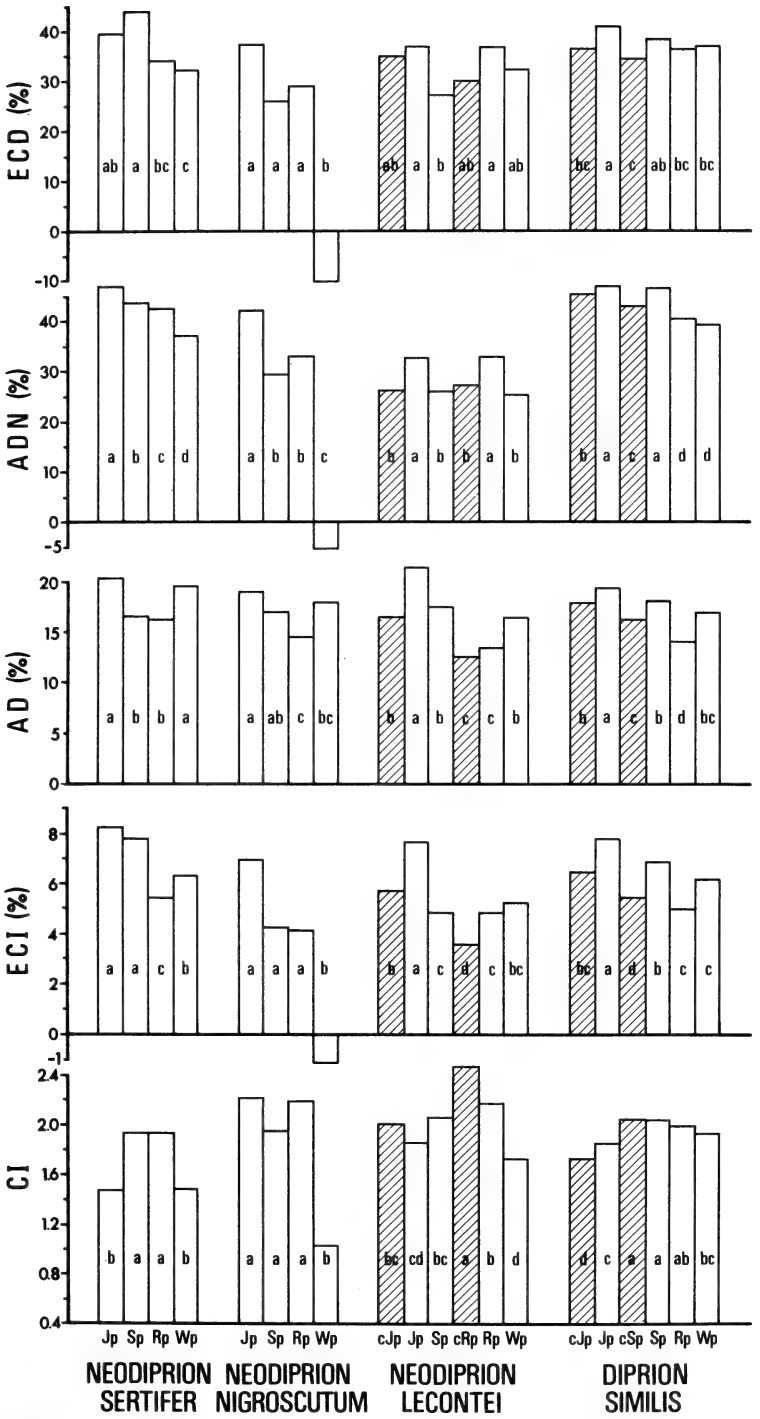

FIGURE 2. Histograms showing the mean utilization indices with the four sawflies on the four host plants. ECD, efficiency of conversion of digested food to body; ADN, approximate digestibility of nitrogen; AD, approximate digestibility of dry matter; ECI, efficiency of conversion of ingested food to body; CI, consumption index. Statistical treatment as in Figure 1.

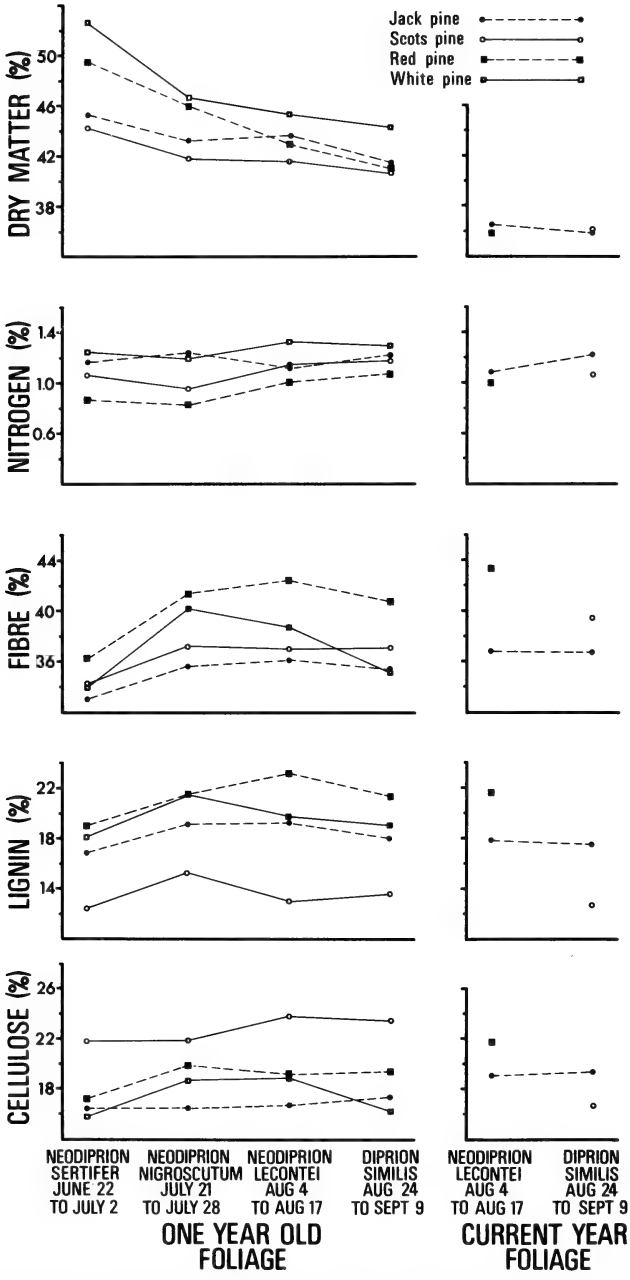

FIGURE 3. Graphs showing the percentage dry matter, nitrogen, fibre, lignin, and cellulose in one-year-old foliage of four pine species, including jack pine, Scots pine, red pine and white pine, fed to: *N. sertifer* from June 22 to July 2; *N. nigroscutum* from July 21 to July 28; *N. lecontei* from August 4 to August 17; *D. similis* from August 24 to September 9. Included also are values for current-year foliage of: jack pine and Scots pine fed to *N. lecontei* from August 4 to August 17; jack pine and red pine fed to *D. similis* from August 24 to September 9.

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HIVE DESIGNS FOR BEEKEEPING IN KENYA

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Abstract

Kenya beekeeping needs a hive that is reasonable in cost, meets the specific requisites of African beekeeping, and promotes both the production of honey and beeswax from movable combs. Two types of hives and several bar and frame designs were compared with standard Langstroth equipment under northern temperate condition. The results indicate that where top bars only are used the hive should have sloping sides. The most suitable hive for all situations appears to be a straight-sided African Long Hive using frames with a median cross bar and a starter strip of masonite. Comb foundation or foundation starter appeared neither necessary or advisable.

* * * * * *

Introduction

In Kenya, a modification of the Greek basket-hive with movable top bars, referred to as Kenya Top Bar Hive (KH), is successfully replacing the traditional log hive with fixed combs. The present study was an attempt to test and, if possible, to improve upon this hive in an endeavour to formulate an optimum hive design for tropical apiculture where African bees exist.

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The origin of the present Kenya Top Bar hive is believed to date back to "J.A.'s" letter written in 1683 and reprinted by Walker (1928) which gave specifications for a hive with sticks "laid across the top" for comb attachment. Walker suggested the inspiration of the design to have come from Wheler's description of the Greek hive in 1682.

The movable comb was in operation in Greece long before Langsroth in America discovered the principle of bee space in 1851. Movable bars were slowly modified into frames of various forms (Wildman 1778, Sydserff 1792). Dzierzon (1882) recommended a frame with a median cross bar "left open below" and provided with firm side pieces.

Comb starters for guiding bees during comb building have been tested and recommended by Abbot (1875) and Langstroth (1893).

During a good honey flow, bees usually construct drone cells for honey storage (Root 1910) and not necessarily for drone rearing. Darchen *et al.* (1957) suggested that a laying queen inhibits drone cell construction. Drone cell construction is instinctive and is probably controlled by the number of drone cells already present (Free 1967).

In the present study, the effect of hive design, various top bars and frame modifications were assessed with respect to comb attachment, comb breakage, comb starters, initiation of comb building, and amount of drone comb construction.

Materials and Methods

The study was carried on at the field laboratory, University of Guelph, Ontario, Canada. Two hive types, six bar types, two modified frame types, and a standard frame were tested.

Hives

A straight-sided Long Hive type (LH), internal dimensions 8¾ in. deep by 18¼ in. wide by 28¾ in. long, and a sloping-sided Kenya Hive type (KH), internal dimensions 8¾ in. deep by 18¼ in. wide at the top and 11 in. wide at the bottom by 28¾ in. long, were designed. Ventilation holes, 1 in. in diameter, were provided 3 in. below the top edge of the hive. Entrances were located either on the side or the end of the hive, according to the design of the experiment (Fig. 2, 3a,b).

Bars

1. *Bar with bevel bottom.* A bar ¾ in. thick by 1½ in. wide by 19 in. long cut to form a V-shape on the underside (Fig. 1a).
2. *Bar with wooden strip starter.* A strip of wood ¼ in. thick by ½ in. wide by 18 in. long fixed in the underside of a top bar (Fig. 1e).
3. *Bar with foundation strip starter.* A strip of beeswax sheet of comb foundation, 1½ in. wide by 18 in. long, was held between two wooden strips on the top bar (Fig. 1f).
4. *Bar with masonite strip starter.* A top bar (as in #1) was saw split into two equal pieces and a strip, 18 in. long by 1¼ in. wide, held between the two pieces (Fig. 1c).
5. *Bar with wire loop.* Nine-gauge wire was looped on the top bar leaving 4 in. on each end of the bar (Fig. 1b,d,e,f).

FIGURE 1. Bar and frame designs used in the experiments.

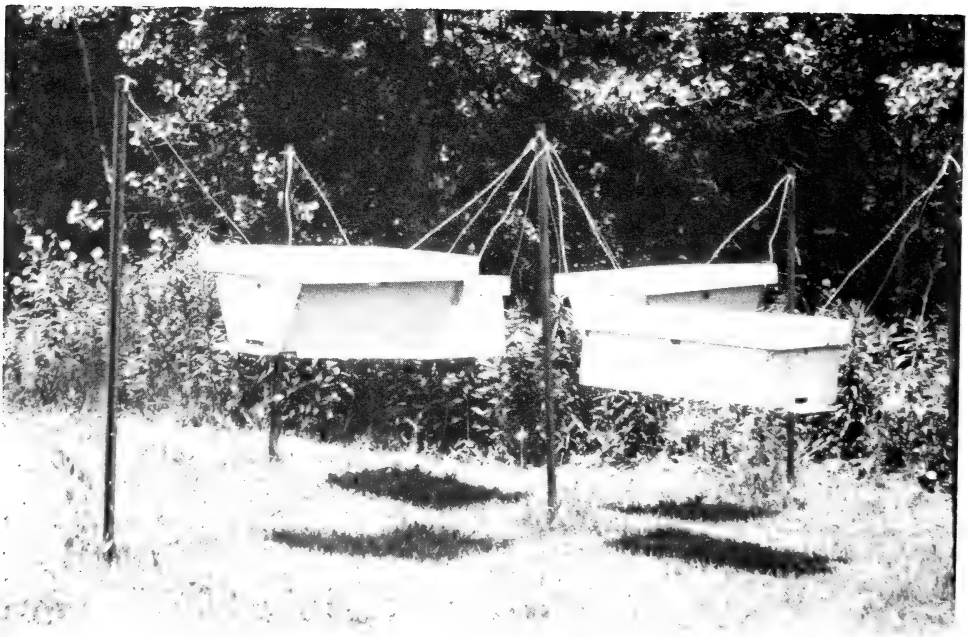

FIGURE 2. A four-hive set with entrances facing outwards and suspended by use of wires and five posts.

6. *Modified frames.* Modified frames consisted of two Langstroth standard frame types without sheets of beeswax foundation. One had four horizontal frame wires only, and the other a median cross-bar; masonite being used as comb starters in both cases (Fig. 1g,h).
7. *Langstroth standard.* A Langstroth standard frame with a wired full sheet of beeswax worker foundation was used as a control (Fig. 1i).

The various treatment combinations are shown in Table I. Each hive received a known weight of bees (Table II). To compensate for the poor nectar flow of 1974, sugar syrup was provided in the hive as required by bees throughout the course of the study.

The methods used in setting up the hives were similar to the African hanging technique commonly used to avoid pests and savannah fires. Hives were hung from posts, three feet from ground level in three groups of four. This four-hive set is shown in Fig. 2.

Periodically during the season the hives were examined and the following factors assessed:

1. *General Management*:

   (a) ease of controlling bees in each group by smoke.

TABLE I. Arrangement of experimental hives.

Hive Number and Group	Entrance Location and Direction	Hive and Bar Types Description
Experimental Arrangement #1 (23-5-74)		
		Hives with Bars
5A	Side-clockwise[1]	KH[2]—Bars with masonite starter
6A	End-outwards[3]	KH —Bars with wire loop and masonite starter
7A	End-outwards	LH[4]—Standard frames) — controls
12A	Side-clockwise	LH —Standard frames)
1B[5]	End-outwards	KH —Bars with bevel bottom
3B	End-outwards	KH —Bars with mixed starters and wire loops
8B	End-outwards	LH —Bars with bevel bottom and wire loops
9B	End-outwards	LH —Bars with masonite starter
2C	Side-clockwise	As in 1B
4C	Side-clockwise	As in 3B
10C	Side-clockwise	As in 9B
11C	Side-clockwise	LH —Bars with bevel bottom
Experimental Arrangement #2 (2-7-74)		
		Hives with Modified Frames (Fig. 1g,h)
8B'	End-outwards	LH —Frame with 4 horizontal frame wires
9B'	End-outwards	LH —Frame with a cross-bar
10C'	Side	As in 8B'
11C'	Side	As in 9B'

[1]See Fig. 3a.
[2]Kenya top bar hive.
[3]See Fig. 2.
[4]Long Hive.
[5]Group "B" later arranged as in Fig. 3b.

(b) the effect of a bee-tight top in controlling the number of bees issuing from the hive in an effort to reduce stinging. Bars were placed close together to form a bee-proof top.

(c) comb breakage, and also the percentage increase in weight and area of combs in the Long Hive over combs in the Kenya Hive were calculated.

2. *The degree of attachment* of the combs to the side walls of the hive. Attached combs were photographed.

3. *The effect of the position of feeder and entrance* on the construction of the first comb and the general building sequence.

4. *The degree of success of the starter as a comb guide.* Observations were made on the ability of the starter to guide bees during comb building. All starters were waxed before placement on the bars.

5. *The effect of absence or presence of foundation* on comb building. The building index was computed as the number of combs built by a pound of bees within the first three weeks with constant feeding. This timing was necessary to avoid participation of young emerging bees. The number of combs was counted, and corrected to the nearest whole number.

6. (a) *The acceptance of 9-gauge wire* as comb support. Wire avoidance, effect on building sequence, and distortion or breaking of the combs during handling were assessed.

(b) *Modified frames.* Avoidance of frame wires and wooden cross-bar, effect on building sequence, and distortion or breaking of combs in a centrifugal radial extractor were assessed.

7. *Amount of drone comb constructed.* A record was made of the percentage of drone cells. The combs in the hive were maintained in the same position within the hive throughout the experiments, and the drone cells recorded on each comb individually.

Results and Discussion

1. **General Management**

(a) The four-hive set (Fig. 2) provided adequate space between the hives for operation. Only two hives could be adequately smoked at the same time in the layout with entrances facing outwards (Fig. 2) and sideways (Fig. 3a). It was possible, however, to smoke all four hives simultaneously when the entrances faced inwards (Fig. 3b). Of the three set-ups, it was only in the one with the entrances facing outwards that bee flight routes were not obstructed during hive operation. These considerations do not, of course, constitute a proof of an effective entrance direction since the aim was to find a possibility of smoking the four hives at once, and therefore more information is required about this factor and the amount of drift and stinging which might occur using African bees. At present, however, the end entrances facing outwards appears preferable.

(b) The bars placed close together to form a bee-tight top reduced appreciable the number of bees flying from the combs to disturb the operator. The "bee-proof cover" of bars suggested by Papadopoulo (1965) was probably for the same purpose.

(c) There was a high breakage frequency of Long Hive combs which was attributed to the comb stress on the top bar due to an increase in the size of comb without an increase in the top attachment. The Long Hive had combs with about 21% more weight and 20% more area than the

Kenya Hive combs. Much more time was required in examining combs on bars compared to frame supported combs, because combs on bars break when tilted sideways. This is due to the fact that they have only one point of attachment as compared to four points of attachment for a frame. In commercial operations with the aggressive African bees, this would probably be a drawback because of the extra time taken and comb breakage. For small operations, however, the Kenya Hive with bars is recommended since it is cheaper and easier to maintain.

2. **The Degree of Attachment of Combs to Hive Body**

Comb attachment was noticed in a significantly higher percentage of Long as compared to Kenya Hives. In the Kenya Hive it was scarce and occurred in only a few hives. Herrod-Hempsall (1930) indicated that attachment does sometimes occur in the Greek hive. Papadopoulo (personal correspondence) never found more than 1% attachment in Greek basket hives and associated the low percentage with the slope of the sides being similar to natural comb. It is evident that some attachment occurs in Greek hives and in Kenya hives, confirming that shape alone is not an adequate control. Papadopoulo suggested that swinging movements of hanging hives could be the cause for attachment, but since there was no attachment in the control test (Table I—7A and 12A), this would probably mean other factors were involved. However, the effects associated with swinging have to be further investigated.

It is primarily the weight of the comb that is related to comb attachment, with the shape and other factors playing some part. The line of attachment as the comb increases in size is important, and in frames it is enormous around the margin. In general terms, the Kenya Hive comb weight was less than the Long Hive comb and probably closer to that prevailing in a natural situation. This could probably explain the variation in attachment in the two hive types. It is, therefore, advisable for beekeepers using bars to adopt the Kenya Hive rather than the Long Hive.

3. **Position of the First Comb in Relation to Feeder and Entrance**

All colonies, except colony 6A, showed a similar trend, namely comb building starting close to the feeder. Carr (1873) suggested that bees carry the honey farthest from the entrance where it can be easily protected. An internal source of food (feeder) was probably protected by centralizing the hive activities (comb building) nearby. By positioning the feeder and entrance in the opposite ends, hive activity should shift away from the entrance and probably reduce stinging.

4. **Starters**

All the starters provided an acceptable comb building guide. This agrees with Langstroth (1893) and Munn (1873) who claimed good acceptance of different starters by bees. The masonite strip starter is relatively harder than the other starters and therefore less subject to damage when combs are cut off for wax production. Although there was evidence in favour of this starter, its price and availability in Kenya is unpredictable. In such cases a switch to wooden strip starters may be necessary.

5. **Effect of Presence or Absence of Foundation**

The highest building indices of 1.8 were obtained in colonies with starters 2C and 6A (Table II). The full sheet of foundation colonies 7A and 12A had low building indices of 1.3 and 1.4 respectively. No doubt, the wire loop or the temporary queenless condition (Table II) might have interfered with the moral of the colonies 8B and 11C, and therefore reduced the rate of building. The re-

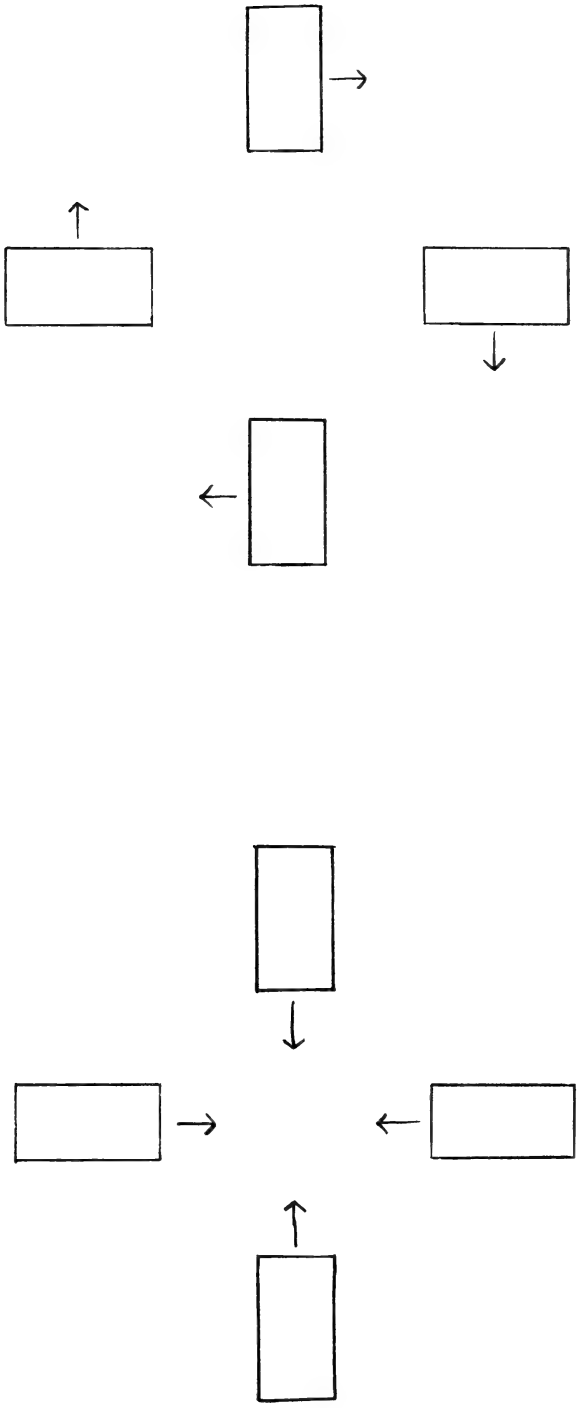

FIGURE 3. Diagrams of four-hive sets; (a) entrances facing sideways in clockwise direction; (b) entrances facing inwards.

sults agree with Quinby (1871) and Root (1875) who found evidence in favour of starters. Tokunda (1955) proved that wax production by bees is a reaction to the absence of comb and does not shorten their life span. In areas of long honey flows, it is advisable to allow bees to build their own combs (Deacon 1900).

TABLE II. Rate of comb building — data recorded three weeks after hive establishment.

Hive Number and Group	Combs Built (to nearest whole number)	Weight of Bees Introduced (in pounds)	Building Index (combs/pound of bees)
1B	7	6.7	1.5
2C	11	6.0	1.8
3B	9	6.0	1.5
4C	7	5.8	1.2
5A	9	6.6	1.4
6A	7	4.0	1.8
7A	3	2.3	1.3
8B[1]	6	5.5	1.1
9B	9	6.3	1.4
10C	9	5.7	1.6
11C[2]	7	6.4	1.1
12A	5	3.5	1.4

[1]Colony queenless and requeened, July 17, 1974.
[2]Colony queenless and requeened, Sept. 5, 1974.

6. (a) **Bars with Wire Loops**

Apparently the bees seemed to detect the presence of the wire and tried to avoid it and in most cases there was a total disorientation in comb building with the bees failing to follow the comb starters provided (Fig. 4). This contradicts results reported by Dzierzon (1882) and Johansson (personal correspondence) who reported the acceptance of this type of wire by bees and also its ability to support combs from breaking. Comb breakage at the point of intersection with the wire was evident. The wire loop design appeared unsatisfacory as a comb support and would probably hinder management.

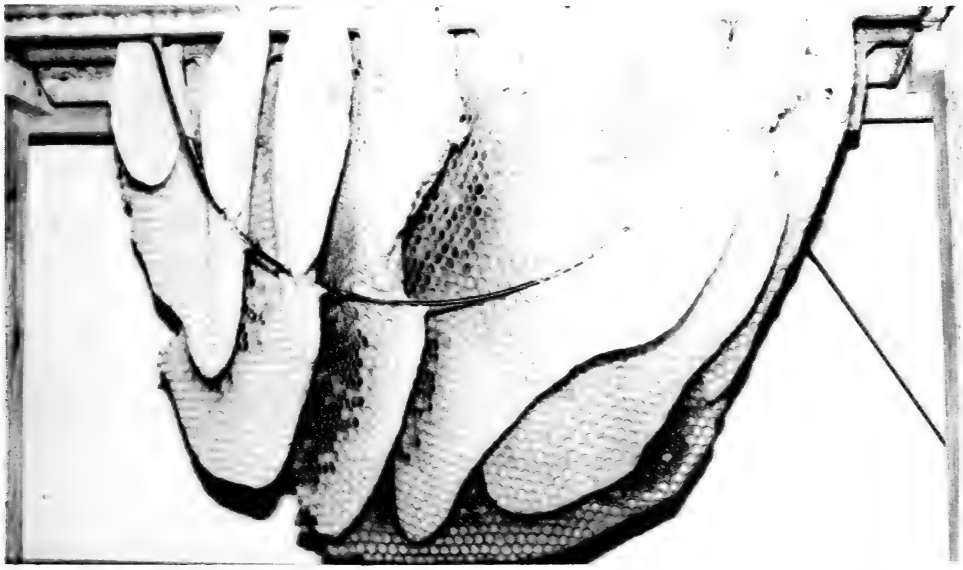

FIGURE 4. Disoriented comb building caused by the inclusion of 9-gauge wire loop.

(b) **Modified Frames**

The median cross-bar and frame foundation wires were incorporated without any apparent avoidance by the bees. Breakage was low during extraction (2/13 frame foundation wire combs were broken and none out of 14 crossbar frames) even in the presence of honey granulation and low moisture content (16.8%). The frame with the median cross-bar can be made easily with material available in Kenya. It is recommended in conjunction with the Long Hive for large operations. However, it may be desirable to dispense with the bottom bar of this frame which was observed to play little part in comb support (Fig. 5).

7. **Drone Comb Construction**

In the first three combs constructed, drone cells averaged 22.3%, dropping to 6.9% in the following four combs (Fig. 6) after which there was a reversion to the construction of mostly worker cells with less than 1% drone cells. The average drone cell construction in all colonies throughout the entire period was

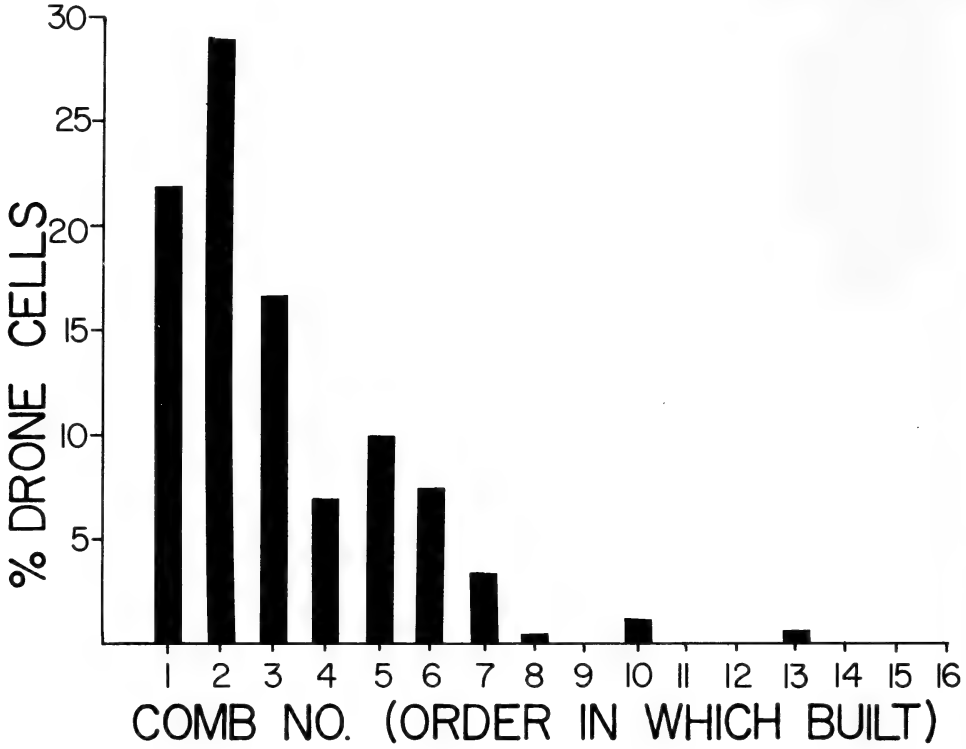

FIGURE 6. Relationship of drone cell construction to comb building.

7.2%. Foundation colony 12A produced approximately 4% drone comb. This agrees with Dadant (1920) who, after noticing the building of drone cells over the top of worker cell foundation, concluded that drone cell construction is instinctive and cannot be inhibited by use of worker foundation. It is therefore suggested that a normal colony left to build its own combs will rear drones according to its needs without over-production.

The experiments showed that bars or frames placed close to each other to form a bee-tight top reduced stinging by controlling appreciably the number of bees issuing from the hive. Where bars are to be used, they should be used in conjunction with sloping-sided Kenya Hives to control both breakage and attach-

ment of comb to the hive body. There is no advantage in using sheets of beeswax foundation and no evidence that the use of foundation inhibits construction of drone cells. Waxed masonite or wooden strip starters provided a satisfactory comb guide.

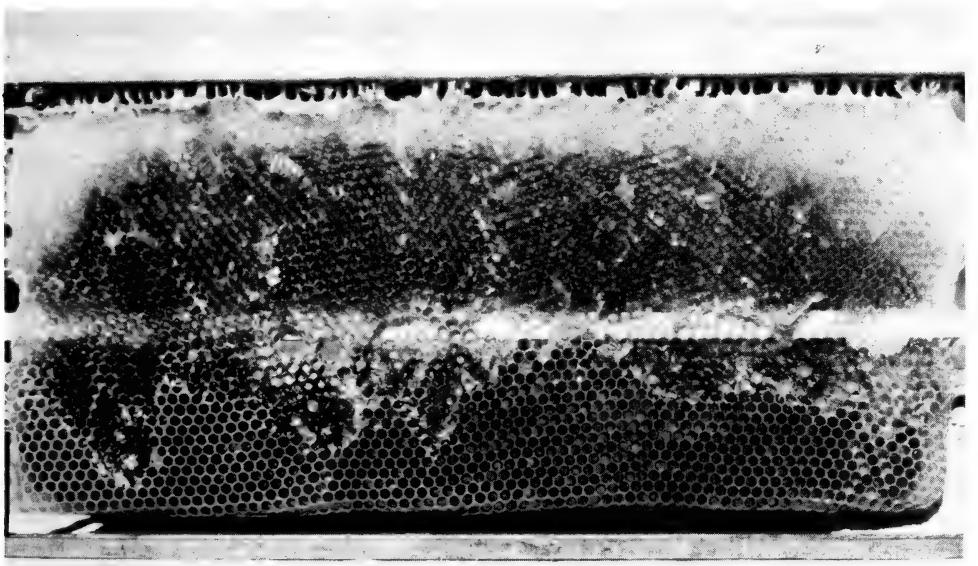

FIGURE 5. A modified standard frame with median cross-bar and masonite starter. The comb has been uncapped and the honey removed using a radial extractor.

For commercial operations, particularly where movement of colonies is likely, the straight-sided Long Hive in conjunction with a frame with a median cross bar (Fig. 5) may be preferable.

These tests were conducted in temperate conditions with European bees, and therefore must be repeated with African bees before any firm conclusions can be drawn about their usefulness in Kenya.

Acknowledgments

Thanks are due to Professor G. F. Townsend and Dr. M. V. Smith for their useful criticisms, and to Mr. A. B. Adie for his excellent technical assistance.

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RELATIONSHIP OF AGE TO BROOD-REARING ACTIVITIES OF WORKER HONEY BEES, *APIS MELLIFERA* L.

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Abstract

An observation hive was set up in which a large proportion of the population was comprised of marked worker bees of known ages. Observations carried out over a period of eight weeks indicated that queen larvae were tended by a higher proportion of older nurse bees than were worker larvae.

* * * * * *

Introduction

Younger bees first undertake a sequence of hive duties, followed by foraging activities outside the colony (Ribbands 1952, 1953). This sequence of duties is not as rigid as Rösch (Ribbands 1953) had supposed, but allows for a considerable degree of flexibility (Lindauer 1953). In an attempt to observe more precisely the relationship between age and brood-rearing activities, an observation hive composed of a single frame of brood and bees was established. A large proportion of the population of this hive was composed of groups of marked bees, separated by 5-day age intervals.

Materials and Methods

On May 24, a comb of emerging brood was placed in the incubator at 33° C and left overnight. The following day, 500 newly-emerged bees were marked with a white paint spot on the thorax (without the use of any anaesthetic). These were

introduced to a small colony in an apiary 4 miles distant from the research laboratory. Every 5 days until June 9th, the procedure was repeated, using a different coloured paint each time.

On June 14th, a single-frame observation hive was set in place in the laboratory, with provision for a flight entrance through the window. Narrow strips of comb were placed crosswise in the hive to encourage the bees to build their cells in longitudinal section against the clear plastic sides. A glass panel on each side, 2 cm from the plastic created an insulating double wall to avoid chilling of the brood.

The colony from the apiary, containing the 4 previously marked groups of bees, was now brought to the laboratory and the laying queen and all the marked bees were transferred to the observation hive. A 5th group of 500 newly-marked bees was also added. Thus the newly-established hive had 5 groups ranging from 1 to 20 days of age; this represented a fairly normal age distribution. Every 5 days thereafter until Aug. 18th, groups of 500 newly-emerged marked bees were added.

In order to maintain normal conditions within the colony it was necessary to have a laying queen. This meant that by July 5th unmarked bees began to emerge into the hive, and their proportion gradually increased as the season advanced. Observations, which were begun on June 28, were discontinued on Aug. 21.

Usually the bees cooperated in rearing worker brood in the cells built against the plastic viewing window. In a few instances larvae less than one day old were transferred into cells that were more favourably situated for observation. This was accomplished by drilling a small hole through the plastic near the open end of the cell, and using the bent flattened tip of an insect pin to transfer the larvae.

A similar procedure was followed in setting up cells for queen larvae against the plastic. Removal or confinement of the queen for a few days following larval transfer enhanced queen cell acceptance by the worker bees.

Since the plastic formed one side of the queen or worker cells, it was possible to observe precisely the behaviour of each bee that entered a cell. Binocular dissecting microscopes were sometimes set up alongside the observation hive to give a magnified view of the nursing activities.

Brood-rearing activities were classified as:

Inspection:

The bee paused and thrust its head into the cell or entered it. It often examined the cell walls or the larva with its antennae, but would then withdraw without carrying out any further activity.

Cleaning:

The bee entered or partly entered the cell and licked the cell walls with its tongue.

Feeding:

The bee entered the cell, examined the larva, then opened its mandibles, often vibrating them slightly, and deposited food in the cell near the larva.

Building:

Two activities were included in this category. Some bees chewed with their mandibles at the wax rim of the cell. This was observed on cells containing larvae of varying ages. It is likely that such bees were obtaining wax for capping (sealing over with a wax covering) the cells of older larvae elsewhere on the comb. Other bees were directly engaged in capping the cell under observation. This occurred only with cells containing more advanced larvae.

The observer chose a queen or worker cell containing a larva situated in such a position that it could be easily viewed, and attempted to record all the visits to this cell by nurse bees. Observations of individual cells extended from a few hours to several days, and were terminated if the bees removed the larva and cleaned out the cell, or when the cell was completely capped. Code letters were used to denote the type of visit and the colour of the bee. Occasionally more than one of the above activities were carried out by a nurse bee on a single visit.

Results and Discussion

During the course of this study, a total of 2,946 visits by marked bees were recorded; 1,642 to 8 queen cells and 1,304 to 20 worker cells kept under observation. The queen cells contained larvae from < 1 to approximately 4 days of age; beyond this the larvae were destroyed and the cells chewed down by the bees. However, the worker larvae were less frequently rejected by the bees, so larvae from < 1 day of age to full development were included in the worker cell observations.

The age distribution of the bees visiting queen and worker brood cells is presented in Figs. 1 and 2. In order to permit a more accurate comparison of the data, the number of visits within each age group is expressed as a percentage of the total visits.

Two differences are apparent from the curves in Fig. 1. Almost four times as many bees in the 1-5 day age group visited worker larvae as visited queen larvae. Also, the number of bees beyond the 6-10 day age group that visited worker larvae rapidly declined, while the curve for visits to queen larvae remained considerably higher.

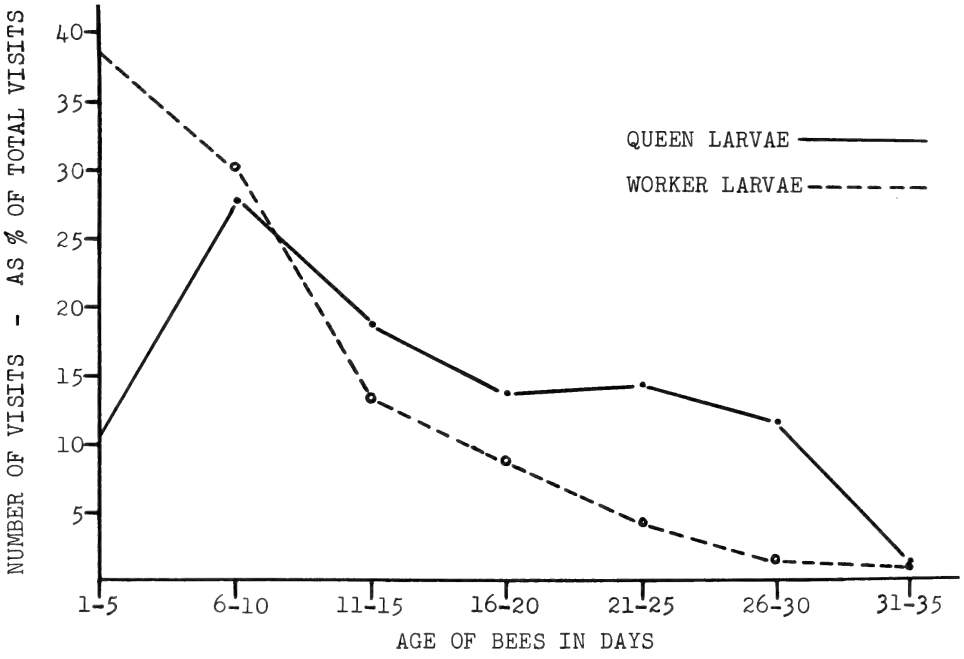

FIG. 1. Number of visits of worker honey bees of different age groups to queen and worker larvae.

In Fig. 2, the data for cleaning, inspecting, feeding and building visits are presented separately. In general, the distribution of the bees within each age class is fairly uniform, regardless of the type of activity. Two irregularities are the high proportion of building visits to worker cells by the 1-5 day age class, and the peak in feeding visits to queen cells by bees 21-25 days of age.

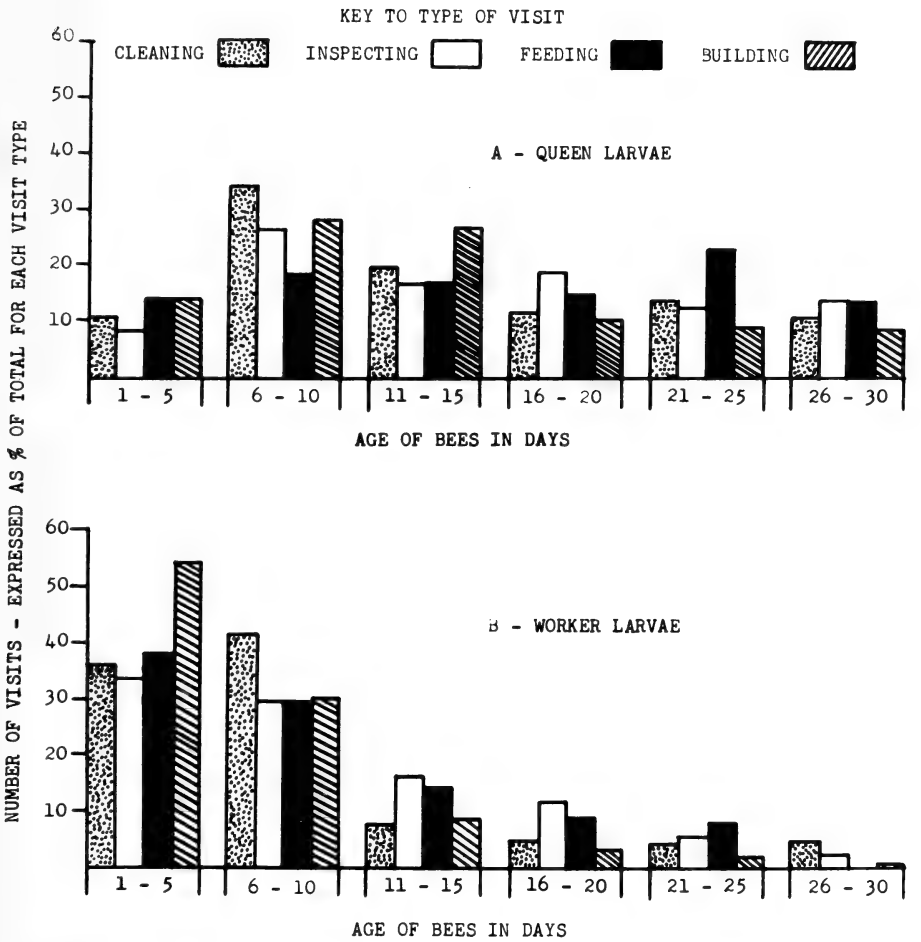

FIG. 2. Relationship of age to type of visit of worker honey bees observed tending A. Queen larvae and B. Worker larvae.

Honey bee workers normally begin foraging at an average age of 19-20 days (Ribbands 1953). However we observed a significant number of bees beyond this age still engaged in brood rearing — particularly in the case of queen larvae. Furgala and Boch (1961) recorded the distribution of marked bees of known ages on brood, and found that older bees tended to be more numerous on queen cells than on worker brood. The development of the salivary glands is believed to play an important part in the brood-rearing activities of honey bees. Free (1960) found bees with developed hypopharyngeal glands on brood of all stages, but noticed no difference in the age distribution of bees on young or older worker larvae. Smith (1954) found that a number of factors affect the rate of development of the hypopharyngeal salivary glands of bees within the same age

group. That older bees are still capable of feeding larvae was demonstrated by Habowsky (1962). His studies on the hypopharyngeal glands of worker bees of known ages showed that although the diameter of the acini of these glands began to decrease significantly by 20-25 days of age, 22.8% of the glandular cells still contained secretion masses.

Habowsky (ibid.) also captured samples of bees observed feeding both worker and queen larvae, and examined their hypopharyngeal glands. These he classified as: I. Little activity; II. Intermediate secretion masses; III. Large active secretion masses. For worker nurse bees he recorded: I. 32.2%; II. 56.0%, and III. 11.8%, while for queen nurse bees the corresponding figures were: I. 2.4%; II. 50%, and III. 47.6%. A somewhat similar trend was found in the secretory activity of the mandibular, postcerebral and thoracic glands. The implication that nurse bees with more active glands (presumably older bees) are involved to a greater degree in the feeding of queen larvae, was borne out by the present study.

Acknowledgements

The author wishes to recognize the help of Mr. A. B. Adie who assisted in the setting up of the observation hive and in the marking of bees, and of George Ayers and Don Cullen who recorded much of the data.

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IV. INDEX

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AUTHOR'S GUIDE

1. Two copies of a manuscript are required by the Editor (including second copy of each figure by print or photostat).
2. Manuscripts should be prepared in the manner described in the "C.B.E. Style Manual for Biological Journals", published by the American Institute for Biological Sciences, 3900 Wisconsin Avenue, Washington, D.C. 20016, U.S.A. 3rd ed. ($6.00).
   (a) Citations in text to bibliographic references should be made by use of the "name-and-year" system.
   (b) Refer to the current Volume of the Proceedings for examples of type and style of titles, headings etc.
3. Arrangements have been made with the staff of Biological Abstracts for them to take abstracts directly from the volumes of the Proceedings. Each author is thus requested to insert an "ABSTRACT" of his article in the manuscript between the author's name (including his address) and the main body of the text.
4. Correspondence concerning, and orders for, reprints should be addressed to the Editor.

ISSN 0071-0768

PROCEEDINGS

of the

ENTOMOLOGICAL SOCIETY OF ONTARIO

Volume One Hundred and Six

1975

Published November, 1976

Errata

In Volume 104 (1972-73) of the Proceedings, the list of Officers of the Society is actually the Officers of the year 1973-74. In Volume 105 (1973-74) the list is the Officers of 1974-75. Thus, the Officers for the year 1972-73 were omitted and never appeared in subsequent issues of the publication. You may well ask, "How could this happen"? Let me try to explain.

The year 1972-73 for the Society began immediately following the Annual Meeting which was held at Queen's University, Kingston, in November 1972. It concluded at the Annual Meeting in November the following year, 1973. The Proceedings were published in late November of 1973, but mailing required some time as we try to avoid the Christmas rush. In some way, the Officers of 1973-74 were included in Volume 104. How and why? Well, instead of the Editor requesting the proper list from the Secretary-Treasurer (who never makes mistakes), he "thought" it all out by himself. The following year, he did it again. Now he hopes to make up for the error. But how? He can publish the list on this sheet of Errata and trust that the wronged officers will be generous and forgiving. What more can he do? You must admit that your Editor's behaviour indicates that he looks forward better than he looks back.

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ISSN 0071-0768

PROCEEDINGS

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ENTOMOLOGICAL SOCIETY OF ONTARIO

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1975

Published November, 1976

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(With date of election)

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E. M. DuPorte (1969)

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G. F. Manson (1968)

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ENTOMOLOGICAL SOCIETY OF ONTARIO

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Correspondence about membership in the Society or exchange of publications should be addressed to the Secretary-Treasurer, D. H. Pengelly, Environmental Biology, University of Guelph, Guelph.

CONTENTS

TAXONOMY

PHYSIOLOGY

I. THE SOCIETY

IN MEMORIAM

The following entomologists, all of whom were members of the Society at some time, died since Volume 105 of the Proceedings was published.

Alex D. Baker (1894-1974), former Chief of the Nematology Section, Entomology Research Institute, died in Ottawa on December 9, 1974. For additional information on the man and his contributions to Nematology, see Bulletin, Entomological Society of Canada 7 (3): 68, 1975.

* * * * * *

J. W. M. (Bain) Cameron (1910-1975), late Director of the Insect Pathology Research Institute, died at the General Hospital, Sault Ste. Marie, Ontario, January 4, 1975. An obituary, prepared by the staff of the Institute, was published in the Bulletin of the Entomological Society of Canada 7 (2): 36-37, 1975 and in the Proceedings of the Entomological Society of Ontario 105: 2-3, 1975.

* * * * * *

Thomas N. Freeman (1911-1975), for 39 years Taxonomist with the Systematic Entomology Unit (now Biosystematics Research Institute), Ottawa, died May 15, 1975 in an Ottawa Hospital. An obituary, prepared by W. C. McGuffin, was published in the Bulletin, Entomological Society of Canada 7 (4): 95, 1975, provides further information about his life and contributions to our knowledge of the Microlepidoptera.

* * * * * *

Hedley G. James (1902-1975), entomologist with the Dominion Parasite Laboratory at Belleville for 37 years, died on June 4, 1975 after a brief illness. The Bulletin, Entomological Society of Canada 8 (1): 19, 1976 contains an obituary of this scientist and friend, prepared by a colleague, M. G. Maw.

* * * * * *

H. Eldon Scott (1916-1975), former Extension Entomologist for North Carolina, died on September 18, 1975 in Raleigh, N.C.

Scottie was born at Carp, Ontario and received his early education there. In 1941, he graduated from the Ontario Agricultural College. From the fall of 1941 to 1948 he served as Instructor in the Department of Entomology and Zoology there and during the growing seasons conducted studies on the carrot rust fly at the Muck Crops Research Station, Bradford Marsh. In 1948, he transferred to Science Service of the Canada Department of Agriculture at Ottawa. While here, leave-of-absence enabled him to complete the requirements for the Ph.D. at Cornell University. In 1953, he accepted a position as Extension Entomologist at North Carolina State University. With the exception of four years with the American Cyanamid Company in New Jersey, he remained at Raleigh until his death.

Eldon "left deep tracks across this State (North Carolina)" in the lives and character of young people, growers and others, who have been won by his smile and inspired by his concern for their success, and his integrity in work and attitude.

During his professional career, Eldon served a term as President of the North Carolina Entomological Society, and also on the Governing Board of the Entomological Society of America.

Dr. Scott leaves his wife, Hilda, and family of five daughters and two sons in Raleigh, N.C. at 1427 Ridge Road, 27607. Two of the daughters are married and one son, John, is on his own.

Stanley G. G. Smith (1909-1975), who until retirement in February 1974, had been Head of the Cytology and Genetics Section, Canadian Forestry Service, died May 12, 1975, while on holiday in London, England. Dr. Smith was one of the founding members of the Genetics Society of Canada and served as its first President.

Dr. Smith was born in Morden, England in 1909. Emigrating to Canada in 1930, he received his B.Sc. from McGill in 1934. Postgraduate studies under the direction of C. L. Huskins dealt with the cytogenetics of speltoid and compactoid wheats.

What was to become a lasting association with Entomology began in 1937, when he contracted with the Dominion Department of Agriculture to investigate the cytotaxonomic status of the introduced European Spruce Sawfly. This study took him to University College, London, for a year. On his return to Canada he alternated between McGill and the Department of Agriculture until 1945, when he moved with the Department to the newly established Forest Insect Laboratory in Sault Ste. Marie. In 1952, he was appointed Head of the Cytology and Genetics Section, and held that position until his retirement. He resisted any attempt to elevate him into administration, a human pursuit he tolerated only under duress.

His active career spanned more than 40 years, and his over 80 publications mirror the tremendous growth and change in Cytogenetics during that time. His range of interest is best indicated by an excerpt from a description he wrote of the scope of study of his Section: "cytotaxonomy and cytogenetics of beetles, moths, and sawflies; chromosome structure; chromosome mechanics, evolutionary pathways; population genetics of forest insects". His attention increasingly turned towards the cytogenetics of Coleoptera, particularly of *Pissodes* and *Chilocorus,* earning for him an international reputation in that field. His productivity was undiminished by retirement: at the time of his death he was nearing completion, in coauthorship with Dr. Niilo Virkki, of a definitive text on the Cytogenetics of Coleoptera.

As a world-wide retinue of cytologists and entomologists will attest, Dr. Smith freely offered stimulating suggestions, co-operation, encouragement, and when he felt it warranted, sharply aimed criticism. Never a man to change his ideas easily, or to be the least bit reticent in advancing those ideas, his sharply honed wit concealed a deeply personal man who judged man and ideas with equal austerity. Those who braved the initial test, and many did, found a man generous of his time for guidance and advice in scientific matters, and intensely loyal to his friends. He greatly valued intelligence, integrity, and industry; possession of these attributes along with a polished sense of humour and a moderately thick skin, was rewarded with the friendship of an open and generous man. These qualities, and an active inquisitive mind, will be sincerely missed by his friends and associates.

For further details, refer to Bulletin 7 (1), The Genetics Society of Canada.

Eric B. Watson (1898-1975), forest entomologist, at retirement with the Forest Entomology and Pathology Branch of the Department of Forestry, Ottawa, died suddenly in Breckenridge, Quebec, on May 18, 1975. For further information refer to the Bulletin, Entomological Society of Canada 7 (4): 96, 1975 for an obituary written by Dr. M. L. Prebble.

II. SUBMITTED PAPERS

RELATIONSHIPS BETWEEN HATCHING OF EGGS OF EUROPEAN RED MITE AND FRUIT BUD DEVELOPMENT IN ONTARIO PEACH AND APPLE ORCHARDS

D. H. C. Herne and Robert Trottier

Agriculture Canada, Research Station, Vineland Station, Ontario L0R 2E0

Abstract

In the Niagara Peninsula of Ontario, peach (cv. Elberta) bud development ranged from green tip to full bloom at the time of first hatch of overwintered eggs of *Panonychus ulmi* (Koch). In various apple growing regions, apple (cv. McIntosh) bud development ranged from green tip to pink at time of first egg hatch. The time from first egg hatch to bloom ranged from 5 to 14 days on apple, while first hatch usually occurred after bloom on peach. The timing of early acaricide sprays based on this relationship is discussed.

* * * * * *

Introduction

The development of successful pest management programs is often limited by the lack of reliable monitoring methods and indices for indicating the need for pesticide applications. In recent years, studies have been undertaken in Ontario to develop such methods and to reassess the validity of phenological indices for timing the pre-bloom acaricide application to fruit trees in southern Ontario.

The following report is based on observations during the past 25 years in Ontario, of the phenological relationship between the development of overwintered eggs of the European red mite, *Panonychus ulmi* (Koch), and fruit bud development of apple and peach. The timing of early acaricide sprays based on this relationship is discussed.

Methods

From the last week in April each year overwintered eggs of European red mite (ERM) were examined in peach and apple orchards and the stage of embryonic development related to fruit bud development. These observations were made in peach orchards (cv. Elberta) in the Vineland and Queenston areas of the Niagara Peninsula between 1949 and 1973, in apple orchards (cv. McIntosh) at Brighton, Northumberland County, from 1960 to 1969. Similar observations were made in all major apple growing areas of Ontario in 1969 with the cooperation of Ontario Ministry of Agriculture and Food extension horticulturists (Fig. 1). Egg masses on the main scaffold limbs in the southern quadrant of each tree sampled were examined for first egg hatch. Small shoots on these limbs were also examined for larvae or nymphs. In the Vineland area the time for development of the first generation (ERM) from egg hatch to ovipositing adults was also determined in peach orchards.

Data were collected from the same cultivars and orchards each season; the orchard locations were selected to represent different climatic areas.

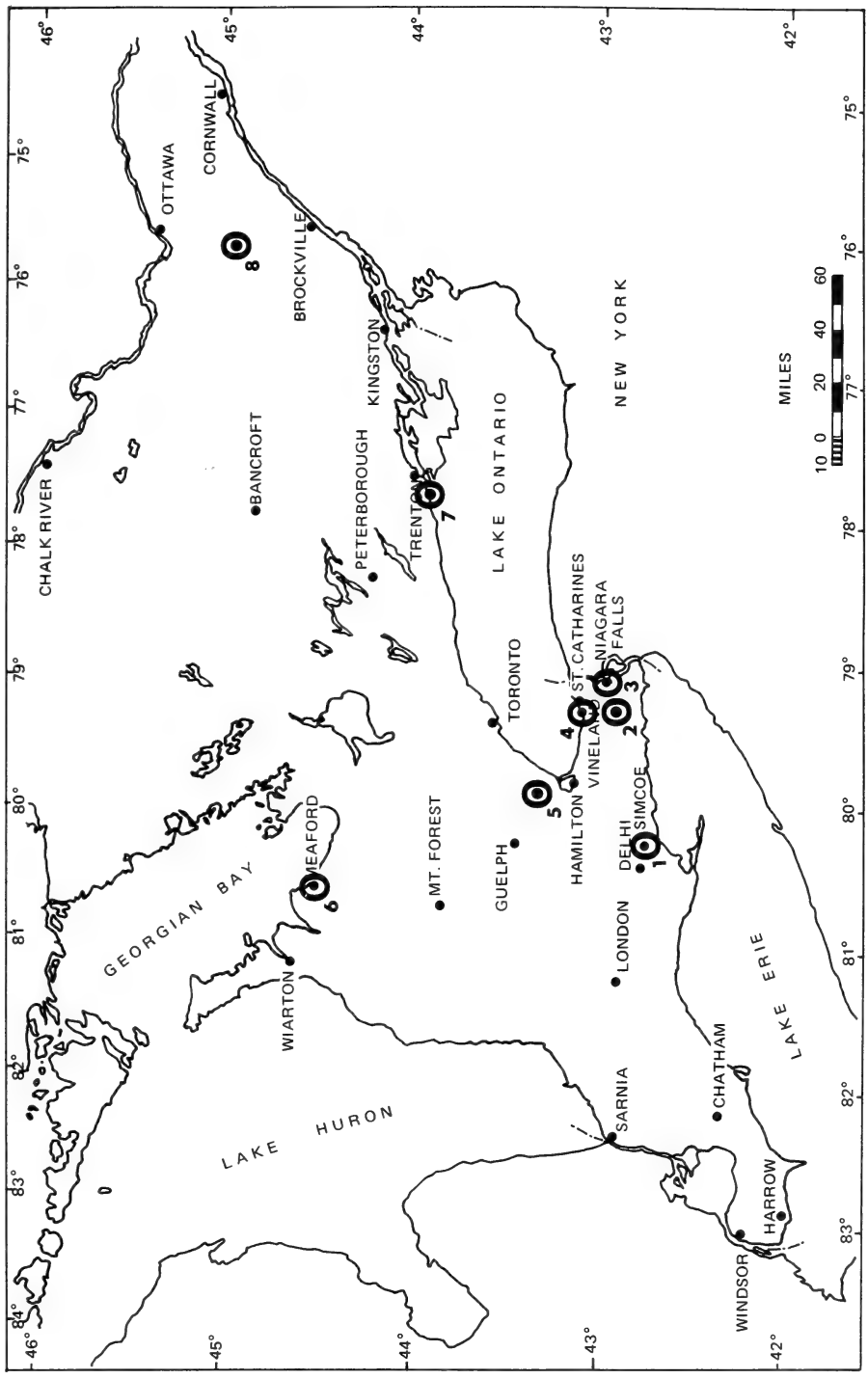

FIGURE 1. Sample orchard locations in southern Ontario: 1. Simcoe; 2. Fonthill; 3. Queenston-St. Davids; 4. Vineland-Jordan; 5. Milton; 6. Georgian Bay, Meaford; 7. Northumberland County, Brighton; 8. Kemptville.

The stages of fruit bud development were classified as green tip, ½ inch green, tight cluster, pink, bloom (Fruit Production Recommendations, O.M.A.F. Publication 360).

Results

Peach Orchards

In the Vineland area wide variation was observed in the relationship between fruit bud development and first hatch of the overwintered eggs of *P. ulmi*. In 1955, 1960, 1972 the buds were in the pink stage at first hatch, while in 1951, 1957, 1967 they were in first bloom, and in 1949, 1950, 1959 they were in full bloom. The date of first hatch ranged from April 30 to May 17 in the Vineland area and the date of first bloom ranged from May 1 to May 10.

From 1969 to 1973 the date of first hatch was 2 to 6 days earlier in the Queenston area than in the Vineland area of the Niagara Peninsula (Table I) due to the cooling effect of Lake Ontario on the Vineland orchards. Peach bud development varied from green tip to full bloom at first hatch in both areas, but the

TABLE I. Hatching dates of *P. ulmi* overwintered eggs and peach bud development (cv. Elberta) in two regions of Niagara Peninsula.

Year	Peach bud stage (date of 1st egg hatch)			
	Jordan - Vineland		Queenston - St. Davids	
1969	Green tip	(May 2)	Green tip	(Apr. 30)
1970	Pink	(May 4)	5% Bloom	(May 2)
1971	First Bloom	(May 14)	5% Bloom	(May 12)
1972	Early Pink	(May 15)	Early Pink	(May 12)
1973	20% Bloom	(May 2)	Full Bloom	(Apr. 27)

buds were always more advanced at Queenston than at Vineland on the same dates. In some years, however, there was less difference in time of hatch than in the stage of bud development between the two areas.

Usually all the overwintered eggs hatched within a 2-week period but in 1973 hatching extended over a 3-week period. Indeed in 1973 overwintered eggs and larvae, and second generation eggs and larvae were observed on peach foliage on May 29.

In the Vineland area the number of days required for ERM to develop from newly-hatched larvae to ovipositing adults in the 1st generation varied from 12 to 34 with a 12-year average of 22 days (Table II). Furthermore, much variation was observed between years, in the stage of tree development at the time second generation immature stages occurred.

Apple Orchards

In Brighton-Northumberland County during 10 years of observation the date of first hatch ranged from May 1 to May 21. The number of days between first egg hatch and full bloom ranged from 5 to 14 days (Table III). The correlation between fruit bud development and first hatch was good in this region of Ontario, however, ranging from early pink to full pink in most years.

In 1969 the date of first egg hatch varied greatly among the major apple growing areas (Table IV), occurring on April 30 at Queenston and on May 21 at Kemptville. However, McIntosh bud development was at about the same stage in all areas at the time of first hatch.

TABLE II. Days for development of 1st generation *P. ulmi* on peach (cv. Elberta) from hatch of overwintered eggs to ovipositing adult during several seasons in the Vineland area.

Year	Date of 1st egg hatch (peach bud stage)	Hatch to adult female (Days)	Hatch to ovipositing adult (Days)
1955	Apr. 30 (Pink)	8	12 (May 12)
1959	May 13 (Full Bloom)	11	15 (May 28)
1971	May 14 (First Bloom)	15	17 (May 31)
1960	May 8 (Early Pink)	15	18 (May 26)
1972	May 15 (Early Pink)	15	18 (June 2)
1961	May 14 (15% Bloom)	15	19 (June 2)
1957	May 1 (First Bloom)	15	26 (May 27)
1973	May 2 (20% Bloom)	23	27 (May 29)
1969	May 2 (Green Tip)	31	34 (June 5)

TABLE III. Apple bud development (cv. McIntosh) at time of first hatch of *P. ulmi* overwintered eggs in Northumberland County, 1960-69.

Year	Apple bud stage (date of 1st egg hatch)		No. of days to full bloom
1969	Tight cluster	(May 8)	14
1968	Early pink	(May 1)	9
1962	Early Pink	(May 5)	9
1964	Early Pink	(May 7)	6
1960	Early Pink	(May 10)	13
1961	Early Pink	(May 15)	7
1967	Early Pink	(May 21)	10
1964	Pink	(May 9)	9
1965	Pink	(May 12)	5
1966	Pink	(May 20)	5

TABLE IV. Hatching dates of *P. ulmi* overwintered eggs, and apple bud development (cv. McIntosh) in 1969 in Ontario apple growing regions.

Region	Apple bud stage	Date of 1st egg hatch
Milton	Green Tip	May 4
Jordan	Half-inch Green	May 2
Queenston-St. Davids	Tight Cluster	Apr. 30
Simcoe	Tight Cluster	May 2
Fonthill	Tight Cluster	May 5
Vineland	Tight Cluster	May 6
Northumberland County (Brighton)	Tight Cluster	May 8
Georgian Bay (Meaford)	Tight Cluster	May 15
Kemptville	Tight Cluster	May 21

Discussion

During the early 1960's it was generally recommended that the first acaricide spray be applied at pre-bloom to fruit trees in southern Ontario for early season control of the European red mite. This recommendation was based on observations that some overwintered eggs hatched prior to bloom on most fruit trees. However, it is evident from the data in Table II that in those years most eggs hatched after bloom in peach orchards. Hence a post-bloom spray would have been more effective than the pre-bloom spray. Furthermore, under conditions of extended hatch

(e.g. in 1973) a post-bloom acaricide spray would be more effective than the pre-bloom application. A post-bloom spray is most effective if timed against peak numbers of immature stages (Herbert, 1970) but clearly the use of peach bud development as the index for timing the spray is not reliable. On the other hand data in Table III suggests that the pre-bloom acaricide spray on apple would have been generally effective because most of the overwintered eggs had hatched at the time of application.

While the trend, in orchards under pest management, is to apply summer sprays only when mite numbers reach critical levels, it may still be necessary to reduce heavy 1st generation populations to manageable numbers. To optimize acaricide applications a more accurate prediction method is required. It is well known that abiotic factors such as temperature and rainfall influence ERM development (Herne, 1968). Bioclimatic indices relating ERM development and weather information are currently being developed at Vineland Station.

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BIOLOGY OF *BATHYPLECTES CURCULIONIS* (THOMSON) (HYMENOPTERA:ICHNEUMONIDAE) A PARASITOID OF THE ALFALFA WEEVIL IN ONTARIO[1]

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Abstract

Populations of *Bathyplectes curculionis* (Thomson) and the alfalfa weevil, *Hypera postica* (Gyllenhal), were monitored by sweep nets from May to August of 1974 and 1975 at Elora, Ontario. Emergence of the first brood of *B. curculionis* from overwintered cocoons, coincided with the initial increase of the population of the host larvae. However, the populations of the adult parasitoid remained low throughout the season because diapause was high among the first-generation larvae of the parasitoid. Parasitism was only 6.3 - 33.3% at the peaks of the host populations, but increased to 60 - 68% later in the season when host populations were lower. The higher percentage parasitism, later in the season, helped to reduce the population of the summer adults of the pest. Overwintering mortality was also significantly less for those parasitoids that went into diapause later in the season so these individuals contributed significantly to the population of the following spring. In 1973, 22.4% of *B. curculionis* were attacked by four species of hyperparasitoids; *Gelis* spp. (12.7%), *Eupteromalus viridescens* (Walsh) (6.9%), *Pteromalus* sp. (2.2%) and *Eupelmella vesicularis* (Retzius) (0.6%).

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[1] Supported in part by N.R.C. Grant No. A6500.

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Introduction

Bathyplectes curculionis (Thomson) is an important parasitoid of the larvae of the alfalfa weevil, *Hypera postica* (Gyllenhal), a major insect pest of alfalfa in Ontario and other parts of North America. In the eastern United States, *B. curculionis* had one complete generation and a partial second generation per season. Most of the second-generation larvae of the parasitoid entered diapause (Brunson and Coles, 1968) and overwintered within cocoons on the ground. The performance of *B. curculionis* in the United States has been hampered by a number of adverse factors, viz—: encapsulation of the parasitoid's eggs by the host (van den Bosch, 1964; Puttler, 1967), hyperparasitism (Puttler, 1966; Day, 1969; Pike and Burkhardt, 1974), high overwintering mortality (Armbrust *et al.,* 1972) and predation by invertebrates (Cherry and Armbrust, 1975). Although the biology of *B. curculionis* is well known in the eastern United States, there are no comparable reports from Ontario. In this paper, we report host-parasitoid synchrony, overwintering mortality and hyperparasitism of *B. curculionis* in Ontario.

Materials and Methods

All developmental stages of the alfalfa weevil and the parasitoid were maintained in the laboratory at 25° ± 2°C, 12-hour photoperiod, and 70 ± 5% RH. An alfalfa field at the Ont. Ministry of Agric. Research Station at Elora, Ontario, was sampled weekly with a 15-inch diameter net (Davis, 1970), from May to August of 1974 and 1975. The percentage parasitism was determined by rearing field-collected third- and fourth-instar larvae (Davis, 1970) in 20 x 12 x 12 cm plastic cages with screen lids. Approximately 50 larvae were caged on bouquets of alfalfa that were changed every 2 days. *B. curculionis* cocoons obtained from rearing were placed on moist filter papers within plastic cages and sprayed with water twice a week. Non-diapausing *B. curculionis* usually emerged 8-12 days after pupation.

In 1974, the cocoons of parasitoids that had not emerged by October 1 were examined and those without visible signs of deformity were counted, put on soil within plastic petri dishes and placed in an alfalfa field at Elora until May 1, 1975. The 6 x 2 cm petri dishes had openings top and bottom for normal movement of water. These were covered with 34-mesh screen. The screen tops of the petri dishes were removed during January to March when there was continuous snow cover. The cocoons were recovered on May 1, by washing the soil through a standard 34-mesh seive. Emergence of adult *B. curculionis* was recorded daily and parasitoids that had not emerged by June 20 were assumed to be dead.

Hyperparasitism of *B. curculionis* was determined from cocoons of the parasitoid that were hand-picked from alfalfa foliage during July 11-19, 1973 and retained in the laboratory for emergence of *B. curculionis* and hyperparasitoids. The remaining cocoons containing diapausing *B. curculionis* were used to assess overwintering mortality as described.

Results and Discussion

Generally, the changes in the populations of the host and the parasitoid as well as percentage parasitism by *B. curculionis* were similar in the two years (Fig. 1). The numbers of weevil larvae were less than 10 per 100 sweeps until the end of May. Thereafter, the population increased sharply and reached maxima in the last week of June. The peak of the host population in 1974 (197 larvae per 100 sweeps), was higher than that of 1975 (175 larvae per 100 sweeps) (Fig. 1). Larval numbers per 100 sweeps declined to less than 20 within four weeks and then decreased gradually to less than 10 for the remainder of the season. Adults

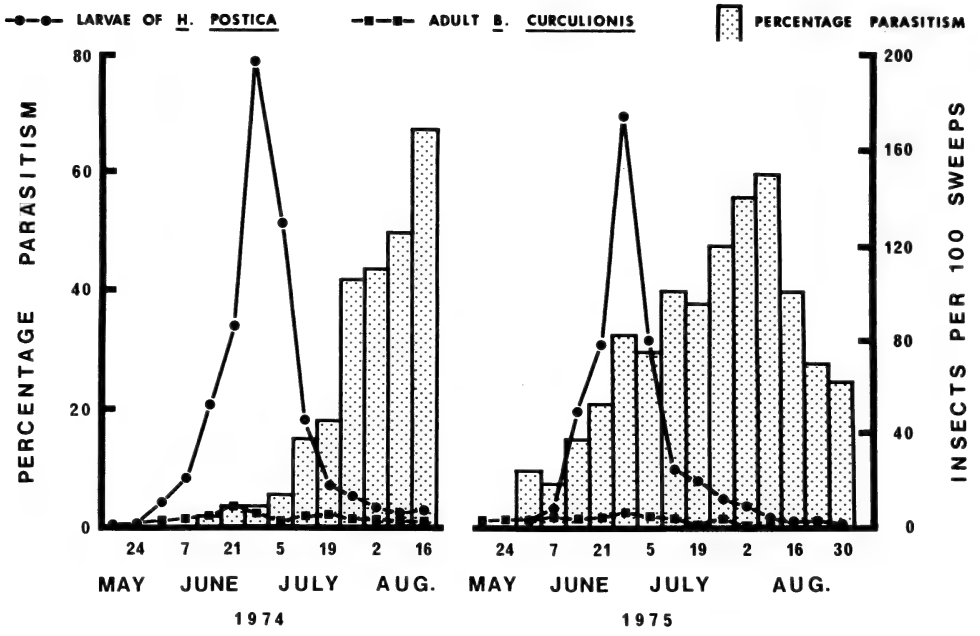

FIGURE 1. Parasitism of larvae of *Hypera postica* by *Bathyplectes curculionis* at Elora, Ontario in 1974 and 1975.

of *B. curculionis* were found in the samples from the end of May to mid-August, coinciding with populations of the host, but there was no marked increase in the percentage parasitism until July when host populations declined.

Rearing 3rd- and 4th-instar larvae from weekly samples showed that 33.3-100% of the parasitoids obtained entered diapause (Table I). In both years, diapause was more than 70% among parasitoids collected after June 15 and somewhat less earlier in the season. The high incidence of diapause, early in the season, was responsible for the minimal increase in the numbers of adult *B. curculionis*. Diapause prior to June 7 was particularly detrimental because these parasitoids could have emerged in time to affect the rising host populations. This re-

TABLE I. Dates when larvae of *Hypera postica* were collected at Elora, Ontario, and percentage of diapausing *Bathyplectes curculionis* obtained.

Date of Collecting Larvae of *H. postica*	% of *B. curculionis* in Diapause		
	1974	1975	Mean ± SD
June 7		33.3	
14	70.0	60.0	65.0 ± 7.1
21	80.0	74.0	77.0 ± 4.2
28	95.5	87.7	91.6 ± 5.5
July 5	84.7	80.0	82.4 ± 3.3
12	100.0	78.0	89.0 ± 15.6
19	93.8	75.2	84.5 ± 13.2
26	75.0	90.0	82.5 ± 10.6
August 2	90.0	82.4	86.0 ± 5.7
9	90.6	78.0	84.3 ± 8.9
16	100.0	95.0	97.5 ± 3.5

lationship between *B. curculionis* and *H. postica* is similar to that observed in the eastern United States (Blickenstaff *et al.* 1972). The increase in percentage parasitism after June was due to a lower host: parasitoid ratio resulting from the natural decline in the host populations.

Data could not be obtained on the overwintering mortality of *B. curculionis* that went into diapause prior to June 20 because insufficient parasitoid cocoons were available. This was due to the minimal parasitism during the early spring. Parasitoids emerged from 39 - 75% of the overwintered cocoons; mean = 57.7 ± 14.4 (Table II). Emergence of adult parasitoids began 5-7 days after the cocoons had been returned to the laboratory and ceased by the 20th day, with most of the emergence occurring between the 7th and 10th day. Mortality was highest among parasitoids that entered diapause in late June and decreased as the summer progressed. These observations, generally agreed with those of Armbrust *et al.* (1972) in Illinois. In late June of 1974 (June 21-28), 80 - 95.5% of the parasitoids diapaused (Table I) but 60 - 61% of these parasitoids failed to emerge after the winter (Table II). Considerable selection pressure for late diapause is evident but there are probably too few summer hosts available to affect a change. Probably

TABLE II. Dates when larvae of *Hypera postica* were collected from Elora, Ontario, in 1974, number of cocoons of *Bathyplectes curculionis* obtained and percentage emergence after overwintering.

Date of Collecting Larvae of *H. postica*	No. of Cocoons of *B. curculionis* overwintered*	% Emergence
June 21	100	40.0
28	100	39.0
July 5	100	51.0
12	100	48.0
19	100	56.0
26	100	63.0
August 2	100	73.0
9	87	74.7
16	36	75.0
Total	823	Mean 57.7 ± 14.4

* Cocoons were overwintered in field cages from October 1, 1974 to May 1, 1975.

part of the mortality of early diapaused cocoons was due to prolonged exposure to high summer temperatures (Casagrande and Stehr, 1973). Incidence of diapause was higher in August (Table I), and a large proportion of the parasitoids that entered diapause during this time survived the winter (Table II). Higher percentage parasitism in the late season also reduced the population of the summer adult weevils and therefore should lower weevil infestations the following year.

Out of 361 cocoons of *B. curculionis* hand-picked from alfalfa foliage during July, hyperparasitoids emerged from 81 (22.4% (Table III). Four species were found; *Gelis* spp. (12.7%), *Eupteromalus viridescens* (Walsh) (6.9%), *Pteromalus* sp. 2.2%) and *Eupelmella* (=*Macroneura*) *vesicularis* (Retz.) (0.6%). Only *Gelis* spp. emerged from cocoons after overwintering in the field cages. In earlier studies at Guelph in 1972 we also reared a few specimens of *Spilochalcis albifrons* (Walsh), *Itoplectis conquisitor* (Say), *Habrocytus* sp., *Eupelmus* sp. and *Agrothereutes* sp. (probably *A. abbreviator similaris* (Prov.)) from field collected cocoons of *B. curculionis*. All of these species have been previously listed as para-

sitoids of *B. curculionis* in North America (Pike and Burkhardt, 1974) except *Pteromalus* sp., *Eupelmus* sp., *Itoplectis conquisitor,* and *Agrothereutes* sp.

TABLE III. Species of hyperparasitoids reared from cocoons of *Bathyplectes curculionis* collected from Elora, Ontario.

Hyperparasitoids[1]	*B. curculionis* coccons parasitized		
	No.	% of Total[2]	% of No. Parasitized
Gelis spp.	46	12.7	56.8
Eupteromalus viridescens (Walsh.)	25	6.9	30.8
Pteromalus sp.	8	2.2	9.9
Eupelmella vesicularis (Retzius)	2	0.6	2.5
TOTAL	81	22.4	100.0

[1] Determined by C. M. Yoshimoto, Entomology Research Institute, Agrciulture Canada, Ottawa, Ontario.
[2] 361 cocoons were hand-picked from alfalfa foliage during July 11-19, 1973.

Acknowledgements

The authors extend their thanks to J. R. Barron, M. Ivanochko and C. M. Yoshimoto of the Entomology Research Institute, Ottawa for identification of hyperparasitoids.

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EFFECT ON NON-TARGET ORGANISMS OF FIELD APPLICATIONS OF CARBOFURAN FOR CONTROL OF *HYPERA POSTICA* (COLEOPTERA: CURCULIONIDAE)

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Abstract

Pest, parasite and predator populations were monitored for two years on alfalfa sprayed or non-sprayed with carbofuran. No pest species, including *Acyrthosiphon pisum* (Harris), *Philaenus spumarius* (L.), *Empoasca fabae* (Harris) and *Adelphocoris lineolatus* (Goeze) increased in numbers in carbofuran-sprayed areas. By October neither 2 oz nor 8 oz AI/acre applied as a foliar application the previous June, had a significant effect on any pest, parasite or predator population. It is concluded that 2 oz AI/acre of carbofuran applied for weevil control is not likely to result in secondary pest problems.

* * * * * *

Introduction

Alfalfa supports a diverse insect fauna (Wheeler, 1971) including several potential insect pests and their predators and parasites. A pest management program to control the alfalfa weevil, *Hypera postica* (Gyllenhal), must consider these other pest species and their natural enemies. Although carbofuran provided the best control of the alfalfa weevil (Davis 1970; Summers *et al.* 1971) it is broad spectrum and expected to effect non-target organisms. Surgeoner and Ellis (1976) reported on the effect of carbofuran on the alfalfa weevil and its parasitoids. In this paper we report on the effect of carbofuran on non-target pests and their parasites and predators in alfalfa. These populations were monitored for two years on alfalfa sprayed or non-sprayed with carbofuran.

Materials and Methods

The alfalfa fields were located at the Ontario Department of Agriculture and Food Research Station at Elora and were managed as previously described (Surgeoner and Ellis 1976). A Hanson boom sprayer with an agitator was used to apply 30 gals. of spray/acre at a pressure of 50 psi. Two 1 acre plots were sprayed on 17 June 1971 with 8 oz and on 19 June 1972 with 2 oz carbofuran AI/acre (Furadan® 4.8 Flowable). Two additional 1 acre plots were the non-sprayed controls.

All plots were sampled weekly in 1971 from 25 May to 5 Oct. A sample consisted of 25 sweeps with a 15 inch diameter net swung through a 180° arc Blickenstaff, 1966). In 1972 samples were taken on a square foot basis as recommended by Armbrust *et al.* (1969).

Results and Discussion

Aphididae and their parasitoids

The pea aphid, *Acyrthosiphon pisum* (Harris) comprised > 97% of the aphid population in this study. This insect was recorded as a pest of Ontario alfalfa by Guppy (1958). Although pea aphids can be collected throughout the growing season, peak populations occurred after mid-June (Guppy, 1958). Aphid populations were greatest during late June in 1971 (Fig. 1A), and mid-July in 1972 (Fig. 2A). A foliar application of 8 oz AI/acre of carbofuran in mid-June

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1971 caused a significant reduction in pea aphids (Fig. 1A). However, numbers of aphids in sprayed and non-sprayed plots equalized by mid-July.

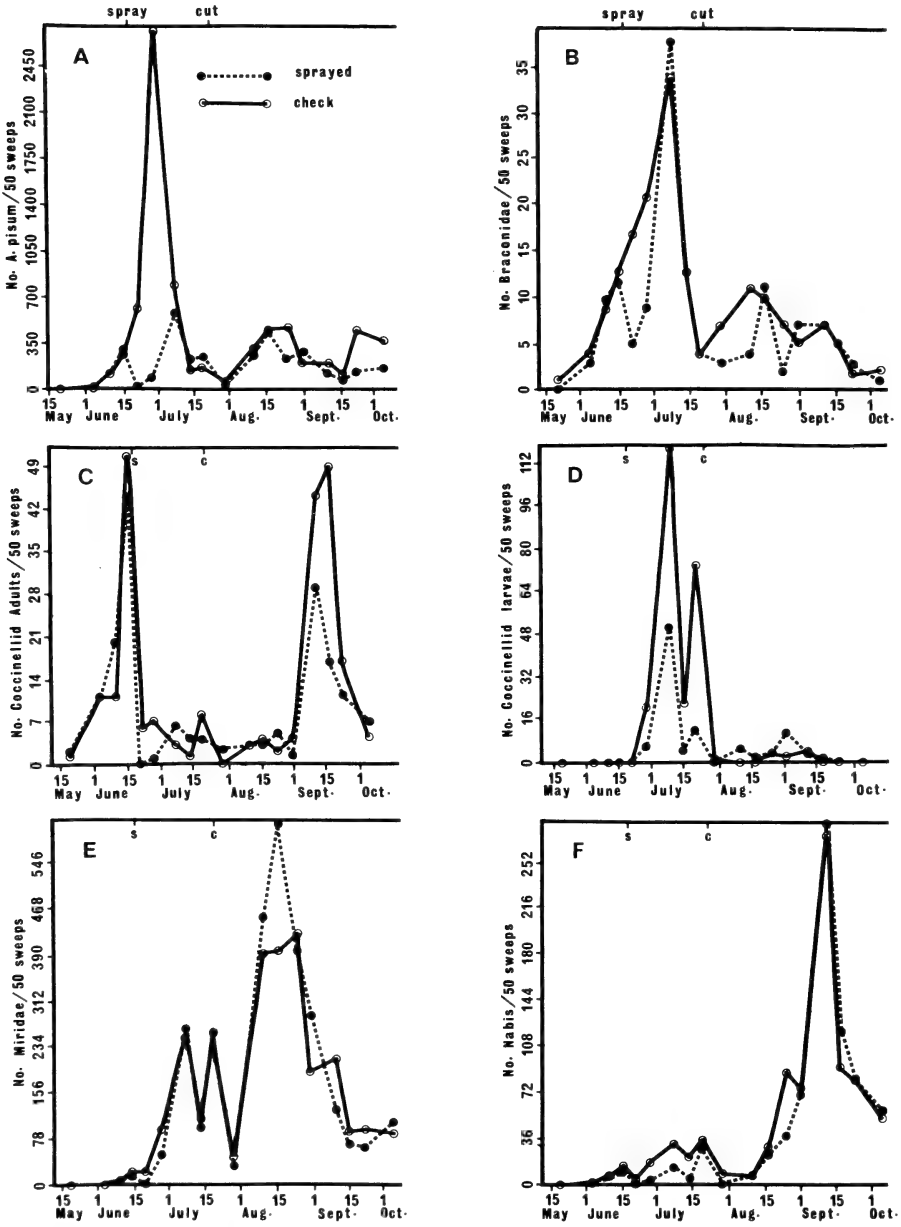

FIGURE 1. Numbers of insects collected per 50 sweeps carbofuran (8 oz AI/acre) sprayed and non-sprayed alfalfa fields at Elora, Ont. 1971: A—*Acyrthosiphon pisum;* B—Braconidae; C & D—adult and larvae Coccinellidae, respectively; E—Miridae; F—Nabidae.

In 1972, carbofuran at 2 oz AI/acre reduced aphid populations by 77% (Fig. 2A). As in 1971, however, populations in sprayed and non-sprayed areas

equalized by mid-July. The cutting of 12 July caused a high mortality of aphids or initiated movement to other crops (Fig. 2A).

Davey and Manson (1958) found that populations of aphids increased significantly in perthane-, toxaphene-, and heptachlor-treated plots of alfalfa and sug-

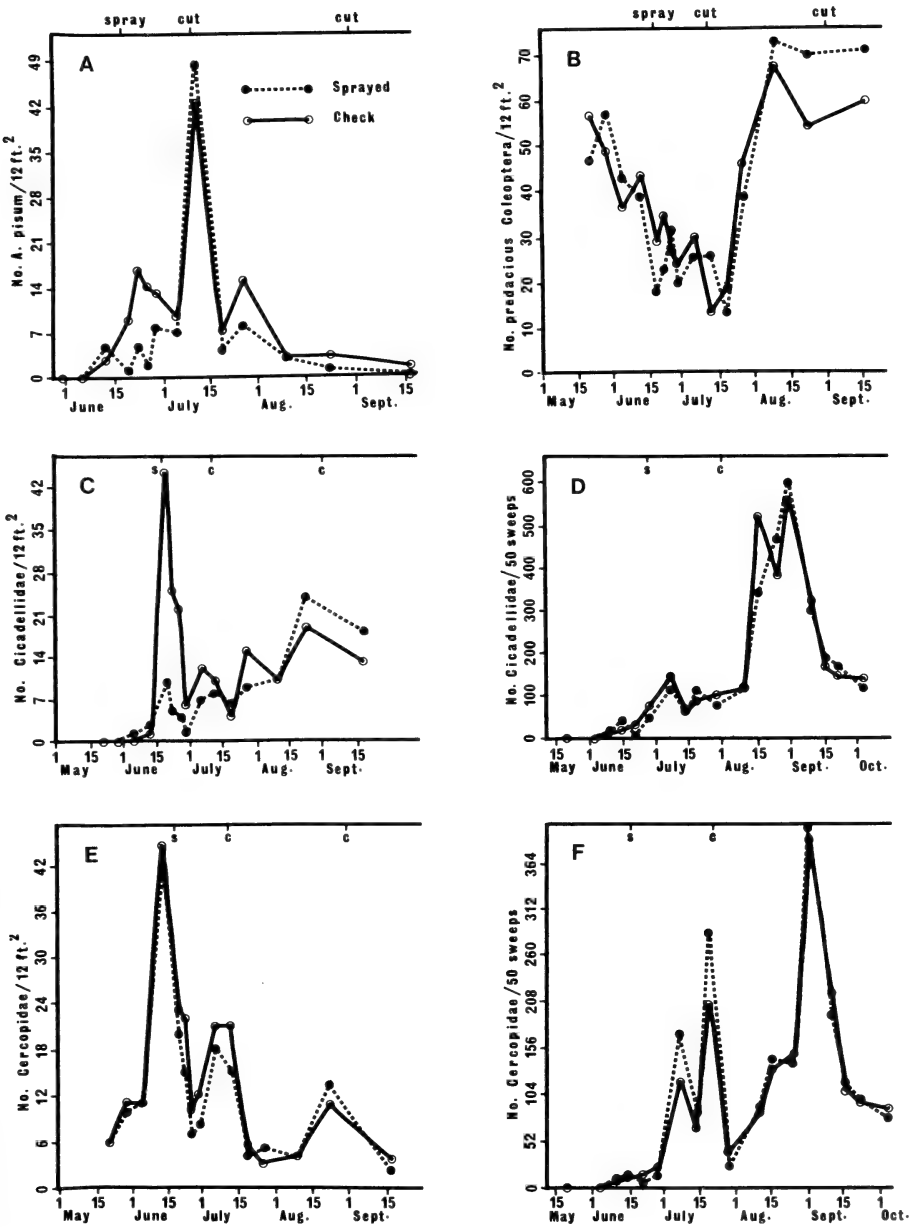

FIGURE 2. Numbers of insects collected from carbofuran sprayed and non-sprayed alfalfa fields at Elora, Ont.: A, B, C and E—carbofuran 2 oz AI/acre, 1972, *Acyrthosiphon pisum*, Predacious Coleoptera, Cicadellidae, and Cercopidae per 12. 1 ft² areas, respectively; D and F—carbofuran 8 oz AI/acre, 1971, Cicadellidae and Cercopidae per 50 sweeps, respectively.

gested that the increase was due to destruction of predators and parasites of the aphid. In this study, carbofuran reduced aphid numbers but did not change population trends. This and similar results obtained by Pass and Parr (1971) with 1 lb carbofuran/acre can be explained by the effective control of aphid populations by carbofuran (Fig. 1A and 2A) and recovery of parasite and predator populations (Fig. 1B, C, D, and F).

Braconidae

In 1971, the predominate species collected in swept-net samples included *Aphidius ervi pulcher* Baker, *Praon occidentale* Baker, and *P. simulans* Viereck which have been described as parasites of the pea aphid (Mackauer and Finlayson 1967). Populations of Braconidae declined 63% immediately following application of 8 oz AI/acre of carbofuran (Fig. 1B). Re-distribution was rapid and 18 days after treatment populations did not differ significantly. That this dosage of carbofuran had a minimum effect on parasitism of *A. pisum* was confirmed the following spring by counting the number of 'mummies' formed by overwintering parasites (Fig. 3). From three sample dates, the mean number of parasitized *A. pisum* per six, square-foot samples in sprayed areas was 6.5 $\pm$ 1.87 as compared to 8.3 $\pm$ 2.05 in non-sprayed areas. These means were not different (5% level). The overwintered parasites included *A. ervi pulcher* Baker (ca. 95%) and *P. occidentale* Baker (ca. 5%).

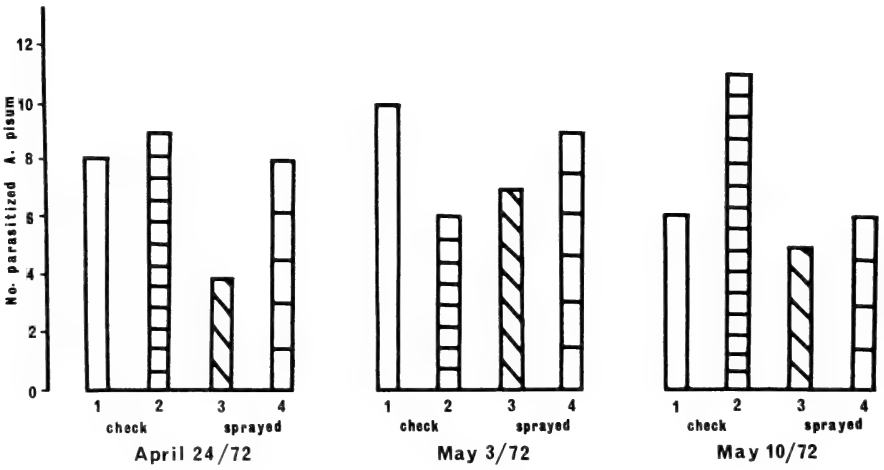

FIGURE 3. Mean number of overwintering parasites of *A. pisum* per 6 ft^2 in areas sprayed with carbofuran 8 oz AI/acre and areas non-sprayed.

Cicadellidae

The predominate species of Cicadellidae recovered in 1971 and 1972 were *Empoasca fabae* (Harris), *Macrosteles fascifrons* (Stal) and *Athysanus argentarius* Metcalf. *E. fabae* comprised ca. 60% of the cicadellid population with maximum numbers in late August and September (Fig. 2D). On 22 June 1971, four days after spray application, the numbers were 70% lower in sprayed areas but re-established by 15 July. In 1972, populations reached a maximum during late June (Fig. 2C) and carbofuran (2 oz AI/acre) caused an 82% reduction. Within 25 days numbers in sprayed and non-sprayed areas were not different. Carbofuran at 2 oz or 8 oz AI/acre in June had no effect on population trends in

August and September. Davey and Manson (1958) also found that populations of *E. fabae* re-established in insecticide treated plots within two weeks and they attributed this to rapid re-infestation from non-sprayed areas.

Cercopidae

The cercopoid most frequently collected in both 1971 and 1972 was *Philaenus spumarius* (L.). Davey and Manson (1958) reported that this species was a pest of alfalfa in Ontario, and Guppy (1958) found that the last nymphal stage occurred in early June, and adults from late June onward with peak abundance in July and August. Populations in carbofuran sprayed and non-sprayed foliage were not different in 1971 (Fig. 2F). Dondale (1972) observed similar results and suggested this was due to protection derived from spittle masses. We confirmed this by caging nymphs on foliage treated with 2 oz AI of carbofuran/acre. Mortality of these unprotected nymphs on treated foliage was 96% as compared to 8% on non-treated foliage.

Coccinellidae

Coleomegilla maculata (DeGeer) comprised ca. 70% of the Coccinellidae and *Coccinella transversoguttata* Faldermann, *Hippodamia tredecimpunctata* (Say) and *C. trifasciata* Mulsant the remaining 30%. These species are all preferential predators of the pea aphid although alfalfa weevil larvae and leafhopper nymphs may be consumed (Yadava and Shaw, 1968).

Populations of adults appeared in late May 1971 and increased until the middle of June as adults moved into the fields from overwintering sites. The population decline of adults in sprayed areas reached 100% as compared to 88% in non-sprayed areas. The decline in sprayed areas we attribute to insecticidal and natural mortality and the decline in non-sprayed areas to both natural mortality of overwintering adults and mortality due to movement into sprayed areas. Populations of adults were low during July and August but increased significantly during September due to emergence of new adults from larvae populations that were maximum during July (Fig. 1D). The fewer adults in sprayed areas (Fig. 1C) in September were attributed to a 60% lower larval population (Fig. 1D) in sprayed areas during July. This lower population possibly was due to insecticidal mortality of the larvae and a reduced population of the host, the pea aphid (Fig. 1A). Populations of Coccinellidae larvae (Fig. 1D) in both sprayed and non-sprayed areas peaked about the first week of July in response to host numbers.

Miridae

The predominate species of Miridae collected from alfalfa fields at Elora included *Adelphocoris lineolatus* (Goeze), *Lygus lineolaris* (Beauvois), *Leptopterna dolabrata* (L.) and *Plagiognathus chrysanthemi* (Wolff). All these species except *L. dolabrata* attacked alfalfa in eastern Ontario (Guppy, 1958). The alfalfa plant bug, *A. lineolatus,* comprised ca. 65% of the Miridae. Two population peaks of Miridae were observed (Fig. 1E). The first occurred during July and the second, larger peak during August. These two peaks corresponded to the nymphal populations of first- and second-generation of *A. lineolatus* as described by Guppy (1958). The population decline after 15 July resulted from the harvest of alfalfa on 22 July and the usual migration of adults to other crops.

Carbofuran at 8 oz AI/acre did not reduce populations significantly (Fig. 1E). Davey and Manson (1958) also found that populations of Miridae recovered rapidly after insecticide-treatment and they attributed this to reinfestation from non-sprayed areas.

Nabidae

Nabis ferus (L.) comprised > 97% of the population. Nabidae are considered predacious on many insect groups including Aphididae, Miridae, Cicadellidae, and lepidopterous larvae (Perkins and Watson, 1972). Population of *Nabis* sp. were reduced significantly during July (Fig. 1F), but were unaffected during peak populations in September. The decline in sprayed areas in July can be explained by insecticidal mortality of adults and by decline in host populations of Aphididae and Cicadellidae (Fig. 1A, and 2D).

Dondale (1972) observed that 8 oz carbofuran AI/acre had a similar effect on predatory Hemiptera.

Carabidae and Staphylinidae

The species most frequently collected were *Philonthus fuscipennis* (Mann.) (Staphylinidae) and *Amara familiarus Duftschmid* (Carabidae). In the laboratory *P. fuscipennis* fed on *H. postica* larvae but *A. familiaris* did not. Populations of Carabidae and Staphylinidae were unaffected by 2 oz of carbofuran AI/acre (Fig. 2B). Apparently 2 oz AI of carbofuran did not penetrate the crop canopy sufficiently to affect this edaphic fauna. This agrees with observations on the edaphic fauna by Dondale (1972) following application of 8 oz of carbofuran AI/acre.

Acknowledgements

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MONITORING AQUATIC INSECT POPULATIONS IN FOREST STREAMS EXPOSED TO CHEMICAL AND BIOLOGICAL INSECTICIDE APPLICATIONS

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Abstract

The methods employed in studies monitoring the effects of forest insect control programs on aquatic insects are outlined and their use illustrated. Surber sampling and drift netting in a river exposed to aerially applied *Bacillus thuringiensis* Berliner revealed no significant adverse effects on aquatic insects. Drift netting studies in a New Brunswick river revealed increases in the drift of aquatic insects and knockdown of terrestrial insects attributable to large-scale phosphamidon spraying.

* * * * * *

Large-scale insecticide applications to control forest pests have been carried out in Canada since 1952 when DDT spraying to control spruce budworm, *Choristoneura fumiferana* (Clem.) was started in New Brunswick. Concern about the effects of these operations on aquatic insect populations in the rivers and streams of forested regions has led to monitoring programs designed to determine the extent and nature of the impact of spray programs on stream insects. The Environmental Impact Section of the Chemical Control Research Institute has conducted programs of this type across Canada.

Methods Employed in Monitoring Studies

The methods employed in aquatic insect monitoring programs have changed little since the inception of such studies. The most widely used method has been to compare the kinds and numbers of organisms present before and after the insecticide application by taking foot square (approximately 0.1 m^2) Surber samples (Surber, 1936) from the same location at appropriate sampling intervals. The portion of stream bottom within a foot square frame is dug up in such a manner that the organisms within this area are dislodged from the substrate and swept into a net by the current. The contents of the net are usually preserved immediately and the insects from each sample sorted, counted and identified at a later date in the laboratory. The results from a number of separate Surber samples are averaged to give a mean value of the number of organisms present each time samples are collected. Changes in populations within treated streams are compared with changes found in untreated streams over the same period.

Another method used is the measurement of the drift of aquatic insects over a period beginning before the insecticide application and lasting until several days after treatment (Hoffman and Surber, 1948). Nets are placed in the current for a set period of time to determine the kinds and numbers of insects being swept down stream over that period. Increases in drift net catches following spraying indicate impact on the bottom fauna, and changes in the composition of the catch reveals the susceptibility of different aquatic insects to the insecticide applied. If the drift net is sampling the surface of the stream it will also indicate the extent and nature of any knockdown of adult aquatic and terrestrial insects caused by the treament. Drift netting is a much more sensitive method of detecting pesticide

effects than Surber sampling because it samples insects from a much larger area than a single square foot. It is therefore useful for determining the levels at which aquatic insect populations begin to be affected by insecticide applications.

Several other methods can be used in conjunction with Surber sampling and drift netting to study effects on aquatic insects. In streams where portions of the substrate consist of large stones, counts of the number of insects present on a set number of similar sized stones gives an indication of the nature of the bottom fauna present before and after spraying. Insect emergence traps of several types have also been used successfully in streams suitable for their use, to show insecticide effects revealed by reductions in adult emergence following treatment (Ide, 1957).

Monitoring programs must measure aspects of the aquatic system which may affect stream organisms during the treatment period. Changes in water temperature, stream discharge and various water chemistry parameters can alter the number of aquatic insects present on the stream bottom or drifting in the current. Insecticide concentrations in the stream water must be determined at the same time drift is sampled to relate effects on drift with spray programs.

The following case histories illustrate the use of some of these methods.

Bacillus thuringiensis — Ontario, 1973

In 1973, aquatic insect populations were monitored in a portion of the Opeongo River in Algonquin Park sprayed with a commercial preparation of *Bacillus thuringiensis*. These studies have been presented in detail in Buckner *et al,* 1974 and are briefly summarized here.

Changes in the bottom fauna populations as determined by Surber sampling at two treatment stations and in a control stream are shown in Fig. 1. Aquatic insect populations at treatment Station 1 declined steadily over the sampling period with stonefly (Plecoptera) and mayfly (Ephemeroptera) nymphal and caddisfly (Trichoptera) larval populations showing the greatest declines. The reductions in populations of these three orders were directly attributable to emergence of adults and this was supported by the increasing numbers of caddisfly pupae found on rocks and observations of swarming adults coinciding with the reductions in larval populations. Dramatic reductions in the aquatic insect populations at treatment Station 2 and the control station occurred before the spray application. These were attributable to a dramatic drop in the water level and flow of current over Station 2 and severe disruption of the substrate by a freshet at the control station. Aquatic insect populations at treatment Station 2 slowly increased from their low pre-treatment levels in the four weeks after spray application, though not to the same extent as at the control station. The recovery at both stations was primarily due to re-establishment of midge larval (Diptera: Chironomidae) populations.

Drift net samples taken at treatment Station 2 before, during and after spray application revealed no substantial increase in the number of drifting larval aquatic insects. The number of adult mayflies and midges captured in drift nets increased sizably during treatment but returned to normal as soon as spraying ceased. This indicates that the spray products knocked down some of the adult aquatic insects swarming over the river during treatment. The knockdown was only partial as swarms of midges and mayflies were observed over the river immediately after the treatment.

It was concluded from the studies carried out that the *Bacillus thuringiensis* treatment had no significant adverse effects on aquatic insects over the study period.

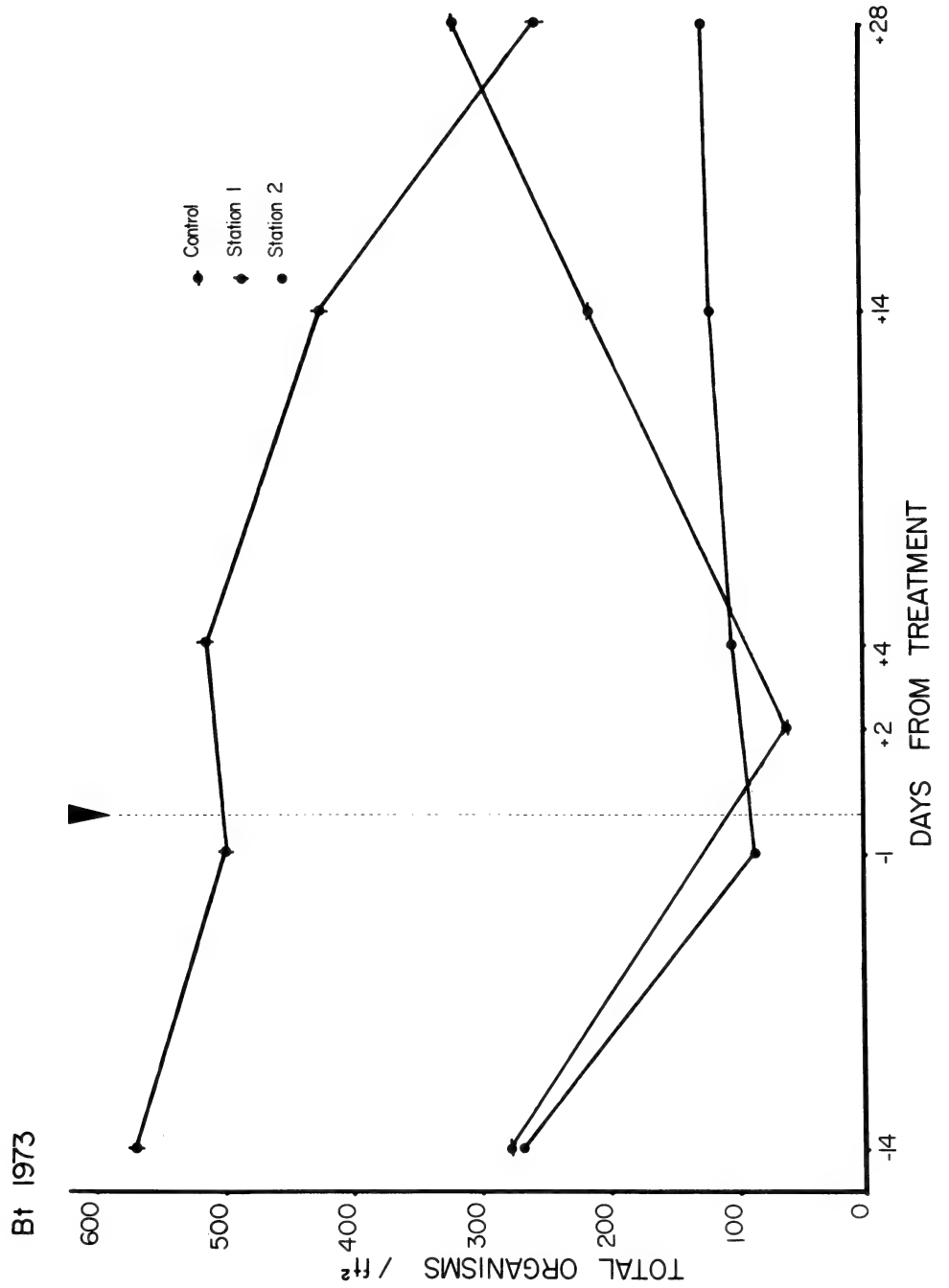

FIGURE 1. Bottom fauna populations at two stations treated with *Bacillus thuringiensis* and an untreated control station. Algonquin Park, 1973. Time scale is expanded around treatment date.

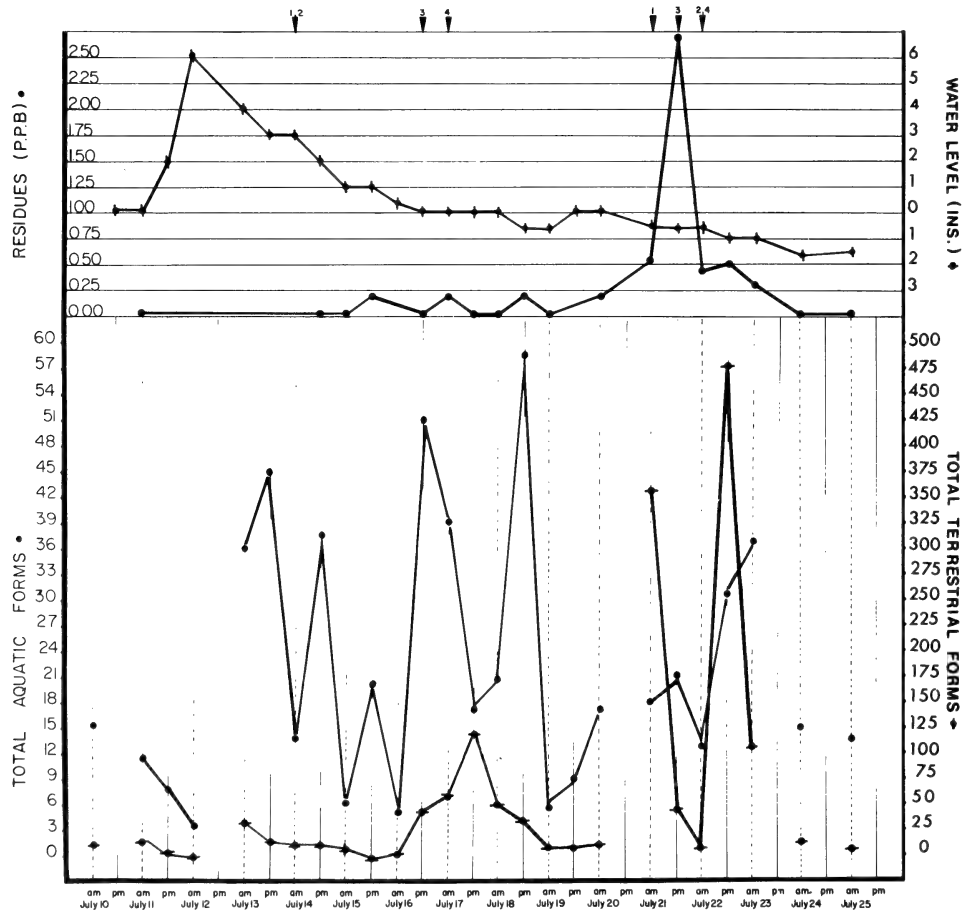

FIGURE 2. Drift net catches of aquatic and terrestrial insects (total of 2 15-min. net sets per sampling period), phosphamidon residues and water level in the Pabineau River, N.B., July 1974. Also shown are dates of treatment of spray blocks 1 to 4.

Phosphamidon — New Brunswick 1974

In mid-July 1974 a two million acre (800,000 hectare) block of spruce-fir forest in Northern New Brunswick was treated with two applications of phosphamidon (Dimecron) applied about a week apart at the rate of 1 oz/acre (70 g/hectare) active ingredient in an attempt to reduce spruce budworm moth populations. Drift nets were set in the Pabineau River which flowed through four blocks being treated by a DC-6 aircraft. Water samples taken concurrently with drift net samples showed that detectable phosphamidon residues were present in the river water at various times over a one-week period. Drift net catches of aquatic and terrestrial insects, phosphamidon concentrations in the water, and water levels are presented together in Fig. 2.

The greatest natural drift of aquatic insects in streams has been shown to occur around dusk (Waters, 1962). Pre-spray drift netting clearly showed peaks in the catch of aquatic insects in the evening but superimposed upon this were the effects of a freshet. A 6 inch (15 cm) rise in the river's water level first suppressed the drift of immature aquatic insects and then caused it to increase substantially. The effect of the freshet decreased steadily as the water level returned to normal. When the river was sprayed with phosphamidon, insecticide residues were found in the water and several increases in the drift of larval aquatic insects were recorded. Some of these peaks in the drift occurred in the morning, contrary to the normal pattern of the drift peaking at dusk. This is strong evidence that the increases in drift were due to the insecticide because natural factors do not usually alter the pattern. Stonefly nymphs and caddisfly and midge larvae showed the greatest increases in drift during the insecticide-related peaks. Increases in the numbers of adult insects caught in drift nets during phosphamidon spraying were even more dramatic. A great variety of adult insects were involved, but most were midges, moths (including spruce budworm moths) and Hymenoptera.

Surber samples revealed no significant depletion of any groups of aquatic insects which showed that the effect on aquatic insect populations detected with drift nets was not significant.

These two examples illustrate the nature and methodology of programs designed to monitor the impact of forest pest control operations on stream insects. Many similar studies have been conducted across Canada in recent years (e.g. Eidt 1975; Flannagan 1975; Kingsbury and Sarrazin 1975; Langer and Taylor 1974; Peterson and Zitko 1974). These studies have generally shown that present day forest pest control practices do not seriously affect aquatic insect populations. Studies of this nature could continue to seek to define safe levels of insecticide application and search for possible long term or synergistic effects of insecticides in the aquatic environment.

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THE GRAPE PHYLLOXERA, *DAKTULOSPHAIRA VITIFOLIAE* (FITCH) (HOMOPTERA:PHYLLOXERIDAE), IN ONTARIO: DISPERSAL BEHAVIOUR OF FIRST-STAGE APTERAE EMERGING FROM LEAF GALLS

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Abstract

The dispersal behaviour of first-stage apteriform crawlers of the grape phylloxera, *Daktulosphaira vitifoliae* (Fitch) [=*Phylloxera vitifoliae* (Fitch)] emerging from galls on leaves of French hybrid cultivars of grape in Ontario was studied. Most of the movement of crawlers from foliage to soil resulted from crawlers being blown or dropping from the vines rather than movement down the vine trunks. Vines infested by the leaf form had heavier root infestations than vines of the same cultivar and in the same vineyard that were free from leaf galls. Banding shoots with Stickem® showed that crawlers dispersing from the galled leaves were negatively geotropic, with no change in the direction of movement observed in late-season generations. However, the later generations exhibited a reduced capacity for gall formation on potted vines as compared with earlier generations. Crawlers reared at 22° C and 10 hr of daylight formed fewer galls on potted vines of cv. Chelois (Seibel 10878) than did those reared at 27° and 16 hr daylight.

* * * * * *

Introduction

The grape phylloxera, *Daktulosphaira vitifoliae* (Fitch) [=*Phylloxera vitifoliae* (Fitch)], occurs in most vineyards in Ontario's Niagara Peninsula, (Stevenson, 1963). Most of the cultivars of grapes grown in the older vineyards are susceptible only to the root form (radicicole) of the phylloxera, but many of the newer vineyards contain cultivars that are also susceptible to the leaf form (gallicole). In 1966 a survey of the grapes grown in the experimental vineyard of the Horticultural Research Institute of Ontario (HRIO) showed phylloxera leaf galls on 83 different cultivars or selections. Although serious crop losses in Ontario due to phylloxera injury to foliage have not been observed, the leaf form is important

in dispersal of the pest. Also, movement of first-stage apterae (crawlers) from leaf galls to the roots can result in the establishment of infestations of the root form or increase the severity of previous infestations.

Crawlers hatching from the eggs laid in leaf galls by the gallicoles move from the galled leaves and attack either the youngest leaves or the roots of the vines. In Ontario, the movement of crawlers from the foliage to the soil occurs from early July until the end of the growing season, reaching a peak about the end of August (Stevenson 1966). Catches of crawlers on sticky traps placed beneath infested vines indicated that most of the crawlers appeared to have been blown from the vines or dropped to the ground. Further observations on the movements of the crawlers were therefore undertaken to determine their dispersal pattern. As a greater proportion of radicicoles are produced later in the season (Grassi 1915), observations were also made on the ability of the crawlers to form galls on the leaves of host cultivars. The results of these studies are presented in this paper.

Materials and Methods

The field work was carried out in the HRIO research vineyard, Vineland and in two commercial vineyards near St. Catharines and Vineland. The cultivars in these vineyards were the French hybrids Maréchal Foch, Chelois (Seibel 10878), and Chancellor (Siebel 7053), all of which are relatively susceptible to the leaf form of the phylloxera.

Experiment 1

To obtain further evidence of the nature of the movement of crawlers, 5 infested vines of cv. Maréchal Foch were banded about the trunks with 2 bands of masking tape coated with Stickem®[1] to prevent the passage of any crawlers moving down the trunk and to capture any falling upon the bands. The bands were placed about 2 in. apart and about 4 to 10 in. above the soil on an area of the trunk from which the outer bark was stripped. The experiment was repeated 3 times. The bands were removed after 48 hours and the numbers of trapped crawlers were counted.

Experiment 2

To determine the effect of the descent of crawlers upon the radicicole infestation, roots were collected from leaf-form infested and non-infested vines on several occasions during the summers 1964 through 1966. Root samples were collected from an area about 1 ft. from the base of vine and to a depth of about 18 in. and the number of root galls (nodosities) on the samples were counted. The roots were then washed in water, oven dried, and each sample was weighed.

Experiment 3

To determine the direction of movement of crawlers emerging from leaf galls, bands of Stickem were placed around shoots above (apically) and below (basally) 3 galled leaves on each of 10 vines. After 48 hours the shoots were removed and examined in the laboratory and the numbers of crawlers trapped on the bands were counted. The first series of determinations was made without regard to the orientation of the shoots, but in later determinations, equal numbers of shoots oriented upwards, horizontally and in some cases, downward were compared.

Experiment 4

To assess the ability of late-season crawlers to form leaf galls on susceptible cultivars, insects were collected from cv. Chancellor in the field on 4 occasions during the season and compared with laboratory-reared crawlers. Twenty-five crawlers of each type were transferred individually to the youngest expanded leaves of potted cv. Chelois vines and the numbers of galls formed by each group

were recorded. Previous work had shown that crawlers from Chancellor readily accepted transfer to Chelois (Stevenson 1970). Vines having two shoots were used, so the two populations were compared on identical plants. A band of Stickem was placed about the base of each shoot to prevent mixing of the two populations.

Experiment 5

Rilling (1964) reported that the proportions of gallicoles and radicicoles among laboratory-reared phylloxera were determined by the temperature and photoperiod at which the insects were reared. To determine the effect of day length and temperature on the responses of the crawlers to the host plant, gallicoles were reared on potted vines of cv. Chelois in environmental cabinets at 27° C, with a 16 hr photophase and at 22° C, with a 10 hr photophase. Crawlers of the 1st and 2nd generations of each colony were compared for their ability to induce galls on the leaves.

Results

Experiment 1

In 3 trials of 5 vines each, a total of 375 crawlers were trapped on the upper and 448 on the lower of pairs of sticky bands placed about the trunks. The trapping of so many crawlers on the lower bands showed that direct migration down the trunk could not have accounted for most of the dispersal from the leaves. Moreover, the distribution of the trapped crawlers on the stickem suggested that most had been blown or dropped onto the bands. Additional evidence for this form of dispersal was shown in the same vineyard when 246 crawlers were trapped over 48 hours on 5 6 in. x 6 in. sticky traps hung between the wires of the trellis to capture phylloxera alates in another study.

Experiment 2

Vines that were infested by the leaf form of phylloxera consistently had more root galls than vines of the same cultivar that were free from foliar damage (Table I).

TABLE I. Comparison of root galling by the grape phylloxera on vines with and without galls on the foliage.

Date of examination	Cultivar	No. root galls/gram of root (dry)[a]	
		with leaf galls	without leaf galls
28 August 1964	Maréchal Foch	25.6	7.7
26 July 1965	Maréchal Foch	17.7	0.3
16 August 1965	Maréchal Foch	154.4	14.7
30 September 1965	Maréchal Foch	51.2	9.0
9 September 1965	Chelois	102.7	29.0
9 September 1966	Maréchal Foch	32.6	11.1

[a] There was a significant difference in No. root galls/gram between vines with leaf galls and vines without leaf galls ($P < 0.05$) when a single "t" test was performed on all the data.

Experiment 3

Banding shoots to trap dispersing crawlers showed that the crawlers tended to move upward on the vines. In 3 series of determinations made on 2nd generation crawlers on cv. Maréchal Foch in July, 99.1, 80.6 and 64.5% of the crawlers were trapped towards the shoot tip. These shoots were oriented in various direc-

tions. Later trials (Table II) showed a significant movement ($P < 0.01$) upwards on both upward and downward-oriented shoots, and, in some cases, a tendency to disperse toward the shoot tips on horizontally-oriented shoots.

TABLE II. Direction of movement of crawlers of the grape phylloxera dispersing from galled leaves of French hybrid grapes, 1967.

Cultivar	Dates	% Crawlers trapped toward shoot tip[a]		
		Direction of shoot orientation		
		Upward	Horizontal	Downward
Maréchal Foch	Aug. 2- 4	82.2x	53.4y	38.1x
Chelois	Aug. 2- 4	72.8x	53.3y	45.7x
Maréchal Foch	Aug. 28-30	58.9x	46.6	
Chancellor	Aug. 28-30	79.7x	59.3y	
Chancellor	Sept. 13-15	73.5x	43.5y	

[a] Letters following values indicate a significant difference between the % of crawlers moving towards the shoot tip and the % moving toward the base of the shoots as determined by chi-square tests. $x = P < 0.01$, $y = P < 0.05$.

It was thought that a change in the prevailing direction of movement of crawlers might be detected in the later generations of the season if the population contained a higher proportion of potential root forms. However, the results of observations made on September 15 did not differ sufficiently from those of mid-season to form any such conclusion (Table II). The population of the leaf form before July was not sufficient to carry out any similar observations on the movement of crawlers, so no comparison between the earliest and latest generations of the season was possible.

Experiment 4

The capacity of the field population of crawlers to form galls on potted vines decreased as the season progressed (Table III). Probably the late-season crawlers did not attempt to establish themselves on the leaves, as there was no evidence of unsuccessful feeding attempts such as aborted galls or necrotic spots on the leaves.

TABLE III. Comparison of leaf galling capabilities of first-stage apterae of field and laboratory strains of the leaf form of the grape phylloxera at different stages of the growing season.

Date	Generation (Field)	Total No. of crawlers of each type	No. galls produced	
			Field strain	Lab strain
July 14	2nd	100	17	46
Aug. 8	3rd	100	3	23
Sept. 5	4th	75	0	53
Oct. 5	5th	200	0	
		100		32

Experiment 5

When gallicoles were reared at 22° C and 10 hr daylight, the ability of the crawlers to form galls on host leaves was reduced, especially in the 2nd generation, as compared with crawlers reared at 27° - 16 hr daylight (Table IV). Rilling, (1964), using similar rearing regimens, found that reduced temperature and day

length favoured the production of radicicoles among the progeny of gallicoles. Perhaps the result reported here can also be explained by the development of more radicicoles at the lower temperature and shorter day.

TABLE IV. Effect of rearing temperature and day length on the ability of crawlers of the grape phylloxera to form galls on leaves of potted Chelois vines.

Rearing conditions	% crawlers forming galls	
	1st generation[a]	2nd generation[b]
27° C—16 hr day	37	40
22° C—10 hr day	30	4.5

[a] 100 crawlers on 4 vines
[b] 200 crawlers on 8 vines

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LABORATORY FEEDING STUDIES OF POTENTIAL PREDATORS OF THE APPLE MAGGOT *RHAGOLETIS POMONELLA* (DIPTERA: TEPHRITIDAE) IN ONTARIO

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Abstract

The prey-finding and attack capabilities of potential predators of the pupae and larvae of the apple maggot, *Rhagoletis pomonella* (Walsh), found on the surface of two orchards on insecticide-free management programs, were tested in a laboratory. Sowbugs, *Oniscus laevis* (Koch), centipedes, *Lithobius forficatus* (L.), earwigs, *Forficula auricularia* L., ground beetles, *Calosoma calidum* F. and *Harpalus pennsylvanicus* DeGeer, and rove beetles, *Staphylinus badipes* Lec., effectively detected, disinterred, and consumed apple maggot pupae. Millipedes, *Oxidus rathkei* (Koch), attacked a few pupae. These predators, in addition to the crickets, previously tested, appeared to be potential mortality factors of the pupae in orchards. Earwigs and two of the species of beetles attacked mature apple maggot larvae in the laboratory.

Introduction

Investigation of the biological control of the apple maggot, *Rhagoletis pomonella* (Walsh), in Ontario indicated that the pupa was the stage most vulnerable to attack by predators or parasites (Monteith, 1971a, b, c, 1972). Predators destroyed 79.5% of the pupae in test lots buried in an orchard on an insecticide-free management program at Rednersville (Monteith 1971a). Parasites appeared unlikely to be more than an infrequent factor in the control of the apple maggot in orchards (Monteith, 1971b, c, 1976b). Only 19% of control lots of buried pupae died from all causes other than predation (Monteith, 1971a). Therefore, the greatest potential for biological control of the apple maggot in orchards appears to be that by predators of the pupae.

Ground crickets, *Gryllus pennsylvanicus* Burmeister and *Allonemobius fasciatus* (DeGeer), destroyed 54.5% of test lots of buried pupae at Rednersville during the late summer and early fall. Undetermined predators attacked 25% of the pupae in the late fall and spring (Monteith, 1971a). The low incidence of *R. pomonella* in a commercial orchard on an insecticide-free program at Ayton (Monteith, 1971b) indicated that predators were probably present.

Preliminary tests indicated that among the arthropod species found in the Rednersville and Ayton orchards, sowbugs, *Oniscus laevis* (Koch), centipedes, *Lithobius forficatus* (L.), earwigs, *Forficula auricularia* L., ground beetles, *Calasoma calidum* F. and *Harpalus pennsylvanicus* DeGeer, rove beetles, *Staphylinus badipes* Lec., and millipedes, *Oxidus rathkei* (Koch), would attack apple maggot pupae. Therefore, further tests of their ability to detect and destroy pupae were conducted.

Methods and Materials

All test animals were collected at Rednersville with the exception of the earwigs which were collected at Ayton. Prey-finding experiments were conducted in aquarium tanks with similated natural surfaces on which grass and clover were growing (Monteith, 1971a) and with other conditions comparable to that in the orchard when the predators were active. Two boards, each similar to one half of a Chant and McLeod trap (1952), with the slots next to the soil, were placed in each tank to provide a retreat for the predators.

Apple maggot pupae were exposed to the predators in three types of random distribution; 10 sound pupae hidden on the surface, 10 buried, or 10 pupae each on the surface and buried. Six tests were made with each species of predator as follows: two tests with each distribution of pupae in which one test of each pair was conducted with quartered apple fruits on the surface as an alternate food, the other without apples present. The two tests for one type of distribution of pupae were made concurrently. The tests for the three different distributions of pupae ran consecutively. The prey were replaced for each test. The number of predators of a particular species used in a prey-finding test was comparable to the average number of that species found in areas of similar size under the trees in the orchard. The numbers of predators used in the two or three replicates in each test are given in the description of the tests with each species.

The readiness of each species of predator to attack active, mature apple maggot larvae was determined in the aquarium tanks. Apparently healthy larvae were placed on the soil surface where they would be exposed to the predators. Any exposure of a particular larva was of short duration as the larva soon burrowed into the soil and formed a puparium. Injured, therefore immobilized, larvae were also exposed to the predators.

As ants and wasps did not attack buried pupae and it would have been difficult to establish colonies in the laboratory, observations of their responses to active larvae were made in the Rednersville orchard as described in the tests with each species.

Results

Earwigs

Though earwigs were found in high concentrations in the orchard at Ayton, cannibalism occurred when they were crowded in the laboratory. Therefore, only five adults were used in each prey-finding test. Each of the six tests consisted of three five-day exposures.

Earwigs were able to detect, disinter, and consume apple maggot pupae (Table I). The earwigs destroyed all of the pupae during tests when the pupae were on the surface, up to 30% when the pupae were buried, and dug up pupae though prey were available on the surface. Each earwig attacked an average of .08 pupae daily in tests where all of the pupae were buried. The presence of apples apparently did not detract the earwigs from prey-searching and feeding on the pupae as more prey were attacked when apples were present that when they were not. The number of pupae attacked by the earwigs in the replicates for any test, where all the prey were not attacked, varied by only one pupa. There was a similar consistency in the tests with the other predators.

Earwigs attacked mature, active, or injured apple maggot larvae on the soil surface. The predator generally carried the prey into a hiding place where it was almost totally consumed.

Centipedes

Five centipedes were used in each prey-finding test. Each test consisted of three five-day exposures. Centipedes were very active in the aquarium tanks and readily detected, disinterred and consumed apple maggot pupae (Table I).

Centipedes destroyed all of the pupae during some exposures when the pupae were on the surface, up to 40% when the pupae were buried, and dug up pupae though prey were available on the surface. Each centipede attacked an average of .16 pupae daily in tests where all of the pupae were buried. The presence of apples apparently did not influence prey-finding by the centipedes.

Centipedes did not attack active apple maggot larvae until they became immobilized and had commenced to form puparia. Centipedes fed on injured larvae.

Sowbugs

As sowbugs were found in high concentrations in the Rednersville orchard and no cannibalism was observed in the aquarium tanks, 15 adults were used in each prey-finding test. Sowbugs were slow moving compared to earwigs or centipedes so each test was conducted as two ten-day exposures.

Sowbugs detected, dug up, and destroyed apple maggot pupae (Table I). Sowbugs destroyed all of the pupae when the latter were on the surface, and, in some exposures, when the pupae were buried. Sowbugs dug up pupae though some prey were available on the surface. Each sowbug attacked an average of .05 pupae daily in tests where all of the pupae were buried. The presence of apples, grass, and clover apparently did not detract the sowbugs from prey-searching and feeding on the pupae.

Sowbugs did not attack mature, active apple maggot larvae but did feed on injured, immobilized larvae.

Millipedes

Five millipedes were used in each prey-finding test. As the millipedes, similar to the sowbugs, were slow moving, each test consisted of two 10-day exposures.

The millipedes attacked few of the apple maggot pupae (Table I). All of the pupae that were attacked by the millipedes were on the surface although many millipedes were found feeding on crop residues beneath the surface in cultivated fields and in turf. The millipedes appeared to be omnivorous and their search for prey may be the reason for their nocturnal movements through apple and cedar trees (Monteith, 1976a).

Millipedes did not attack active apple maggot larvae but they did feed on injured, immobilized larvae.

Ground Beetles and Rove Beetles

Five *H. pennsylvanicus* were used in each prey-finding test. Only two *C. calidum* or *S. badipes* were used in each test because of their large size and mobility. As there were insufficient *S. badipes* available for six tests, only the tests with apples present were made with this species. Each test with each species of beetle consisted of three five-day exposures.

All three species of beetles were able to detect, dig up, and destroy pupae (Table I). All three species dug up pupae though prey were available on the surface. Each *C. calidum, S. badipes,* and *H. pennsylvanicus* attacked an average of .40, .43 and .16 pupae daily, respectively, in tests where all of the pupae were buried.

C. calidum and *S. badipes* attacked active, mature apple maggot larvae in the laboratory. The presence of apples during tests with *C. calidum* and *H. pennsylvanicus* apparently did not influence prey-finding by the beetles (Table I).

Ants

The larger species of ants found under the trees would attack active apple maggot larvae when a larva was placed near an ant on the surface of the orchard. However, no such attack was observed to occur naturally under field conditions. All species of ants fed on injured larvae.

Wasps

Wasps, *Vespa* spp., fed in great numbers on fallen fruit or damaged apples in the trees. However, after 25 hours spent, throughout the late summer and fall, observing wasps feeding on apples in and under trees known to be infested by the apple maggot no wasp was seen to carry an apple maggot larva from, or to leave an injured larva in, or beneath, an apple.

Discussion

Earwigs, centipedes, sowbugs, and the three species of beetles effectively detected, disinterred and consumed apple maggot pupae in the laboratory. Although millipedes only attacked pupae on the surface of the soil in the current tests, millipedes do feed beneath the soil surface and may attack some naturally-buried pupae in orchards. The number of buried pupae attacked per day by each of the other species of predator ranged from .05 to .43. In the laboratory, the highest rate of predation of buried pupae, per predator daily, was by the larger beetles, *C. calidum* and *S. badipes,* with *H. pennsylvanicus* and the centipedes consuming about one-third as many, and the earwigs and sowbugs with the lowest rate, one-sixth that of the larger beetles. However, if the rate of predation determined for each species of predator in the laboratory occurs in an orchard, the order of ef-

TABLE I. Percentage of available apple-maggot pupae attacked and number attacked per predator daily when the prey was available in three types of distribution, in the presence or absence of apple fruit.

Predator	Quartered apples present						No apples present					
	Pupae on surface		Pupae buried		Pupae on surface and buried		Pupae on surface		Pupae buried		Pupae on surface and buried	
	%	No	%	No	%	No	%	No	%	No	%	No
Earwig	100	<.40	30	.12	100 & 10	.44	100	<.40	10	.04	80 & 10	.36
Centipede	83	.33	40	.16	83 & 10	.37	90	.36	37	.15	50 & 30	.32
Sowbug	100	<.07	100	<.07	90 & 40	.09	100	<.07	40	.03	90 & 20	.08
Millipede	20	.04	0	0	10 & 0	.02	10	.02	0	0	0 & 0	0
C. calidum	93	.93	43	.43	60 & 6	.66	90	.90	37	.37	63 & 10	.73
H. pennsylvanicus	66	.27	40	.16	60 &30	.36	60	.24	37	.15	63 & 23	.35
S. badipes	100	1.00	43	.43	47 & 40	.87	—	—	—	—	— —	—

fectiveness of the species would be reversed due to the much greater populations of sowbugs and earwigs than of the other predators (Monteith, 1976a).

There would be a high percentage mortality of the apple maggot pupae produced in successive years if the rates of predation obtained in the laboratory occur in orchards, through the 1-3 year exposure of the apple maggot pupae in the soil (Monteith, 1971a, b). This would be especially true in the case of the sowbugs and earwigs as there were thousands of them under the trees in the Rednersville and Ayton orchards, respectively. Moreover, as most individuals of each species of predator, tested in the current study, lived through a period in the laboratory that would be the equivalent in the orchard of that from spring emergence to fall freeze-up, similar longevity in the orchard would permit each predator to attack pupae during an extensive period.

Apparently, there was little, if any, predation between the adults of the various predators tested in the current study. There was no evidence of interspecies predation when two or three species were held temporarily in an aquarium tank. Millipedes, centipedes, and sowbugs tended to remain hidden when earwigs were present, a pattern similar to that observed in the orchards.

The behavioural patterns by the predators tested in the laboratory indicated their adaptability as predators of apple maggot pupae. All of the predators, especially the earwigs and centipedes, were continually active in the test tanks. The predators appeared to forage for prey although plant foods (apples, grass, and clover) were available. All of the predators, except millipedes, dug up pupae though some prey were available on the surface. However, none of the predators tested in the current study, detected or dug up apple maggot pupae as effectively, or attacked pupae or larvae as voraciously, as did the crickets (Monteith, 1971a).

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PERSISTENCE OF VELSICOL HCS-3260 (AG-CHLORDANE) IN MINERAL AND ORGANIC SOIL[1]

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Abstract

Velsicol HCS-3260 (AG-chlordane) emulsifiable concentrate (EC) was applied at 3.4 kg AI/ha and incorporated into sand and muck soil contained in small field plots. Soil samples were taken at intervals over 3 years. Carrots and radishes were seeded annually to serve as indicator crops for absorption of insecticide residues. Soil and crop samples were extracted and analyzed by gas chromatography. The EC contained < 1% total heptachlor and nonachlor, 24.8% γ- and 70.7% of α-chlordane. Residues of heptachlor and nonachlor in soils were minimal and none were detected in the crops in the first year. Residues of γ- and α-chlordane declined rapidly in sand and to a lesser extent in muck over the first growing season. One year after treatment 77% of the initial γ- and 84% of the α-chlordane had dissipated from the sand; in muck the respective decline was 36 and 40%. Subsequent decline was slow. After 3 years 11% of the initial concentration of γ- and 16% of the α-chlordane was still present in the sand; 30 and 36% respectively in muck. Residues of both insecticides were absorbed by radishes and carrots, more so from sand than muck.

* * * * * *

Introduction

Uses of several organochlorine insecticides have been restricted in Ontario because of undesirable side effects. Partly as a result of these restrictions, the use of technical chlordane has increased markedly over the past 5 years. It is a complex mixture in which the main insecticidal components, α- and γ-chlordane and heptachlor comprise ca. 28% (Harris, 1972a). He suggested that much of the insecticidal activity of technical chlordane was due to its ca. 8.5% heptachlor content. The latter is one whose use has been restricted in Ontario. The other 2 major insecticidal components of technical chlordane, i.e. the α- and γ-isomers, while only 1/10 as toxic as heptachlor are still relatively effective soil insecticides (Harris, 1972a). Velsicol HCS-3260 is a high purity chlordane consisting primarily of a mixture of these 2 isomers. In a laboratory study Harris (1972b) found that it had a spectrum of insecticidal activity by direct contact and in soil similar to technical chlordane and Dorough *et al.* (1972) found it to be equal to or better than technical chlordane for alfalfa weevil control. However laboratory results indicated that HCS-3260 was more persistent in soil than technical chlordane (Harris, 1972b). Short term field studies, of 6 to 12 months duration, in the southern United States and western Canada also indicated that HCS-3260 may be relatively persistent in soil (Dorough and Pass, 1972; Dorough *et al.*, 1972; Wilson and Oloffs, 1973a) and that residues of α- and γ-chlordane were absorbed from soil by some crops (Dorough and Pass, 1972; Wilson and Oloffs, 1973b; c). This report summarizes results obtained in a 3 year study on the persistence of HCS-3260 in soil and its absorption by crops relative to soil type.

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Methods and Materials

The study was done in the field in microplots 2.2 m long x 0.9 m wide surrounded by fiberglass barriers 30 cm deep dug into the ground to a depth of 20 cm (Harris *et al.,* 1974). The soil in the plots was replaced to a depth of 20 cm with insecticide residue-free Plainfield sand or muck. HCS-3260, formulated as an emulsifiable concentrate (EC), was applied at the beginning of May as a broadcast application at 3.4 kg AI in 455 1. water/ha with an Oxford Precision sprayer. The treatment was raked immediately into the soil to a depth of 5 cm. Treatments and control sand and muck plots were duplicated. Subsequently the plots were seeded with radish (Red Boy) and carrots (Nantes) to serve as indicator crops for absorption of insecticide ersidues. No further insecticide applications were made. In the 2nd and 3rd years after treatment the plots were spaded each spring, to a depth of 15 cm to simulate ploughing and radishes and carrots were planted.

Soil samples comprising 5, 4 x 15 cm cores were taken from each plot prior to and immediately after incorporation of the insecticide and at intervals thereafter (Fig. 1) for 36 months. Samples from the duplicate plots were combined, the composite samples screened and mixed thoroughly and a representative 200 g aliquot weighed into a 900 ml screw cap bottle. One hundred ml acetone were added, followed by 200 ml hexane. The bottle was then capped and tumbled end-over-end for 1 hr. The extract was decanted into a 2 1. separatory funnel through glass wool, 1200 ml water and 100 ml saturated sodium sulfate were added and the funnel shaken for 1 min. After separation, the water-acetone layer was discarded. The procedure was repeated twice and the final hexane extract drained through anhydrous sodium sulfate into a screw cap storage bottle which was capped and stored in a freezer until analyzed.

Radishes were harvested in mid-June and carrots in mid-August of each year. Samples from the duplicate treatments were combined. The plants were topped and the roots lightly scrubbed in water to remove soil particles. Depending on size they were halved or quartered and pieces selected randomly to comprise the desired weight. The composite samples were diced, placed in a blender and macerated with acetone (1 ml/0.5 g plant material) and hexane (1 ml/g) for 2 min. The macerate was decanted into a 2 1. separatory funnel and treated as described above.

Concentrated aliquots of the soil or plant extracts were rinsed into glass columns 50 cm long x 13 mm I.D. fitted with a coarse sintered glass disc at the base and loaded with 2 g anhydrous sodium sulfate, 32 g Florisil and 5 g anhydrous sodium sulfate. The column was eluted with: 250 ml petroleum ether; 200 ml benzene; and 200 ml chloroform to yield 3 fractions: fraction 1 would contain heptachlor and nonachlor; fraction 2, heptachlor epoxide, α- and γ-chlordane; fraction 3, 1-hydroxychlordene. Samples were analyzed by gas chromatography using a Model 1200 Varian Aerograph GC equipped with a 170 cm long x 2 mm I.D. glass column packed with 5% DC 200 coated on 100/120 mesh Aeropak 30, and a tritium electron capture detector. Operating parameters were: column oven temp. 185° C; electrometer x 16, range 10^{-10}; nitrogen flow 60 ml/min.

Results and Discussion

Reference grade HC-3260 contains 68% α-chlordane, 29.4% γ-chlordane, 1% heptachlor and 0.6% nonachlor (Harris, 1972a). The EC used in this study contained similar concentrations of the 4 materials; 70.7, 24.8, 0.5, and 0.4% α-, γ-chlordane, heptachlor and nonachlor, respectively. Soil and crop samples were analyzed for these four compounds and for heptachlor epoxide and 1-hydroxychlordene, 2 degradation products of heptachlor.

Considering the small percentages of nonachlor and heptachlor in the EC, low residues were expected in soil. Initial nonachlor residues in sand were 0.01 declining to $<$ 0.01 ppm in the 1st month. In muck 0.02 ppm were present initially and 12 months after treatment, declining to 0.01 ppm at 24 and 36 months. No residues of nonachlor were detected in radishes or carrots grown in either sand or muck in the 1st year. Crops were not analyzed for nonachlor in the 2nd and 3rd years.

In sand initial heptachlor residues of 0.01 declined to $<$ 0.01 ppm a month later. Initial residues of 0.04 ppm in muck declined to 0.01 and $<$ 0.01 ppm 12 and 15 months after treatment. No heptachlor epoxide or 1-hydroxychlordene were detected in sand, muck, radishes or carrots in the first year. Crops were not analyzed for these compounds in the 2nd and 3rd years.

The initial γ-chlordane residue of 0.71 ppm in sand declined markedly in the first few months with ca. 24% remaining 4 months after treatment (Fig. 1).

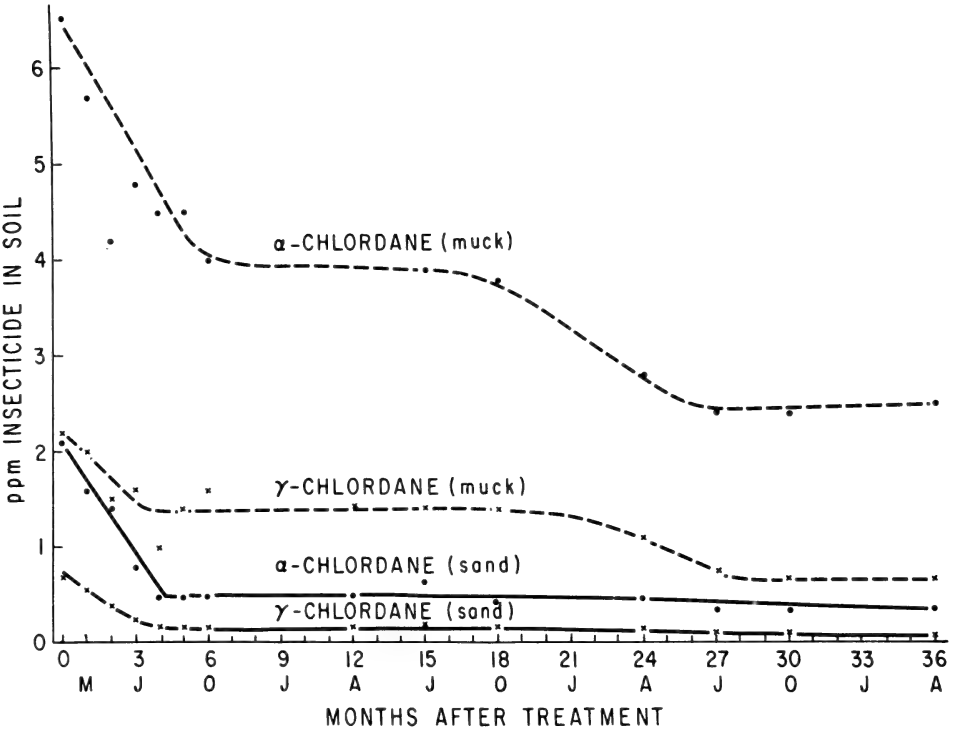

FIGURE 1. Occurrence and persistence over 3 years of α- and γ-chlordane in sand and muck following application of HCS-3260 at 3.4 kgAI/ha.

Subsequent decline was slow, with 23, 21 and 11% of the initial residues remaining 12, 24 and 36 months after treatment. Gamma-chlordane was considerably more persistent in muck with ca. 73, 64, 50 and 30% of the initial application remaining 6, 12, 24 and 36 months later respectively (Fig. 1).

As would be expected α-chlordane residues were highest. The initial concentration of 2.1 ppm in sand (Fig. 1) declined rapidly in the 1st 4 months with only 22% remaining then. Subsequent decline was slow with 16% remaining in the soil after 36 months. In muck, 67, 60, 43 and 39% of the initial concentration was detected 6, 12, 24 and 36 months later.

Residues of α- and γ-chlordane were detected in radishes and carrots grown in each of the 3 years (Table I). Although the concentrations of the 2 insecticides were much higher in muck than sand (Fig. 1, Table I) they were lower in radishes and carrots grown in the muck illustrating the moderating effect of soil type on absorption of soil insecticide residues by plants.

TABLE I. Residues of α- and γ-chlordane found at harvest in carrots and radishes grown in sand and muck treated initially with 3.4 kg AI/ha HCS-3260.

Insecticide	Year	ppm[1] present in					
		Sand[2]	Radish	Carrot	Muck[2]	Radish	Carrot
α-chlordane	1	2.1	1.1	0.41	6.5	0.05	0.02
	2	0.49	0.09	.07	3.9	.01	.01
	3	.47	.04	.05	2.8	<.01	<.01
γ-chlordane	1	.71	.53	.14	2.2	.02	<.01
	2	.16	.02	.02	1.4	<.01	<.01
	3	.15	.01	.01	1.1	<.01	<.01

[1] ppm based on oven-dry weight of soil and fresh weight of crop.
[2] Residues present initially and 12 and 24 months after treatment.

Heptachlor and nonachlor, comprised < 1% of the HCS-3260 EC, and did not occur at significant levels in soil or plants grown in treated soil. The 2 major residues, α- and γ-chlordane, were similar in behaviour. In mineral soil ca. 77-84% of the 2 isomers dissipated in the 1st year. These results were in good agreement with earlier studies (Dorough and Pass, 1972; Dorough *et al.*, 1972; Wilson and Oloffs, 1973a). However residue levels declined slowly in the 2nd and 3rd years. Both compounds were more persistent in organic soil. Although their behaviour was similar there is some indication that α- may be slightly more persistent in soil than γ-chlordane. In the first year of the study radishes contained higher levels of the 2 isomers than carrots (Table I). Wilson and Oloffs (1973c) obtained similar results. However in the 2nd and 3rd years residues of α- and γ-chlordane in the 2 crops were similar. A logical explanation for the higher residues in radishes in the first year is that radishes germinate in a few days and reach maturity in a month, i.e. when the insecticide residues were maximum. By contrast carrots take several weeks to germinate and an additional 2 or more months to mature. They were therefore exposed to lower "average" residues than the radishes during their growth period. In subsequent years after α- and γ-chlordane residues had stabilized, the time required to reach maturity was less critical and, as a result, residue levels in the 2 crops were similar.

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APPRAISAL AND IMPROVEMENT OF COLE CROP SPRAYING IN ONTARIO

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Abstract

Condition and operation of 17 growers' cole crop sprayers were evaluated. Sprayer design, spray coverage, and looper control varied widely. A coverage rating of 2.1 (in a scale of 1 - 10) was adequate for looper control with growers' sprayers when recommended materials were used. A hydraulic boom sprayer with #8004 nozzles, 980 - 1120 kPa pressure (142.2 - 162.5 psi), 986 - 1230 1/ha and 4.8 km/h driving speed, and a Conjet air-boom with #8006 nozzles at 3.2 km/h and 252 1/ha or #8008 nozzles at 4.8 km/h and 236 1/ha, provided efficient coverage on cabbage, cauliflower, brussels sprouts, rutabaga and broccoli.

* * * * * *

Introduction

Each year insects and diseases cause losses to growers of row crops. The magnitude of economic losses directly due to these pests depends on insect abundance, supply of disease inoculum, weather conditions, and the effectiveness and cost of a control programme. An effective programme depends largely on the use of proper pesticides, timing of sprays and very importantly, the efficiency of chemical application. The variability in sprayer design and in the operational efficiency of this equipment is of major concern to those charged with recommending standardized chemical control measures for row crops. In Ontario, sprayer evaluations based on design, spray coverage, and disease and insect control have led to specific spray recommendations for strawberries (Fisher and Hikichi, 1972 a, b), potatoes, peppers and onions (Fisher and Hikichi, unpublished).

This paper presents recommendations for spraying cole crops based on a survey of sprayer types and their operational efficiencies and on results of ex-

periments with hydraulic boom and air-blast sprayers that evaluated spray coverage and pest control.

Materials and Methods

Sprayer Survey

In a survey of 17 sprayers (home-made boom, commercial boom, air-blast) records were made of manufacturer, tank size, type and capacity of pump, length of boom, number of nozzles per row and their location, swaths coverd by air-blast sprayers, and nozzle size and wear (measured by taper-gauge).

When plants were nearing maturity, Phosphor 2283 fluorescent dye was applied at a rate of .67 g/1 in a regular spray to cabbages. When the spray had dried, ten plants were sampled for coverage using the second outer wrapper leaf. Coverage was rated in seven locations on the under surface of the leaf using a scale of 1 to 10 (Fisher and Hikichi, 1971). For boom sprayers where each row was similarly treated, samples were taken from one row. Where an air-blast sprayer was used, every second row was sampled across the whole swath.

Records were made of the number of sprays and the insecticides used during the season to control cabbage worm and looper. For pest damage assessment, 10 plants were chosen for coverage evaluation. Ten leaves from each plant were examined and feeding holes of 1 cm or larger recorded.

Field Experiments

(1) 1974—Simcoe, Ontario—A 18.3 m x 183 m plot of well-drained sandy loam soil was divided into two 9.15 m sub-plots each containing 1 row planted to each of cauliflower, broccoli, brussels sprouts, rutabaga, chinese cabbage and cabbage. A tractor-mounted hydraulic sprayer with 6.1 m boom was fitted with 3 nozzle outlets, 51 cm apart, for each row. Droparms with nozzles at the ends and flexible portions at the top were attached to the outer positions. Three rows were sprayed per swath. Four different nozzle arrangements, 2 pressures, sprays with and without surfactants, and 2 driving speeds (Table II) were compared in one experiment. In a second experiment on separate broccoli plots, a tractor-mounted hydraulic sprayer with 18.3 m boom and #8002 nozzles spaced 51 cm apart along the boom was tested at 4.8 km/hr with 3 pressures, 689, 1378, and 2067 kPa, and with and without 0.5 g/1 Niagara spreader-sticker. All plots received Dipel (*Bacillus thuringiensis*) at a concentration of 2 g/1 throughout the season, and for coverage assessment Phosphor 2283 dye at 0.67 g/1. Coverage and insect damage were assessed as described under "Sprayer Survey".

(2) 1975—Two sprayers were used:

(a) a high pressure hydraulic sprayer with fan nozzles #8004 spaced 51 cm apart, about 62 cm above the crop, with pressures of 1378, 2067, and 2760 kPa and driving speed of 4.8 km/h.

(b) a Conjet compressed-air boom sprayer with air-shear nozzles composed of a K 180 flood nozzle for the shearing air stream which impinged on liquid from a fan #8006 or #8008 even-spray nozzle. Sprays were applied to cabbage, cauliflower, broccoli and brussels sprouts at air pressures of 13.7, 20.6, and 27.6 kPa and driving speeds of 3.2 km/h for #8006 and 4.8 km/h for #8008 nozzles. For cabbage, 4.8 km/h was used for #8006 and 3.2 km/h for #8008. Coverage assessments were made at 5 locations on the lower surface of each of 10 leaves per plot. The 50 readings were averaged. Cabbage looper damage was assessed on 10 leaves on each of 10 plants per plot. Sprays were applied for pest control as follows: Aug. 18, endosulfan, 1.68 kg/ha for aphid and cabbageworm; Aug. 27 and Sept. 9, Thuricide® 2.8 1/ha + .125 g/l spreader-sticker.

Results and Conclusions

Sprayer Survey

Every sprayer and method of operating it was unique. Seven commercial models and five home-made boom sprayers were used. Coverage ratings varied from 0.5 to 2.8. Eighty percent of cone nozzles on booms produced ratings of 2.1 or more, while fan nozzles at the low pressures used (275-395 kPa) gave ratings less than 2.0. The 3 air-blast sprayers gave 1.8, 2.1 and 2.8. While no comparisons between sprayers could be made owing to differences in location, time, weather conditions, and chemicals used, no sprayer giving coverage below 1.9 achieved control of looper. Also, sprayers giving a coverage of 2.1 or more achieved commercial control with recommended chemicals when 2 or more sprays were applied. This contrasts with the coverage of 4 to 7 needed for control of minute orchard pests such as mites and fungi.

TABLE I. Dye ratings on cabbage, chinese cabbage, brussels sprouts, rutabaga, broccoli, and cauliflower after application of sprays with and without surfactant.

Nozzle[1]	Driving speed[4] km/h	Droplet size μ	Pressure[5] kPa	Volume[6] 1/ha	Rating
No surfactant[2]					
#8002—no droparms	4.3	370	689	348	2.5
#8002—no droparms	4.8	390	415	224	2.1
#8002—top + droparms	4.8		689	348	2.8
#8002—top + droparms	4.8		415	224	2.6
D_4-25—top, D_3-25 on droparms	4.8	225	689	310	2.7
D_4-25—top, D_3-25 on droparms	4.8		415	236	2.8
D_2-33—top + droparms	4.8	325	689	325	3.1
D_2-33—top + droparms	4.8		415	258	2.3
Surfactant added[3]					
#8002—no droparms	3.2		415	336	2.2
#8002—no droparms	4.8		415	224	1.9
#8002—no droparms	3.2		689	515	2.4
#8002—no droparms	4.8		689	348	2.3
#8002—top + droparms	3.2		689	515	3.2
#8002—top + droparms	4.8		689	348	3.3
D_4-25—top, D_3-25 on droparms	3.2		689	358	3.6
D_4-25—top, D_3-25 on droparms	4.8		689	325	3.4
D_2-33—top + droparms	3.2		689	444	3.5
D_2-33—top + droparms	4.8		689	325	2.4

[1] 3 Nozzles/row
[2] Ratings are for 6 crops
[3] Ratings are for 5 crops (chinese cabbage omitted)
[4] 1.6 km/h = 1 mph
[5] 6.89 kPa = 1.00 psi
[6] 11.2 1/ha = 1 gal/acre

Field Experiments 1974

Coverage with all nozzle systems with droparms was as good as the best obtained in the survey of growers' sprayers (Table I). Droparms improved the performance of #8002 nozzles. With cone nozzles D-25 and D-33[1] coverage was

[1] D_2-33 is a D-series No. 2 orifice plus a No. 33 swirl plate (Spraying Systems Co., Bellwood, Illinois).

better at 3.2 km/h than at 4.8 km/h. Coverage improved with increase in pressure from 689 to 2067 kPa (Table II). Addition of surfactant gave much better coverage on cabbage, moderate improvement on rutabaga, broccoli, and cauliflower, but none on brussels sprouts (Table III). Obviously, if mixed cole crops are to be sprayed, surfactant should be added.

TABLE II. Coverage ratings on broccoli sprayed with #8002 nozzles spaced 51 cm apart on a boom.

Pressure kPa	(psi)	Volume 1/ha	(gal/acre)	Surfactant	Rating
689	(100)	625	(56)	—	3.5
1378	(200)	895	(80)	—	4.4
2067	(300)	1100	(98)	—	4.9
2067	(300)	1100	(98)	+	5.2

TABLE III. Effects of surfactant on spray coverage on various cole crops.

Crop	Coverage rating no surfactant	surfactant added	Percent increase
Cabbage	2.1	3.6	72
Brussels sprouts	2.8	2.9	7
Rutabaga	2.5	3.4	36
Broccoli	3.1	4.6	48
Cauliflower	2.7	4.2	55

Though differences in coverage with different nozzles and arrangements were not great, control of cabbage looper was better when droparms were used, when driving speed was 3.2 km/h rather than 4.8 (Table IV). Unsprayed controls showed that cabbage was most susceptible to loopers. It was not possible in these tests to determine whether reduced control at 4.8 km/h was due to poorer droplet distribution or lower volume per hectare but, since the Dipel rate exceeded the minimum 0.28 kg/ha (R. Jaques, private communication) needed for control, the higher volume per hectare probably gave more effective control by virtue of droplets per unit area.

Field Experiments 1975

Coverage ratings were much higher than those obtained by growers or with the nozzle arrangements and pressures used in 1974 tests (Table V). The #8004 nozzles at the higher pressures (1378, 2067, 2760 kPa) gave much higher volumes per hectare than the nozzles used in 1974 with correspondingly greater numbers of droplets per unit area. The air-shear Conjet nozzles produced smaller and, therefore, more numerous droplets than the nozzle systems in 1974 tests with the low volumes per acre. On cauliflower, Conjet treatments were all effective. The boom sprayer at 2760 kPa was poorest followed by boom at 1378 and 2067 kPa. On brussels sprouts all systems performed well except for the boom at 2760 kPa (Table V). For economy of time, volume and power Conjet #8008 at 21 kPa air is preferred. An air pressure of 14 kPa was too low for effective atomization of 236 1/ha. A pressure of 2760 kPa on the hydraulic boom produced droplets too fine for good impingement at low velocity. On cabbage, Conjet #8008 at 3.2 km/h and applying 356 1/ha was most effective; Conjet #8006 was less effective at 4.8 km/h, low air speed and 168 1/ha; boom was weak at

TABLE IV. Total damage by cabbage loopers (holes per 100 leaves) for separate nozzle systems and for all nozzle systems on each crop at 3.2 km/h and 4.8 km/h and 689 kPa.

Nozzle	Speed[2] km/h	Volume[3] 1/ha	Holes/ 100 leaves	
D_2-33—top and on droparms	3.2	494	231	
	4.8	326	557	
D_4-25—top, D_3-25 on droparms	3.2	460	350	
	4.8	302	448	
#8002—top and on droparms	3.2	530	297	
	4.8	350	504	
#8002, no droparms	3.2	530	838	
	4.8	350	1350	
#8002 no droparms (425 kPa)	3.2	336	1531	
	4.8	225	1934	
Crop				Control
Cabbage	3.2		934	5000
	4.8		1616	
Brussels sprouts	3.2		939	592
	4.8		1134	
Rutabaga	3.2		823	1200
	4.8		1126	
Cauliflower	3.2		540	1870
	4.8		916	

[1] 6.89 kPa = 1 psi
[2] 1.6 km/h = 1 mph
[3] 11.2 1/ha = 1 gal/acre

2760 kPa but good at 1378 and 2067. On broccoli the boom at 2067 kPa was the most effective and, strangely, least effective at 1378. There were no significant differences among the remaining nozzle arrangements.

According to coverage values obtained, effective practical coverage exceeding a rating of 4 can be achieved with 252 1/ha using Conjet #8006 at 3.2 km/h and 236 1/ha using Conjet #8008 at 4.8 km/h. Where water is plentiful and a boom sprayer is already in use, #8004 fan nozzles spaced 51 cm apart are also effective with a pressure of 1378 (985-1120 1/ha) and speed of 4.8 km/h.

No significant differences in looper damage could be shown among the plots within a crop. Looper damage means for crops were as follows: cauliflower: treatment 9.5 holes/100 leaves, check 29.3; brussels sprouts: treatment 6.3, check 27.6; cabbage: treatment 10.1, check 42.3; and broccoli: treatment 5.4, check 16.1. Therefore, the effective threshold coverage value of 2.1 suggested by the

grower survey is probably adequate for looper control on cole crops. All values in 1975 tests were higher than 2.1 and the more efficient systems mentioned above are, therefore, recommended.

TABLE V. Comparisons of coverages obtained with two sprayers on 4 cole crops using fluorescent dye tracer.

Sprayer	Driving speed (km/h)	Air pressure (kPa)	Liquid pressure (kPa)	Volume (l/ha)	Coverage means[1]
Cauliflower					
Conjet—#8008	4.8	21	28	236	7.04 a
Conjet—#8006	3.2	28	28	252	6.76 ab
Conjet—#8006	3.2	14	28	252	6.58 abc
Conjet—#8006	3.2	21	28	252	6.42 abcd
Conjet—#8008	4.8	28	28	236	6.34 abcde
Conjet—#8008	4.8	14	28	236	5.93 cdef
Boom-hydraulic—#8004	4.8		2067	1120	5.62 defg
Boom-hydraulic—#8004	4.8		1378	980	5.40 fgh
Boom-hydraulic—#8004	4.8		2760	1400	3.94 i
Brussels sprouts					
Conjet—#8008	4.8	21	28	236	6.16 a
Conjet—#8006	3.2	21	28	252	6.14 ab
Conjet—#8008	4.8	28	28	236	5.92 abc
Boom-hydraulic—#8004	4.8		1378	985	5.70 abcd
Conjet—#8006	3.2	14	28	252	5.60 abcde
Conjet—#8006	3.2	28	28	252	5.30 abcdef
Boom-hydraulic—#8004	4.8		2067	1120	5.26 abcdefg
Conjet—#8008	4.8	14	28	236	4.96 cdefgh
Boom-hydraulic—#8004	4.8		2760	1400	3.90 i
Cabbage					
Conjet—#8008	3.2	28	28	356	7.46 a
Conjet—#8008	3.2	14	28	356	7.12 ab
Conjet—#8008	3.2	21	28	356	7.05 abc
Boom-hydraulic—#8004	4.8		2067	1120	6.07 d
Boom-hydraulic—#8004	4.8		1378	985	5.89 de
Conjet—#8006	4.8	28	28	168	5.77 def
Conjet—#8006	4.8	21	28	168	4.68 g
Conjet—#8006	4.8	14	28	168	4.52 gh
Boom-hydraulic—#8004	4.8		2760	1400	3.43 i
Broccoli					
Boom-hydraulic—#8004	4.8		2067	1120	6.72 a
Conjet—#8006	3.2	21	21	252	5.84 b
Conjet—#8006	3.2	14	28	252	5.80 bc
Conjet—#8006	3.2	28	28	252	5.78 bcd
Boom-hydraulic—#8004	4.8		2760	1400	5.76 bcde
Conjet—#8008	4.8	14	28	236	5.30 bcdef
Conjet—#8008	4.8	28	28	236	5.26 bcdefg
Conjet—#8008	4.8	21	28	236	5.10 bcdefgh
Boom-hydraulic—#8004	4.8		1378	985	4.16 h

[1] Means followed by the same letter do not differ significantly at 5% point (Duncan's multiple range analysis).

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TESTS WITH SOIL APPLICATIONS OF GRANULAR SYSTEMIC INSECTICIDES AGAINST THE FIRST BROOD OF *OSTRINIA NUBILALIS* (HUBNER) IN FIELD CORN IN SOUTHWESTERN ONTARIO

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Abstract

Several granular systemic insecticides applied to plots of field corn soon after planting were evaluated for their effects on the first brood of the European corn borer, *Ostrinia nubilalis* (Hübner). The results showed that disulfoton 15% G and phorate 10% G at 1 lb AI/acre and carbofuran 10% G at 1, 2 and 3 lb AI/acre did not significantly reduce damage to plants which were naturally infested.

* * * * * *

Introduction

Corn growers often apply granular systemic insecticides to the soil for control of the northern corn rootworm, *Diabrotica longicornis* (Say). One of these materials, disulfoton, decreased infestations by the corn leaf aphid, *Rhopalosiphum maidis* (Fitch) in three of four years in southwestern Ontario (Foott, 1975). There are reports from other areas that soil applications of carbofuran are effective against the first brood of a bivoltine strain of the European corn borer, *Ostrinia nubilalis* (Hübner) in field corn.

Edwards and Berry (1972) applied granular carbofuran at planting as a band 3½ in. to the side of the row and 2½ in. below the soil surface at rates of 2, 3 and 4 lb AI/acre. The degree of control depended on when plants were artificially infested. In 1968, all three rates resulted in significant decreases in the mean cavities/10 plants when plants were artificially infested with two egg masses 52 days after planting, but not when plants were infested 59 days after planting. In 1969, all three rates gave significant decreases in mean cavities when plants were artificially infested either 39 or 45 days after planting, but not when the infestations were made 52 days after planting. Wedderburn *et al.* (1973) treated plots with carbofuran at planting time in bands and in the furrows at rates of 0.75, 1 and 2 lb AI/acre. The percentages of plants with leaf damage and the numbers of tunnels/plant were significantly lower in both the banded and furrow

treatments at the 2 lb AI/acre rate, but not at the other two rates. There were no significant differences in numbers of larvae. The authors did not indicate whether infestations were natural or artificial. Hills *et al.* (1972) applied carbofuran as a 6-in. band at planting at 1 lb AI/acre. There were no significant differences in mean cavities/100 plants between treated and untreated plots even though every plant was artificially infested with two egg masses.

This paper reports the results of a 3-year study of the effects of granular systemic insecticides, particularly carbofuran, on damage by natural infestations of the first brood of the European corn borer in field corn.

Materials and Methods

The investigation was conducted in plots of the single cross variety, WF9 X M14, with seeds planted 10 in. apart in 40 in. rows. A treatment plot was one row of 37 to 41 plants with three replications per treatment. Granular systemic insecticides were applied as a side dressing on each side of the rows in furrows 2 in. deep and 2 in. from the plants soon after the plants emerged.

In 1971, carbofuran 10% G, disulfoton 15% G and phorate 10% G were applied at 1 lb AI/acre, the maximum rate which is currently registered for control of the northern corn rootworm in Ontario. A record was made of plants infested per treatment and the numbers of cavities in the leaves and sheaths. All infested plants were then split and the numbers of cavities in the tassel, stalk and brace roots determined. Damage was always assessed before second brood larvae were present.

In 1972, carbofuran at 1, 2 and 3 lb AI/acre was the only insecticide tested. Damage was measured as in 1971 and a record was also kept of the number of borers in the plants.

In 1973, the experimental procedure was similar to that in 1972 except that a record was made of the lengths of the stalk cavities.

Differences between treatments were tested by analysis of variance and Duncan's multiple range test. Values followed by the same letters are not significantly different at the 5% level of probability.

Results

In 1971, the following percentages of plants were infested: carbofuran, 26.8 a; disulfoton, 47.2 b; phorate, 48.1 b; untreated, 44.8 b. The mean cavities/infested plant were: carbofuran, 3.3 a; disulfoton, 3.6 a; phorate, 3.5 a; untreated, 3.4 a.

In 1972, when carbofuran was tested at three rates, the percentages of plants infested were: 3 lb AI/acre, 64.3 a; 2 lb, 84.6 a; 1 lb, 88.3 a; untreated, 84.7 a. Mean cavities/infested plant were: 3 lb, 2.6 a; 2 lb, 3.8 c; 1 lb, 3.4 bc; untreated, 3.0 ab. Mean borers/infested plant were: 3 lb, 1.8 ab; 2 lb, 2.4 c; 1 lb, 1.9 b; untreated, 1.6 a.

In 1973, the percentages of plants infested were: 3 lb, 81.7 a; 2 lb, 74.2 a; 1 lb, 80.8 a; untreated, 85.0 a. Mean cavities/infested plant were: 3 lb, 5.9 a; 2 lb, 4.5 a; 1 lb, 5.3 a; untreated, 8.3 a. Mean total length (in.) of cavities/infested plant were: 3 lb, 6.5 a; 2 lb, 4.8 a; 1 lb, 5.7 a; untreated, 8.4 a. Mean borers/infested plant were: 3 lb, 2.4 a; 2 lb, 1.4 a; 1 lb, 1.4 a; untreated, 2.1 a.

Discussion

There was no evidence from this investigation that carbofuran decreased borer damage when plants were naturally infested. One of the main differences in results between the present investigation and that of Edwards and Berry (1972), who observed significant decreases in borer injury in carbofuran-treated plots, was the low level of injury in their plots. Although they artificially infested every plant with two egg masses, the mean number of cavities/10 plants in the check plots was only 5.00 when plants were infested either 52 or 59 days after planting in 1968, and 7.25 and 6.25 for plants infested 39 and 45 days after planting, respectively, in 1969. Wedderburn *et al.* (1973) recorded a mean of 34.75 cavities/10 plants in untreated plots in the only year they tested carbofuran as a soil insecticide, a figure which approximated the three-year average in the present study when cavities in the mid-vein and sheath were excluded from the data. It is doubtful that this degree of injury would cause a significant decrease in yield.

It should be noted that none of the data analysed by the other investigators appeared to include leaf and sheath injury, other than to record the percentage of plants damaged. Guthrie (1974) in his study of host plant resistance to corn borers found that counts of stalk cavities are not good criteria for measuring resistance to a first-brood infestation in areas where 100% of the larvae pupate to form a second brood. He stated that corn borer larvae are primarily external feeders for at least 20-25 days after egg hatch, and, if pupation occurs 30-35 days after egg hatch, the larvae have not been inside the stalk long enough to cause extensive damage to stalk tissue.

The results of this investigation make it apparent that soil applications of granular carbofuran cannot be depended upon for control of the first brood of the corn borer in field corn under natural conditions of infestation.

Acknowledgment

The technical assistance of Mr. P. R. Timmins is gratefully acknowledged.

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EFFECT OF FRAGMENTATION OF EARS OF FIELD CORN ON REPRODUCTION BY *GLISCHROCHILUS QUADRISIGNATUS* (SAY) (COLEOPTERA: NITIDULIDAE)

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Abstract

Ears of field corn remaining in the field after harvest and subsequently plowed into the soil, are the principal reproductive sites for *Glischrochilus quadrisignatus* (Say). Tests were conducted to determine if fragmentation of entire ears into partial ears and detached kernels before burial would decrease the attractancy of corn to the beetles and thereby reduce oviposition. The results showed that significant decreases in oviposition seldom occurred unless the ears were broken into quarters or less.

* * * * * *

Introduction

Glischrochilus quadrisignatus (Say) is a serious pest of several crops. The adult beetle bores into ripe raspberries, infests kernels of sweet corn initially damaged by other insects or birds, and imbeds itself deeply in the flesh of damaged processing tomatoes being held in hampers between harvest and delivery to factories. Ears of field corn remaining in the field after harvest are the principal, and often the only, sites for reproduction by the beetle in the spring. Growers have asked if anything could be done with the corn to reduce its availability to the beetles. One method investigated was to bury the ears before oviposition started (Foott and Timmins, 1971). However, beetles located the ears regardless of whether they were buried in the fall or spring under 7.5 cm or 15 cm of soil.

Results from the above investigation indicated that beetles were attracted to corn by the odor of decomposing kernels. The fact that mice often dig down several inches to buried ears of corn is further evidence that an odor permeates to the soil surface. Since a reduction in size of the ear unit should result in decreased attractancy for the beetles, a study was made to determine if fragmentation of entire ears into partial ears and detached kernels before burial significantly reduced oviposition.

Materials and Methods

Tests were conducted in plots of soil near Dresden, Kent Co., an area where large numbers of *G. quadrisignatus* occur. Experimental units comprised: entire ears, ¾-ears, ½-ears, ¼-ears, 50 detached kernels, and 25 detached kernels. Care was taken to ensure that ears to be cut into smaller pieces were similar in size to ears that were to remain entire. Detached kernels were placed in a group in the soil rather than scattered. Five replicates of every experimental unit were buried in each of the following plots: fall-buried under 7.5 cm of soil, fall-buried at 15 cm, spring-buried at 7.5 cm, spring-buried at 15 cm. Since the spring-buried ears were on the soil surface of a corn field throughout the winter, the experimental procedures simulated shallow and deep plowing in the fall and spring. Plots were 4.6 m by 3 m in size and 1.8 m apart. Experimental units within the plots were 0.9 m apart in one direction and 0.6 m apart in the other. Metal grating was placed over the plots to prevent destruction of the corn by mice.

Experimental units, together with adjacent soil, were removed from the plots during June and examined for eggs, larvae and pupae of the beetle. To determine

whether mutilation of the ears was effective in reducing oviposition, the numbers of immature stages found on experimental units smaller than an entire ear were multiplied by the appropriate number to make each unit equivalent to an entire ear. In the case of detached kernels, an entire ear was considered to have 700 kernels.

Results and Discussion

There were large variations in numbers of immature stages between plots and years, but in most instances ears had to be reduced to quarters or detached kernels before significant reductions in oviposition occurred (Table I). Significant reductions occurred in 10 of the 12 plots when groups of either 25 or 50 kernels were buried and in 8 plots when ears were cut into quarters. In only one instance did reduction to a half ear result in a significant decrease in immature stages. Smaller units, in addition to having lower levels of infestation, decomposed at a faster rate than the larger units. It is possible that a larger proportion of larvae on the smaller units would fail to mature because of an insufficient quantity of suitable food.

TABLE I. Numbers of immature stages of *G. quadrisignatus* found on ears and portions of ears of field corn buried in soil at two depths in the fall and spring, 1971-1974.

Experimental unit buried	Mean no. of immature stages in relation to season buried and depth of burial[1,2]			
	Fall 7.5 cm	Fall 15 cm	Spring 7.5 cm	Spring 15 cm
1971-72				
Entire ear	125.5 a	182.2 a	44.0 a	91.8 a
¾-ear	143.8 a	90.9 ab	6.7 a	28.0 ab
½-ear	49.2 ab	21.6 b	2.8 a	44.0 ab
¼-ear	17.6 b	0.0 b	40.8 a	7.2 b
50 detached kernels	2.8 b	0.0 b	0.0 a	2.8 b
25 detached kernels	5.6 b	5.6 b	0.0 a	0.0 b
Totals	344.5	300.3	94.3	173.8
1972-73				
Entire ear	573.6 a	504.5 a	336.4 a	384.0 a
¾-ear	474.6 a	303.6 ab	422.1 a	167.5 ab
½-ear	476.0 ab	608.8 a	360.0 a	152.8 ab
¼-ear	271.2 bc	100.0 b	100.8 b	94.8 b
50 detached kernels	98.0 c	64.4 b	44.8 b	36.4 b
25 detached kernels	95.2 c	117.6 b	11.2 b	44.8 b
Totals	1988.6	1698.9	1275.3	880.3
1973-74				
Entire ear	384.0 a	317.9 a	108.6 a	147.6 a
¾-ear	500.8 a	298.8 a	74.4 a	40.0 ab
½-ear	435.6 a	237.6 ab	132.0 a	142.4 a
¼-ear	192.8 ab	125.6 ab	44.8 a	12.0 b
50 detached kernels	42.0 b	5.6 b	36.4 a	14.0 b
25 detached kernels	5.6 b	0.0 b	67.2 a	0.0 b
Totals	1560.8	985.5	463.4	356.0

[1] The mean no. of immature stages for experimental units less than an entire ear were multiplied by the appropriate number to raise the unit to the equivalent of an entire ear. In the case of detached kernels, an entire ear was considered to have 700 kernels.

[2] Figures followed by the same letter are not significantly different at the 5% level (Duncan's multiple range test).

Reproduction was greater on fall-buried than spring-buried ears. The former were more decomposed at the time beetles oviposited and emitted a stronger odor.

Since it was necessary to break ears into quarters or less to significantly reduce oviposition, an extension of the investigation to examine the capability of various machines to fragment ears was not warranted. The combined results of this study and a previous investigation (Foott and Timmins, 1971) offer little hope that populations of *G. quadrisignatus* can be reduced by manipulation of ears of corn remaining in fields.

Acknowledgment

The technical assistance of Mr. P. R. Timmins is gratefully acknowledged.

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CHEMICAL CONTROL OF THE CORN LEAF APHID AND EFFECTS ON YIELDS OF FIELD CORN

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Abstract

Spray applications of the following insecticides to the whorls of plants before pollination gave good control of the corn leaf aphid, *Rhopalosiphum maidis* (Fitch), and provided significantly higher yields of field corn: dimethoate, 0.43 kg AI/ha; endosulfan, 1.12 kg AI/ha; malathion, 1.05 kg AI/ha; oxydemeton-methyl, 0.50 kg AI/ha.

* * * * * *

Introduction

Foott and Timmins (1973) found that moderate to severe infestations of the corn leaf aphid, *Rhopalosiphum maidis* (Fitch), caused substantial yield reductions in field corn, particularly if plants were under moisture stress. It was apparent that most feeding injury occurred before pollination and aphicides would be ineffective unless they were applied before the tassels became completely exposed near the start of pollination.

Other investigators also reported that the timing of treatments was very important. Dicke (1969) stated that the whorls of a sample of plants should be dissected at about the mid-whorl stage of growth to determine colony size. A subsequent dissection about one week before tassel eclosion was the critical time for a treatment decision. Neiswander and Triplehorn (1961) were of the opinion that most insecticide treatments for aphid control are applied too late to be of important economic value. Triplehorn (1960) observed that for the best results insecticides must be applied before tassels have completely emerged but not before

the upper whorl leaves have opened to expose the tassel. He stated that in 1959 at least 100,000 acres of Ohio corn were treated with insecticides but in many cases materials were wasted primarily because they were applied too late.

Data are available to show the effect of foliar applications of insecticides on aphid numbers, but there is a scarcity of information on the effect of aphid control on yield. This paper reports the results of a three-year study to show the effects of insecticides on both aphid numbers and yield of field corn when plants were treated before pollination.

Materials and Methods

The investigation was conducted in plots of field corn at Harrow, Ontario from 1970 to 1972 inclusive. Seeds of the single cross hybrid WF9 X M14 were planted 25 cm apart in 1 m rows. A good stand was guaranteed by planting two seeds per hill and later thinning to one plant. Tillers were removed. Treatment plots comprised 33 to 37 plants and were replicated four or five times. All insecticides were applied with a knapsack sprayer with the spray being directed into the whorls of the plants.

In 1970, dimethoate at 0.43 kg AI/ha was applied eight days before pollination. The whorl leaves had opened sufficiently to expose the tips of the tassels on most plants, but some tassels were still enclosed.

In 1971, dimethoate at 0.43 kg, endosulfan at 1.12 kg and malathion at 1.05 kg AI/ha were applied eight days before pollination when the tips of the tassels were exposed.

In 1972, oxydemeton-methyl at 0.50 kg AI/ha was applied 10 days before pollination when most of the tassels were still enclosed. In other plots, oxydemeton-methyl at the above rate and endosulfan at 1.12 kg AI/ha were applied five days before pollination when the degree of tassel exposure ranged from partial to almost complete.

Populations of live aphids on the tassel of each plant were estimated at pollination and categorized as: 0, nil aphids; 1, up to 50 aphids; 2, 50 to approximately 400; 3, many hundreds on part of the tassel; 4, many hundreds on most of the tassel; 5, many hundreds on all of the tassel and whorl leaves.

The ears were individually bagged at harvest and placed in a drying room until the moisture level was lowered to approximately 7%. The kernels were then removed with a hand-operated sheller and weighed.

Results and Discussion

Every treatment during the three years of experiments reduced aphid infestations and provided significant increases in yield (Table I). The systemic materials dimethoate and oxydemeton-methyl were particularly effective.

In 1970, the application of dimethoate eight days before pollination appeared to completely eradicate aphids, whereas all levels of infestation occurred in the untreated plots. A rainfall of 12.47 cm during July (the month in which aphid infestations started and pollination occurred), almost double the long-term average of 6.68 cm, provided ample moisture and minimized yield reductions due to aphids in untreated plots.

The greatest increases in yield in treated plots occurred in 1971. The results provided a good example of the greater loss in yield which occurs when aphid-infested plants are under moisture stress. Precipitation during the 22 days preceding pollination was only 0.66 cm.

TABLE I. Levels of *R. maidis* infestations at pollination and mean yields per plant when plots of field corn were treated with insecticides, 1970-1972.

Insecticide	Rate kg AI/ha	No. days before pollination	No. plants per level of aphid infestation[1] 0	1	2	3	4	5	Mean yield shelled corn per plant (g)[2]
1970									
dimethoate	0.43	8	144	0	0	0	0	0	152.4 a
untreated			2	47	85	11	5	1	135.5 b
1971									
dimethoate	0.43	8	114	13	3	0	0	0	158.6 a
endosulfan	1.12	8	77	47	6	1	0	0	147.6 a
malathion	1.05	8	90	31	7	0	0	0	144.0 a
untreated			0	14	98	15	5	0	118.3 b
1972									
oxydemeton-methyl	0.50	10	126	2	0	0	0	0	183.3 a
oxydemeton-methyl	0.50	5	132	0	0	0	0	0	183.0 a
endosulfan	1.12	5	124	8	0	0	0	0	178.6 a
untreated			0	12	104	10	2	0	166.0 b

[1] Definitions of aphid infestations: 0, no live aphids; 1, up to 50 aphids; 2, 50 to 400; 3, many hundreds on part of tassel; 4, many hundreds on most of tassel; 5, many hundreds on all of the tassel and whorl leaves.

[2] Means not followed by a common letter are statistically different at the 5% level (Duncan's multiple range test).

The early application of oxydemeton-methyl in 1972 did not provide an increased yield over the later application of this material. Probable reasons were that damaging populations of aphids failed to develop between the treatment dates and 2.54 cm of rain prevented moisture stress. Nevertheless, the results showed that the systemic action of oxydemeton-methyl was capable of providng effective control of aphids even when most of the aphid-infested tassels were still enclosed within the whorl leaves.

When there is evidence from an early examination of plants that moderate to severe infestations of aphids are likely to occur by pollination, it might be advantageous for plant breeders and profitable for corn seed growers to treat their nurseries and seed fields. The results of this investigation showed that effective insecticides are available. Endosulfan and oxydemeton-methyl are the only two materials registered for aphid control on field corn in Ontario when it will be used for feed or in industry.

Acknowledgment

The technical assistance of Mr. P. R. Timmins is gratefully acknowledged.

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TESTS OF INSECTICIDES FOR ASPARAGUS BEETLE CONTROL AND RESIDUES ON THE CROP

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Abstract

Five insecticides applied to asparagus fields provided control of asparagus beetle egg laying. The average initial residues on spears were 6.5, 4.0, 0.85 and 0.65 ppm of methoxychlor, carbaryl, rotenone and malathion respectively. These residues were within tolerance limits and decreased steadily with half-lives of 19, 16, 35 and 8 hours respectively.

All insecticides applied as contact sprays in a spray tower were toxic to beetle adults. The most effective was mevinphos, followed by cartap, carbofuran, malathion, permethrin, rotenone, carbaryl, methoxychlor and DDT.

* * * * * *

Introduction

The asparagus beetle, *Crioceris asparagi* (L.), and to a lesser extent the spotted asparagus beetle, *C. duodecimpunctata* (L.), are consistent economic pests in asparagus fields in southern Ontario. Control recommendations seem to have developed gradually as new insecticides became available. A total of 12 insecticides have been listed at one time or another for asparagus beetle control in Ontario. They were all likely acceptable to growers and some remained as suggested treatments for years. For example lead arsenate after harvest was recommended in Ontario from 1927 until 1965. No published papers could be found dealing with comparative effectiveness of various treatments, and it was considered important to investigate this, since treatment costs varied as much as four-fold.

Asparagus may be picked 3 times weekly at the peak of production, and the required 3-day interval between application of methoxychlor and a harvest, in effect since 1972, limits the usefulness of this material. Miles and Niemczyk (1962) analyzed asparagus 24 hours after spraying and found that residues of malathion, TEPP, methoxychlor and mevinphos were well within the tolerance range. Research was conducted at Harrow in 1972 and 1974 to investigate the initial spray residues on asparagus and the rate of decline. Information on the control of adult beetles and egg laying in these trials was supplemented in 1975 by laboratory studies on the contact toxicity of a number of insecticides.

Materials and Methods

Insecticides currently recommended for asparagus beetles in Ontario were applied May 1972 to single row plots 7.6 m long, with treatments replicated 4 times in 2 commercial fields near Harrow. A compressed air hand sprayer was used to treat a band 30 cm wide which included all the spears in the row. Spears at least 12 cm long were harvested daily, with the first cut made soon after the spray was dry. After asparagus beetle eggs were counted, spears from each plot were frozen for later residue analysis. In 1974 a cooperative experiment was arranged with a commercial grower who sprayed 1.35 ha asparagus with methoxychlor at a rate of 1.68 kg active ingredient per ha with a 3-row sprayer. This treatment was applied at 9 pm and the spray did not dry before dark, so an initial sample was not feasible, but others were taken 9, 21 and 45 hours after the spray, for egg counts and residue analysis.

Colorimetric methods of analysis were used to determine residues of carbaryl (A.O.A.C. 1970) and rotenone (Goodhue 1936). Although samples were taken from plots sprayed with mevinphos, the complex cholinesterase inhibition residue analysis was not undertaken, especially since residues of this material are known to be very short-lived. Malathion and methoxychlor determinations were by standard gas chromatographic analysis (A.O.A.C. 1970). The Fisher 2400 gas chromatograph was equipped with a Ni^{63} detector operating in a pulse mode of 4 μsec every 500 μsec. The column, 6 mm by 1.83 m long, was packed with 4% OV-101 and 6% OV-210 on Chromosorb W AW DMCS, and operated at 200° C. The other operating parameters were: range 10^{-10} ma, attenuation 4, injection port 205° C, detector temperature 250° C, and N_2 flow rate 86 ml per minute. The recovery of each insecticide was determined by analysis of spiked samples of macerated asparagus.

Linear regression lines were obtained by plotting the logarithm of the residue (Y) against the period of time since spraying (X). The regression equations were tested by the least squares method, and the residue half-life was calculated from the regression equation.

Asparagus beetle adults were collected from unsprayed fern growth in May 1975. They were held overnight with food and sprayed in the morning. A Potter spray tower delivering 2 μl spray per cm^2 was used to treat petri dishes containing 10 adults and a piece of asparagus spear on filter paper. Each concentration of insecticide was applied to 4 replicates and mortality counts were taken after 24 hr. Materials tested were carbaryl, carbofuran, cartap (Padan), DDT, malathion, methoxychlor, mevinphos, permethrin (NRDC 143), and rotenone.

Results and Discussion

The degree of asparagus beetle control was difficult to measure in the field trials since the adults were disturbed by the spraying and flew out of the plot area, even from check plots. This was reflected in overall reduction of eggs from pretreatment levels. Treated plots had fewer eggs after several days than the check plots, but no distinctions could be made between materials. In the 1972 trials, on the third day after treatment only 4 eggs were found on 588 spears from treated plots, while the check plot count was 13 eggs on 108 spears. In the larger 1974 plots the methoxychlor spray reduced egg deposition by 69% on spears harvested 45 hours later. Some of these eggs could have been over 2 days old, so the adult control was likely higher than the egg counts indicated.

The analytical methods for carbaryl and methoxychlor were sensitive and accurate. When known amounts of insecticide were added to untreated asparagus samples, the analysis indicated 94 and 95% recovery respectively. Malathion and rotenone were partially lost in the clean up of the extracts because of their water solubility, and the recoveries were 32 and 34%. The residue figures in Table I are corrected values.

Asparagus spears had relatively low residue due to their shape and low ratio of surface area to weight, compared to leafy plants. As indicated in Table I, there was a distinct difference in the residues from the two fields. The asparagus from Mills' field was producing thicker spears than at Papke's, and samples from the former had higher residues on the average. There was also considerble variability between plot replicates. The highest residue determination was 11.3 ppm methoxychlor in one replicate of the first sample taken in 1972. Residues of methoxychlor after the commercial application in 1974 were 8.82, 4.62 and 2.67 ppm in samples taken 9, 21 and 45 hours after spraying.

TABLE I. Residues of insecticides on spears of asparagus harvested daily after treatment.

Insecticide	Kg Active per Ha	Farm	Residue in ppm on spears harvested after (hours)*					Residue Half-life in hours
			0.5	24	48	72	96	
Malathion	1.12	Mills	.697	.001	0			
		Papke	.595	.129	.012	0		8.4
Methoxychlor	1.68	Mills	8.40	4.11	2.60	1.01	0.21	18.9
		Papke	4.65	2.85	1.26	0.65	0.13	19.2
Carbaryl	1.12	Mills	4.98	2.07	1.38	0.54	0.15	19.7
		Papke	2.99	1.95	0.63	0.18	0.01	11.8
Rotenone	0.28	Mills	0.62	0.60	0.33	0.26	0.12	40.2
		Papke	1.07	0.62	0.32	0.14	0.14	29.8

* Corrected values.

The residues present on asparagus spears disappeared at various rates depending on the insecticide. A constant factor which would decrease the residue of any insecticide would be growth dilution. Only the portion of the spear above the ground at the time of spraying would carry the deposit, and this becomes proportionately less of the spear weight. Most of the disappearance of rotenone is likely due to growth dilution. A rapid degradation is important in the reduction of residues on particular spears that might have received an extra heavy dose of spray. Malathion degraded most rapidly.

The laboratory spray tower tests provided a good measure of the comparative toxicity of materials to adult beetles (Table II). The recommended rates of field application adequately allow for the differences in toxicity. For example, one pound of actual malathion in 100 gal water, sufficient to spray one acre, would have a finished spray concentration of 1000 ppm.

TABLE II. Percent mortality of adults of the asparagus beetle 24 hr after spraying with various insecticides in a spray tower.

	Concentration of insecticide (ppm)							
	2.5	5	10	25	50	100	250	500
Mevinphos	6	8	11	86	100			
Cartap		2	3	73	98			
Carbofuran			2	33	100			
Malathion			0	26	52	85		
Permethrin				5	58	93		
Rotenone				16	27	80	100	
Carbaryl					0	74	100	
Methoxychlor				0	17	28	55	100
DDT						18		100

It is interesting to note the toxicity of DDT in contrast to its lack of action against the Colorado potato beetle adults (McClanahan 1975). Potential new materials for asparagus beetle control would be cartap, carbofuran and permethrin. The latter is the least toxic to mammals.

In conclusion, these studies support the effectiveness of present recommendations for control of the asparagus beetle. The residue data indicates that a one day interval to harvest would be sufficient for methoxychlor in view of the tolerance level of 14 ppm. The grower's choice of insecticide can be based on the cost of the treatment, which varied from $0.71 to $2.43 per ha in 1975.

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NOTE ON THE OVICIDAL EFFECT OF THREE INSECTICIDES AGAINST THE CODLING MOTH (LEPIDOPTERA: OLETHREUTIDAE)

Elmer A. C. Hagley

Abstract

Azinphos-methyl (50% WP, 0.43 - 0.57 kg a.i./hectare) and phosmet, (50% WP, 1.1 kg a.i./hectare) were toxic to codling moth eggs at all stages of embryonic development. Phosalone, (30% WP, 0.8 - 1.1 kg a.i./hectare) did not affect egg hatch.

* * * * * *

Introduction

Azinphos-methyl and phosmet are widely used at reduced rates (.43 - .57 kg a.i. and 1.1 - 2.3 kg a.i./hectare, respectively) in pest management programs for control of the codling moth. In 1973 observations in two orchards indicated that these materials might have ovicidal activity against this pest. To control 1st generation codling moth larvae, a spray of azinphos-methyl, (.46 kg a.i./hectare, in one orchard, and phosmet (1.1 kg a.i./hectare) in another, was applied on June 21. The next spray is intended primarily to control apple maggot adults, as well as the codling moth, and is normally applied about 8-10 days after 1st maggot emergence or 20 days after June 21. When this spray was delayed an additional 7 days female moths were able to survive long enough to oviposit and eggs were recovered from fruit clusters in both orchards. However, all eggs observed in the orchard treated with azinphos-methyl and 21% of those in the other treated with phosmet were dead. Eighty percent of the eggs had died in the 'black head' stage of development. In an unsprayed 2-acre block of apples adjacent to the phosmet treated

orchard, egg mortality was $< 1\%$. These observations suggested that residues of the chemicals on the foliage were absorbed by the developing eggs in sufficient quantity to cause mortality in the late stages of embryonic development.

As there are no previous reports on the ovicidal effects of these compounds against the codling moth, laboratory and greenhouse tests were undertaken to assess their efficacy in this regard. Phosalone, which is also used for apple insect control, (0.8-1.1 kg/hectare), was included in the tests.

Materials and Methods

Waxed-paper cages (George and Howard, 1965) containing 0- to 3-day-old eggs that had been laid in the laboratory were cut into strips each containing 80-150 eggs. These strips were held for 3 days at 18°-24° C and 25-55% RH, then dipped for 3 sec in suspensions of the insecticides and dried in an exhaust chamber. To determine whether toxicity of the materials varied with stage of embryonic development, eggs were held on the waxed-paper strips at 24 ± 1° C and 75% RH for 1, 3 and 5 days prior to treatment. Azinphos-methyl (50% WP), phosmet (50% WP), and phosalone (30% WP) were used at concentrations currently recommended for control of apple pests. Eggs were observed at 1-2 day intervals subsequent to treatment until they either hatched or died.

In the greenhouse, gravid females were confined on 10-15 cm high apple seedlings and eggs were deposited on the leaves. After 2 or 3 days the seedlings were brought into the laboratory and the eggs dipped as described above. To assess the residual effects of the chemicals, apple seedlings were dipped in suspensions of the insecticides and held in the greenhouse for 7 days. Five or six pairs of moths were then confined on the seedlings and allowed to oviposit for 3 days after which the moths were removed and adult mortality recorded. To assess larval mortality a collar of bristol board 16 cm in diam was placed around the base of the plant and the upper edge ringed with bird tanglefoot. Two halves of a small green apple were placed on the collar and served to collect the surviving larvae in each treatment.

Angular transformations were made on the data prior to an analysis of variance. Treatment means were separated by Duncan's multiple range test.

Results and Discussion

Phosmet and azinphos-methyl significantly reduced hatch of codling moth eggs laid on waxed-paper and leaves of apple seedlings (Table I). Phosalone had no effect on hatch at the concentration used. Hamilton *et al.* (1954) reported the

TABLE I. Effect of insecticides on hatch of codling moth eggs.

	Percent larval emergence[1]				
Substratum	Check	Azinphos-methyl 900 ppm a.i.	Azinphos-methyl 500 ppm a.i.	Phosmet 500 ppm a.i.	Phosalone 900 ppm a.i.
Waxed paper[2]	74.1 a[4]	20.7 b	37.6 b	26.8 b	
Apple leaves[3]	88.5 a		53.0 b,c	50.2 c	82.5 a

[1] Tests on waxed paper and leaves done with different egg groups and not comparable.
[2] Replicated 3 times, 174-191 eggs/treatment.
[3] Replicated 4 times, 405-723 eggs/treatment.
[4] Means followed by the same letters not significantly different ($P = 0.05$).

ovicidal activity of several other organo-phosphates of which parathion was the most effective, and Matvievskij (1967) obtained a 50% reduction in hatch with the carbamate, sevin.

Hough (1936), and Steiner and Summerland (1943), reported increased ovicidal effectiveness of sprays containing nicotine with increased age of eggs while Schoene and Jefferson (1935) obtained considerable variation in mortality with 1-6 day old eggs. Although there was some indication that reduced hatch occurred as the age of eggs at treatment increased the differences observed (Table II) were not significant.

TABLE II. Percent hatch of codling moth eggs after treatment with insecticides at different ages.

Treatment[1] [2]	Age of eggs when treated (days) 1	3	5
Azinphos-methyl (500 ppm a.i.)	51.6 a[3]	50.8 a	37.2 a
Phosalone (900 ppm a.i.)	72.6 b	63.5 b	63.0 b
Phosmet (500 ppm a.i.)	41.4 c	37.0 c	30.3 c
Check	72.1 d	68.9 d	77.0 d

[1] Each treatment replicated 4 times, 230-410 eggs/treatment.
[2] Comparisons made only between individual treatment means at 1, 3, and 5 days.
[3] Means followed by the same letter not significantly different (P = 0.05).

When gravid females were allowed to oviposit on foliage 8-10 days after treatment with the insecticides, there were no significant differences in egg hatch (Table III). However, the results were very variable as female mortality was high, particularly in the azinphos-methyl and phosmet treatments, and the number of eggs deposited accordingly was very low. Possible inhibitory effects of the chemicals on moth oviposition were not assessed.

TABLE III. Residual effect of insecticides on hatch of codling moth eggs and on larval and adult mortality.

Treatment	Rate (ppm)	Percent egg hatch	Percent mortality[1] Male	Female	Emerging larvae
Azinphos-methyl 500 ppm a.i.		38.3 a[2]	90.0 a	82.6 a	90.0 a
Phosmet 500 ppm a.i.		42.6 a	90.0 a	90.0 a	90.0 a
Phosalone 900 ppm a.i.		56.9 a	71.1 a	68.1 a	83.7 a
Check		61.4 a	19.8 b	0.0 b	5.1 b

[1] Total of 325, 308, 106 and 86 eggs was observed in 3 replicates in check, phosalone, phosmet and azinphos-methyl treatments, respectively.
[2] Means followed by the same letter not significantly different (P = 0.05).

It is apparent, therefore, that azinphos-methyl and phosmet have ovicidal activity against codling moth eggs. Application of these materials is usually timed to coincide with the emergence of 1st instar larvae for maximum effectiveness. However, as eggs in all stages of development are also affected, timing of this spray to achieve maximum control may become less critical.

Acknowledgements

The author thanks Mr. D. Barber for technical assistance.

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A CHECK LIST OF THE BUTTERFLIES OF THE PROVINCE OF NEWFOUNDLAND INCLUDING LABRADOR[1]

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Abstract

Sixty-one species of butterflies, representing seven families, have been found in Newfoundland and Labrador. Of these, twenty-eight are common to insular Newfoundland, including Labrador, twenty-one to Newfoundland only and twelve to Labrador only.

* * * * * *

During the past twenty-five years the writer has made periodic collections of Lepidoptera in various parts of Newfoundland and Labrador. A small number of light traps were also operated in various localities and some diurnal species were captured by netting. The identity of all specimens listed was determined by members of the Lepidoptera and Trichoptera Section, Biosystematics Research Institute, Ottawa.

The check list presented here includes all species from Newfoundland and Labrador contained in the Canadian National Insect Collection, Ottawa, and private collections in Canada and the United States. It also includes records contained in earlier publications of prominent Lepidopterists who studied the butterflies of Newfoundland and Labrador. The most informative of these earlier papers were by Gosse (1883), Packard (1888), dos Passos (1935, 1936 and 1938), Freeman (1943), Klots (1951) and Krogerus (1954).

The list is, therefore, an updated record of the species of butterflies which are now known to occur in insular Newfoundland and Labrador. With further intensive collecting in Newfoundland and Labrador, in the future, there is little doubt that additional new records and possibly new species will be identified.

[1] Contribution No. 52, Research Station, Agriculture Canada, St. John's West, Newfoundland.

System of recording used in this list. In the arrangement and nomenclature, with minor exceptions resulting from more recent research, this list follows the format of the McDunnough Check List of 1938. The advantages of this list are well known despite changes in specific and generic nomenclature. Species entries are preceded by the McDunnough list numbers.

No.	Scientific Name	Common Name	Nfld.	Labr.
	Family *PAPILIONIDAE*	The Swallowtails		
4	*Papilio polyxenes asterius* Stoll	Black or Parsnip Swallowtail	+ (a)	
5	*P. brevicauda* Saunders	Short Tailed Swallowtail	+	+
15	*P. glaucus glaucus* Linnaeus	Eastern Tiger Swallowtail	+	
15a	*P. glaucus canadensis* Rothschild & Jordan	Canadian Tiger Swallowtail	+	
	Family *PIERIDAE*	The Whites & Sulphurs		
39	*Colias hecla* Lefèbre	Arctic Sulphur		+
41	*C. eurytheme* Boisduval	Alfalfa Butterfly	+	
42	*C. philodice* Godart	Common Sulphur	+	
45	*C. interior* Scudder	Pink Edged Sulphur	+	+
50	*C. pelidne* Boisduval & LeConte	Pelidne Sulphur	+	+
51	*C. palaeno chippewa* Edwards	Palaeno Sulphur		+
52	*C. nastes* Boisduval	Nastes Sulphur		+
83	*Pieris napi frigida* Scudder	Mustard White	+	+
86	*P. rapae* (Linnaeus)	European Cabbage Butterfly	+	
	Family *DANAIDAE*	The Monarchs		
89	*Danaus plexippus* (Linnaeus)	Monarch	+	
	Family *SATYRIDAE*	The Satyrs & Wood Nymphs		
109	*Coenonympha inornata inornata* Edwards	Inornate Ringlet	+	+
109a	*C. inornata mcisaaci* dos Passos	McIsaac's Ringlet	+	
127	*Oeneis chryxus* (Doubleday)	Chryxus Arctic	+	
129	*O. taygete* Geyer	White Veined Arctic		+
130	*O. jutta terraenovae* dos Passos	Jutta Arctic	+	+
136	*O. polixenes* (Fabricius)	Polixenes Arctic		+
138	*O. melissa* (Fabricius)	Melissa Arctic	+	+
144	*Erebia disa* (Thunberg)	Disa Alpine		+
	Family *NYMPHALIDAE*	The Brush-footed Butterflies		
171	*Speyeria atlantis* (Edwards)	Atlantis Fritillary	+	+
200a	*Boloria selene atrocostalis* (Huard)		+	+
200b	*B. selene terraenovae* (Holland)	Silvered Bordered Fritillary	+	+
202	*B. eunomia* (Esper)	Bog Fritillary		+
206	*B. chariclea* (Schneider)	Arctic or Chariclea Fritillary	+	+
206a	*B. titania boisduvalii* (Duponchel)	Purple Lesser Fritillary		+
208	*B. freija* (Thunberg)	Freija Fritillary	+	+
210	*B. polaris* (Boisduval)	Polaris Fritillary		+
211	*B. frigga saga* (Staudinger)	Saga Fritillary		+
212a	*B. bellona* (Fabricius)	Meadow Fritillary		+
256	*Chlosyne harrissii* (Scudder)	Harris' Checkerspot	+	
265a	*Phyciodes tharos arctica* dos Passos	Pearl Crescent	+	+
287	*Polygonia satyrus* (Edwards)	Satyr Angle Wing	+	
287a	*P. satyrus neomarsyas* dos Passos		+	
288	*P. faunus* (Edwards)	Green Comma	+	
292	*P. gracilis* (Grote & Robinson)	Hoary Comma	+	+
294	*P. progne* (Cramer)	Grey Comma	+	
295	*Nymphalis vau-album* ([Denis & Schiffermueller])	Compton Tortoise Shell	+	+
297	*N. milberti milberti* (Godart)	Milbert's Tortoise Shell	+	
297a	*N. milberti viola* (dos Passos)		+	
298	*N. antiopa* (Linnaeus)	Mourning Cloak	+	+
299	*Vanessa atalanta* (Linneaus)	Red Admiral	+	
300	*V. virginiensis* (Drury)	American Painted Lady	+	
301	*V. cardui* (Linnaeus)	Painted Lady	+	+
321	*Limenitis arthemis* (Drury)	White Admiral	+	+
	Family *LYCAENIDAE*	The Gossamer Winged Butterflies		
403	*Callophrys augustinus* (Westwood)	Brown Elfin	+	+
403a	*C. augustinus helenae* dos Passos		+	
413	*C. niphon clarki* (Freeman)	Pine Elfin	+	

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No.	Scientific Name	Common Name	Nfld.	Labr.
433	*Lycaena dorcas* Kirby	Dorcas Copper	+	+
434a	*L. epixanthe phaedrus* Hall	Bog Copper	+	
449	*Plebejus argyrognomon aster* (Edwards)	Northern Blue	+	+
449a	*P. argyrognomon empetri* (Freeman)	Northern Blue		+
452	*Plebeius aquile* (Boisduval)	Arctic Blue	+	+
473	*Glaucopsyche lygdamus couperi* Grote	Silvery Blue	+	+
475	*Celastrina argiolus pseudargiolus* (Boisduval & LeConte)	Spring Azure or Jenny Lind	+	+
	Family *HESPERIIDAE*	The Skippers		
515	*Pyrgus centaureae* (Rambur)	Grizzled Skipper	+	+
563	*Carterocephalus palaemon* (Pallas)	Arctic Skipper	+	+
584	*Hesperia comma borealis* Lindsey	Comma or Labrador Skipper	+	+
614	*Polites coras* (Cramer)	Peck's Skipper	+	+

(a) A doubtful record.

Acknowledgement

Sincere thanks to members of the Lepidoptera and Trichoptera Section, Biosystematics Research Institute, Ottawa, for identifying most species collected and to Mr. H. Morry for his technical assistance.

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TESTICULAR DEVELOPMENT IN THE COCKROACH, *PERIPLANETA AMERICANA* (L.)

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Abstract

The effects of the corpus allatum and the hormone ecdysterone on development of the testes of the cockroach, *Periplaneta americana* (L.) were investigated by extirpating endocrine glands, transplanting testes, and by injecting the hormone ecdysterone into experimental animals.

It was found that testes would continue to develop in the absence of hormones, but that the presence of the corpora allata retarded development while ecdysterone accelerated development.

* * * * * *

Introduction

Naisse (1966) provided the first indication that androgenic hormones may occur in insects and more recently it has been shown that juvenile hormone and ecdysone or its analogue ecdysterone, affect spermatogenesis. Sehnal (1968) found that implanted corpora allata would cause testes of last stage *Galleria mellonella* (L.) to remain in a larval condition following the next ecdysis. Blaine and Dixon (1970) showed that allatectomy accelerated spermatogenesis in the cockroach, *Periplaneta americana* (L.), but only in nymphs moulting to precocious adults. Takeuchi (1969) working with the silkworm, *Bombyx mori* (L.) found that development of the testes was delayed in isolated pupal abdomens receiving adult corpora allata which are known to secrete large amounts of juvenile hormone. Development of embryonic testes was fastest when transplanted into fifth-instar larvae which have the greatest concentration of ecdysone. Ketchel and Williams (1953) Williams and Kambysellis (1969), and Kambysellis and Williams (1971a, 1971b) found that ecdysone or ecdysterone was required for development of the testes of several species of saturniids. However the presence of ecdysone alone was not sufficient. A macromolecule which appeared after ecdysone was injected, was also necessary. Church (1955) found that ecdysone was essential for meiosis and spermatid formation in the sawfly, *Cephus cinctus* Nort. Yagi *et al.* (1969) showed that ecdysone stimulated the development of the testes of the rice stem borer, *Chilo suppressalis* Walker, *in vitro and* Takeda (1972) obtained similar results for the slug moth, *Monema flavescens* Walker. Both workers showed that naked spermatocytes were more sensitive to ecdysone than those in cysts.

Since this work was completed, Kuroda (1974) and Dumser and Davey (1974) have reported on the influence of hormones *in vitro* during testis development of *Drosophila* and *Rhodnius* respectively. Both studies indicate that with these species, as is shown for *Periplaneta* in the present study, there are periods of relative independence to hormonal influence during testicular development.

Materials and Methods

The cockroaches, *Periplaneta americana* (L.) were kept in the laboratory under standard conditions. Selection of animals and operational procedures were described in a previous paper (Blaine and Dixon 1970). Cockroaches which were to be used immediately after the moult were selected in the preceding instar and kept until the moult occurred. Ecdysterone (Becton, Dickinson and Co.) was dissolved in 2% ethanol in Ludwig's saline to give a final concentration of 10 μg per μl. Injections were made intersegmentally in the abdomen.

Testes were examined as squashes by phase contrast microscopy. Experimental testes were rated as to whether development had proceeded farther than in normal testes in a similar time period. These stages are described among the results.

Results

Testis development

The testes are formed of approximately sixty round tubules each of which contained numerous cysts in various stages of development. Secondary spermato-

cytes developed early in the eighth instar and spermatids were the latest stage found at the beginning of the ninth instar in *Periplaneta*. Mature sperm were not seen until the instar was one-third complete which was approximately fifty-five days from the beginning of the eighth instar. Early in the tenth instar, two-thirds of the tubules had sperm and late in the instar the majority of cysts of almost all tubules had sperm.

Effect of allatectomy on testis development

The corpora allata were removed from ten eighth-instar cockroaches immediately after the moult. The results (Table I) show that two animals moulted to precocious adults with advanced testes. One moulted to a semi-adult. Two took longer than normal to moult, and had accelerated rates of spermatogenesis, although not as great as in precocious adults. In the other five cockroaches, development was normal. Thus five out of ten animals showed accelerated testis development following allatectomy.

TABLE I. Development of the testes of eighth-instar *Periplaneta americana* (L.) following allatectomy.

Length of Instar	Moult	Condition of Testes
35	Nymphal	Normal (spermatids)
38	Nymphal	Normal
38	Semi-adult	Advanced (mature sperm in half of tubules)
38	Nymphal	Normal
39	Nymphal	Normal
40	Nymphal	Normal
52	Nymphal (wings slightly elongated)	Advanced (mature sperm in half of tubules)
55	Nymphal (wings slightly elongated)	Advanced (mature sperm in half of tubules)
56	Adult	Advanced (mature sperm in three-quarters of tubules)
64	Adult	Advanced (mature sperm in three-quarters of tubules)

Average length of instar of normal cockroach: 40 days.

Effect of ecdysterone (20-hydroxyecdysone) on testis development

Testes were taken from seventh- and eighth-instar nymphs and transplanted into newly metamorphosed adult cockroaches which were either allatectomized or non-allatectomized (normal). Both groups were ecdysterone treated, controls were saline injected. Within each group the two testes of a nymphal donor provided a transplant for, (a) an ecdysterone treated cockroach and, (b) the saline injected control (Table II). Cockroaches received 15 μg of ecdysterone every six days. The controls received 2% ethanol in saline only. The testes were removed for examination twenty days after the first injection.

Ecdysterone accelerated spermatogenesis in transplanted testes in both normal and allatectomized hosts (Table II). However the rate of acceleration was slight. That is to say, if development proceeded to mid-spermatid formation among the controls, containing the eighth-instar transplant, development in the experimental animals reached the late spermatid stage.

Ecdysterone was also injected into newly moulted, allatectomized or normal eighth-instar cockroaches. They received 10 μg every six days (total of 40 μg) and were examined twenty days after the first injection. Controls were injected with 2% ethanol in saline. All insects were left for six to seven days to allow allatecto-

TABLE II. The effect of ecdysterone on development of seventh- and eighth-instar testes of *Periplaneta americana* (L.) transplanted into adults.

Number of Roaches	Treatment of Adults	Development of Testes
10 experimental 10 control	Allatectomized + ecdysterone Allatectomized + saline	Slight acceleration of development in experimental animals in 9 out of 10 cases, no acceleration of development in controls.
10 experimental 10 control	Non-allatectomized + ecdysterone Non-allatectomized + saline	Slight acceleration of development in experimental animals in 8 out of 10 cases, no acceleration of development in controls.

Experimental animals received 15 μg of ecdysterone every six days. Total 60 μg.
Controls received 2% ethanol in saline only.

TABLE III. The effect of ecdysterone on development of insect testes of eighth-instar *Periplaneta americana* (L.).

Number of Roaches	Treatment	Development of Testes
9	Allatectomized, 40 μg of ecdysterone added	Acceleration of development in all, mature sperm in almost all tubules
9	Corpora allata intact, 40 μg of ecdysterone added	Acceleration of development in all, mature sperm in almost all tubules
8	Corpora allata intact, 2% ethanol in saline added	Development normal, secondary spermatocytes only

mized cockroaches to recover. In all nymphal cockroaches ecdysterone increased the rate of spermatogenesis (Table III). Mature sperm were found in most tubules and several tubules were almost completely filled with sperm. Ecdysterone caused greater acceleration of nymphal testicular development *in situ* than did ecdysterone injected after the nymphal testes were transplanted into adults.

Discussion

Transplanted nymphal testes will develop in allatectomized adults showing that they will mature in the absence of both corpora allata and the prothoracic glands, since the latter degenerate in normal adults after metamorphosis. However, both the corpora allata and ecdysterone influence the rate of development. Allatectomy increased the rate of development. The fact that acceleration of testis development did not occur in half the allatectomized cockroaches may be due to the level of residual hormone. Wigglesworth (1970) cited samples of delay in precocious development after allatectomy which he attributed to a higher residual level of juvenile hormone. Testis development following allatectomy parallels the development of other adult characteristics such as degree of wing development and accessory gland development (Dixon and Blaine 1972).

Ecdysterone accelerated testis development in all cases. Its influence was greatest when injected into nymphal cockroaches whether allatectomized or not, although adults with transplanted testes received 20 μg more ecdysterone than did the nymphs. Immediately following metamorphosis, the prothoracic glands degenerate. Thus the lower rate of testes development in adults, compared with nymphs, treated with ecdysterone might be due to either a higher, natural ecdysone level in nymphs or in the case of adults an already low ecdysone level may be accompanied by a faster rate of ecdysterone metabolism and degradation. The slower development of these nymphal testes transplants compared with the accelerated rate of development of the intact testes cannot be due to such factors as severed nerve connections, since earlier work (Blaine and Dixon 1970) demonstrated that nymphal testes when transplanted back into the animal developed normally. Moreover this work had also demonstrated that testicular development was not retarded when nerves or nerve cord were severed.

The fact that testes will develop in an adult in the absence of prothoracic glands, and in spite of active corpora allata suggest that they can be relatively independent of hormonal influence. The presence of sperm in last instar nymphs suggests that testes mature in the relative absence of juvenile hormone. Kuroda (1974) has found spermiogenesis but not early spermatogenesis to occur in *Drosophila* testes *in vitro* without exogenous ecdysone. Kuroda suggests two possibilities, (a) differing hormone dependence during growth; spermiogenesis may be completely independent and (b) there may exist a difference in hormone retention within germ cells, there being a low retention during the early stages. Dumser and Davey (1974) suggest that an "endogenous level" of development is maintained during low levels of hormone concentration. Our results are consistent with these notions. It may be that the progressive development of testes during nymphal stages is attributable to the cyclical release of ecdysone, and their maturation is held in check by the cyclical release of juvenile hormone.

Acknowledgments

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AUTHOR'S GUIDE

1. Two copies of a manuscript are required by the Editor (including second copy of each figure by print or photostat).
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FELLOWS OF THE ENTOMOLOGICAL SOCIETY OF ONTARIO

(With date of election)

A. W. A. Brown (1969)

E. M. DuPorte (1969)

R. Glen (1969)

G. P. Holland (1971)

G. F. Manson (1968)

C. R. Twinn (1963)

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CONTENTS

I. THE SOCIETY

IN MEMORIAM

The following entomologists, all of whom were members of the Society at some time, died during 1976.

J. Frank Brimley (1883-1976), one of Canada's "old time" naturalists, died in Wellington, Ontario on January 6, 1976. An obituary, prepared by E. C. Becker, was published in the Bulletin of the Entomological Society of Canada 8 (2): 12-13, 1976.

* * * * * *

Alan G. Dustan (1892-1976), developed vegetable insect studies in Canada and was associate head of Field Crop Insect Investigations when retired. After retirement he worked each winter for the Bermuda Department of Agriculture for a decade and several summers with the Commonwealth Institute of Biological Control. The Bulletin, Entomological Society of Canada 8 (3): 7, 1976, contains an obituary prepared by a colleague, W. G. Matthewman.

* * * * * *

James J. Fettes (1915-1976), Director, Chemical Control Research Institute, Canada Department of Environment, died in Ottawa on July 10, 1976.

* * * * * *

W. Gilbert Garlick (1894-1976), who spent 34 years on the staff of the Dominion Fruit Insect Laboratory (now Research Station) at Vineland Station, Ontario, died in London, England on Christmas Day, 1976. G. G. Dustan, a colleague for many years, prepared an obituary which was published in the Bulletin of the Entomological Society of Canada 9 (1): 35-36, 1977.

* * * * * *

Frank O. Morrison (1911-1976), chairman of the Department of Entomology at Macdonald College of McGill University, died on May 2, 1976. An obituary and a bibliography, prepared by R. K. Stewart of the College, was published in the Annals of the Entomological Society of Quebec 22(1): 67-71, 1977 and in the Bulletin of the Entomological Society of Canada 9(4), 1977.

* * * * * *

Benoit J. Parent (1922-1976), an expert on phytophagous mites and their control, died on March 16, 1976. An obituary (French) prepared by a colleague, R. O. Paradis, was published in the Bulletin, Entomological Society of Canada 8 (2): 11, 1976.

Jacob G. Rempel (1903-1976). Emeritus Professor of Biology, University of Saskatchewan, died May 30, 1976, at Victoria, B.C. An obituary, prepared by Robert Glen, is contained in the Bulletin, Entomological Society of Canada 8 (3): 4-6, 1976.

* * * * * *

Kenneth B. Turner (-1976), forest entomologist, died in Toronto on August 22, 1976 following a lengthy illness. He joined the Ontario Department of Lands and Forests upon graduation and spent his entire career with it and its successor the Ministry of Natural Resources. An obituary, prepared by a colleague, R. M. Dixon, appeared in No. 70 of The Professional Forester in December 1976.

II. SUBMITTED PAPERS

SCIOMYZIDAE (DIPTERA) POPULATION PARAMETERS ESTIMATED BY THE CAPTURE-RECAPTURE METHOD[1]

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Department of Entomology, Cornell University, Ithaca, New York 14853

Abstract

Adults of *Sepedon fuscipennis* Loew were captured, individually marked, and released on 28 occasions over 3 years. Reproductive outputs of females were sampled for 24 h at each capture to estimate parameters rarely studied in insect capture-recapture surveys. Jolly-Seber estimates of population size peaked in late summer each year at 0.45-1.1 adult m^{-2} of emergent vegetation. Oviposition rate was correlated with temperature and photoperiod, and was 15-30 eggs $female^{-1}$ day^{-1}. Reproductive incidence was 40-95% from June-August each year, but dropped rapidly to 0% near the time of the autumnal equinox. Collection of ecological data from each animal captured can enhance the cost-effectiveness of capture-recapture sampling.

* * * * * *

Introduction

The Sciomyzidae, or marsh flies, have been the object of an intensive research effort during the last several years. The diversity of strategies by which the larvae attack and consume Mollusca has aroused much interest (Berg and Knutson in press), as has the possible use of Sciomyzidae for the biological control of snail vectors of trematode parasites of man and domestic animals (Berg 1973). During the last decade, most quantitative ecological studies of the Sciomyzidae have focused on *Sepedon fuscipennis* Loew, a relatively large, common marsh fly distributed throughout much of North America. From research on this species, guidelines for the quantitative study of other sciomyzid populations may emerge.

There are about 600 species of Sciomyzidae, and the food habits of the larvae of about one third of these are known (L. Knutson unpublished[2]). Though almost all studied sciomyzid larvae feed on aquatic or terrestrial snails, natural histories of the species do not conform to a single pattern. A spectrum of correlated adaptations extends from the terrestrial parasitoid larvae, typified by members of the tribe Sciomyzini, to the aquatic predatory larvae of some Tetanocerini (Berg and Knutson in press).

Sepedon fuscipennis larvae typify the aquatic predators. They are found at the surface film around emergent vegetation in marshes, backwaters, and margins

* Present address: Department of Biological Sciences, State University College, Brockport, New York 14420.

[1] A report of research of the Cornell University Agricultural Experiment Station.

[2] Knutson, L. 1976. Annotated checklist of the Sciomyzidae, Phaeomyiidae, and Heloscomyzidae of the world. Unpublished manuscript. 52 pp.

of lakes, ponds, and rivers. Adult females oviposit on emergent vegetation, and the first instar larvae fall into the water upon eclosion. The larvae search out and kill many snails of various pulmonate families during their development, and finally form free-floating puparia. The adults are long lived relative to their developmental periods (Neff and Berg 1966), and the females continue to oviposit long after they can make significant contributions to the intrinsic rate of increase (Barnes 1976b). Like some other Sciomyzidae of permanent aquatic habitats, *S. fuscipennis* has overlapping, nonsynchronous generations throughout the warm part of the year, and all stages of the life cycle can be found simultaneously throughout the summer (Eckblad and Berg 1972). Adults emerging during short days of September and October enter reproductive diapause (Barnes 1976b), and are thought to be the only members of the population that overwinter (Peacock 1973).

This preliminary report contains the first results of a 3-year field study of the *Sepedon fuscipennis* population of 4 experimental marshes. During a capture-recapture survey, the reproductive status of each female was assessed, and the eggs each female laid in a 24-hour period were collected. In addition to the estimates of population size, survival, and recruitment normally obtained from recapture sampling, data on oviposition rate, reproductive incidence, egg fertility, egg mortality, egg development rate, and adult dispersal were collected. Such a multipurpose sampling plan may prove useful in other insect population studies. Population size, oviposition rate, and reproductive incidence methods and results are reported here.

Materials and Methods

In June 1973, 4 ponds were drained at the Cornell Experimental Ponds, Ithaca, New York. Clumps of grasses and sedges were transplanted into the pond basins from local marsh habitats, and the ponds were refilled to a mean depth of 20 cm. The experimental marshes thus created were 20 m square, arranged in a 2 x 2 array. Six species of aquatic pulmonate snails and more than 10 species of Sciomyzidae subsequently established themselves. *Sepedon fuscipennis* and *Dictya expansa* Steyskal were the dominant marsh fly species.

Sepedon fuscipennis adults were surveyed using the capture-recapture method during 1974-6. Over 1-3 day periods every 1-3 weeks 50-150 flies were captured by sweeping through emergent vegetation or by stalking flies observed from a distance. During each period, relatively constant effort was expended per unit area of emergent vegetation. From the sweep net the flies were isolated in 8.5 x 2.5 cm vials and returned to a nearby unheated laboratory. There each fly was sexed, and if unmarked, marked with a 5-spot pattern on the dorsum of the thorax, using up to 5 colors of artists' oil paint (Southwood 1966, p. 59). Colors that were close to those of the flies were used to reduce the likelihood that marked flies would be subject to higher rates of capture or predation than unmarked flies. The marks were quite durable, lasting 9 months in the field in one case. Since the loss of color spots was rare, and the loss of spots was thought to be statistically independent, I assume that no marked fly was misclassified as unmarked.

After marking, flies were held individually for 1-3 days in 8.5 x 5.0 cm clear styrene plastic vials. The vials were provided with screen lids, damp cotton substrate, sticks for resting, and match-head-size portions of honey-yeast food mixture. Fluctuating temperatures and natural photoperiod prevailed in the field laboratory during this period, and daily maximum and minimum temperatures were recorded. At release time, normally active flies were returned in their vials to a central point in their respective marshes of capture. There the vial lids were

removed gently so as not to cause the flies to take wing. (*Sepedon fuscipennis* adults acclimated to such vials fly infrequently unless the vials are handled roughly.) After several hours the vials and any remaining flies (presumed to be injured during marking) were retrieved. Records were maintained for each of the ca. 1800 flies encountered in the survey, showing the date and marsh of each capture and release. This sampling plan was used during May-October on 28 occasions over the 3-year period.

The capture-recapture statistics were extracted independently from the individual recapture histories and coded for each of 2 computer programs (White 1971a, b, P. Goldstein unpublished[3]) which computed Jolly-Seber estimates of population size (number of individuals). The Jolly-Seber statistical model efficiently uses the data from a multiple recapture census, and not all animals captured must be released (Jolly 1965, Seber 1965, Southwood 1966, pp. 83-87). Verification of data coding and program logic for all estimates for which the 2 programs differed suggested modifications of Goldstein's program for sampling dates with no recaptures. When the programs produced identical estimates, population sizes and their standard errors were estimated for 15 subsets of the data. The subsets were females, males, and both sexes pooled, for each marsh separately and for all 4 marshes pooled.

The reproductive status of each female *Sepedon fuscipennis* was assessed by (1) examination of her abdomen after marking but before feeding, (2) collecting all eggs each female laid in captivity, and (3) counting those eggs laid in the 24-h oviposition trial beginning after marking and feeding. Two variables were calculated from these data. Oviposition rate is the mean number of eggs laid per female per day among females that laid eggs during the oviposition trial. Reproductive incidence is the percent of females in the population that are functionally reproductive, i.e., not prereproductive or diapausing. This was estimated as the percent of females completing the 24-h oviposition trial that either oviposited, or had fully developed eggs visible through the thin integument of the abdomen. This is an underestimate to the extent that some females may lay all their eggs just before capture and are indistinguishable from diapausing females.

Results and Discussion

Even with adequate sample sizes and sufficient numbers of recaptures, the Jolly-Seber model does not provide estimates of population size for the first and last sampling dates. Insufficient sample size or numbers of recaptures can further reduce the number of estimates possible. Though the standard errors are large for the 1975 estimates because of insufficient sampling intensity, means from the other 2 years show the expected upward trend (Fig. 1). This trend is also supported by subjective estimates of yield per unit sweeping effort. Since reliable Jolly-Seber estimates cannot be made when the population is sparse or for the first or last sampling dates, the initial jump in numbers when the first young of the year emerge is not apparent in Fig. 1, nor is the drop in numbers around the first frost in the fall. In 1976 the peak population occurred over 0.11 ha of emergent vegetation for a density of 0.53 fly m^{-2}.

Two previous studies of *Sepedon fuscipennis* populations employed capture-recapture methods. Eckblad and Berg (1972) obtained Petersen estimates (Seber 1973, p. 59 et seq.) (= Lincoln Indexes, Le Cren 1965) on 7 occasions by recapturing 3 h after release. Their estimates of 50-200 adults in about 210 m^2 of emergent vegetation indicate a slightly denser population (ca. 1 fly m^{-2}) than

[3] Goldstein, P. 1972. Calculation of various population parameters from capture-recapture data using the method described by G. M. Jolly. Unpublished computer program. 528 cards.

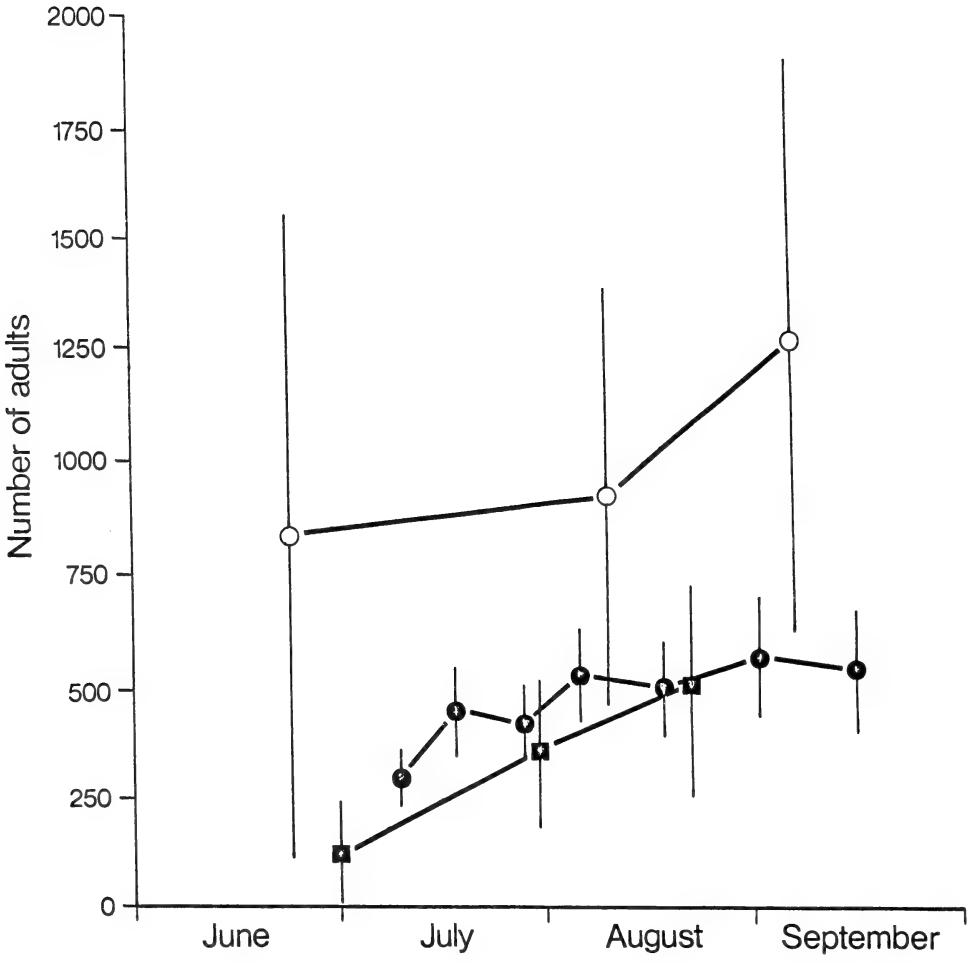

FIGURE 1. Number of *Sepedon fuscipennis* adults in the experimental marsh population in 1974 (■), 1975 (○), and 1976 (●), as estimated from data for both sexes and all marshes pooled by the Jolly-Seber method. Vertical bars are ± 1 asymptotic standard error (Jolly 1965). Only sampling dates for which sufficient numbers of recaptures were made are plotted.

found in this study. They give no standard errors. Peacock (1973) used his recapture rates only for subjective comparisons of dispersal rates from his several sampling sites, since his populations were not closed (i.e., no recruitment or loss) as required for Petersen estimates. My success in marking large fractions of the population (mean of 17% for the 13 samples shown in Fig. 1) can probably be attributed to the population's relative isolation.

Some inferences can be made from the recapture histories of individual flies. The most important individual recapture history in this study was that of a female first marked in August 1974 and subsequently recaptured in May 1975. She was at least 285 days old and reproductive when she was recaptured. This is the first proof under field conditions that *Sepedon fuscipennis* can overwinter as an adult.

Further computations and refinements of the recapture results are necessary. Both of the computer programs used in this study must be modified to use Seber's (1973, p. 204) bias-corrected estimation formulae. The data must be tested for conformity to the assumptions of the Jolly-Seber method, especially for differences between the behavior of flies of different sex, age, and recapture history (White 1975). Recruitment and survival estimates provided by the Jolly-Seber model remain to be evaluated.

Oviposition rates were calculated for the 19 dates on which females laid eggs (Fig. 2). The rates were positively correlated to temperature and photoperiod. Barnes (1976a) found that *Sepedon fuscipennis* oviposits mostly during

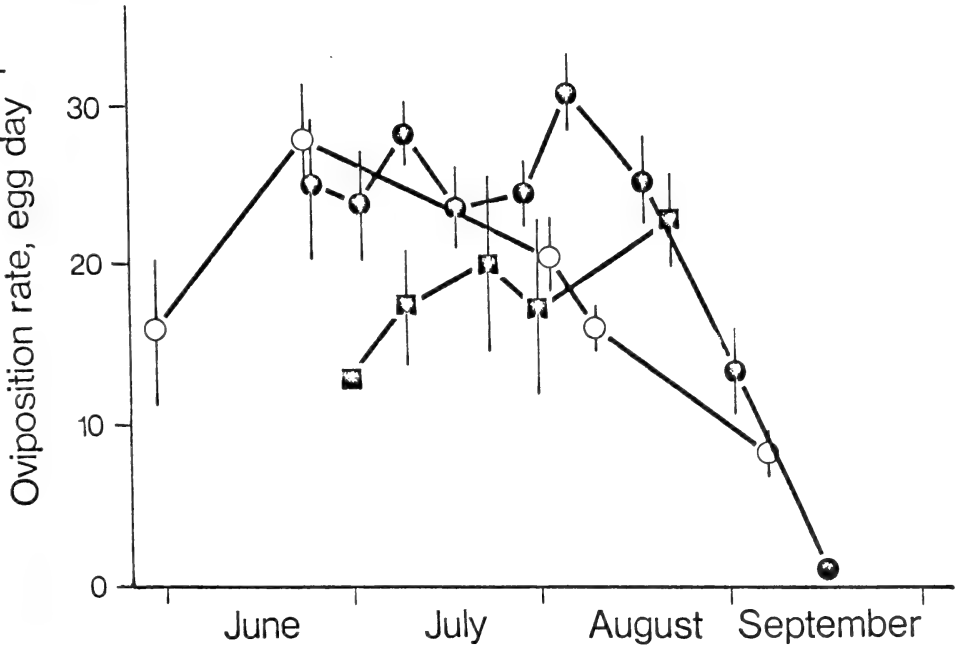

FIGURE 2. Oviposition rate by captured *Sepedon fuscipennis* females that oviposited during the 24-h oviposition trial in 1974 (■), 1975 (○), and 1976 (●). Vertical bars are ± 1 standard error. Only one female oviposited on each of the first sampling date in 1974 and the last date in 1976.

the photophase, and (1976b) determined the oviposition rates of *S. fuscipennis* at 5 constant temperatures in growth chambers. My data provide an opportunity to validate an oviposition rate model for *S. fuscipennis* using parameters determined from the data of Barnes (1976b), since temperature data are available for each oviposition trial period.

The peak of reproductive incidence occurred in midsummer, when the number of prereproductive females had fallen to a low value relative to the number of older females in the population, but the incidence of diapause was still very low (Fig. 3). To what extent the drop in reproductive incidence in August was caused by the death of the older reproductive females, and to what extent by increasing diapause incidence, is not yet known. Oviposition ceased at the same time each year, when photoperiod was shortening at the maximum rate. This is further evidence for a photoperiodically initiated diapause in *Sepedon fuscipennis,*

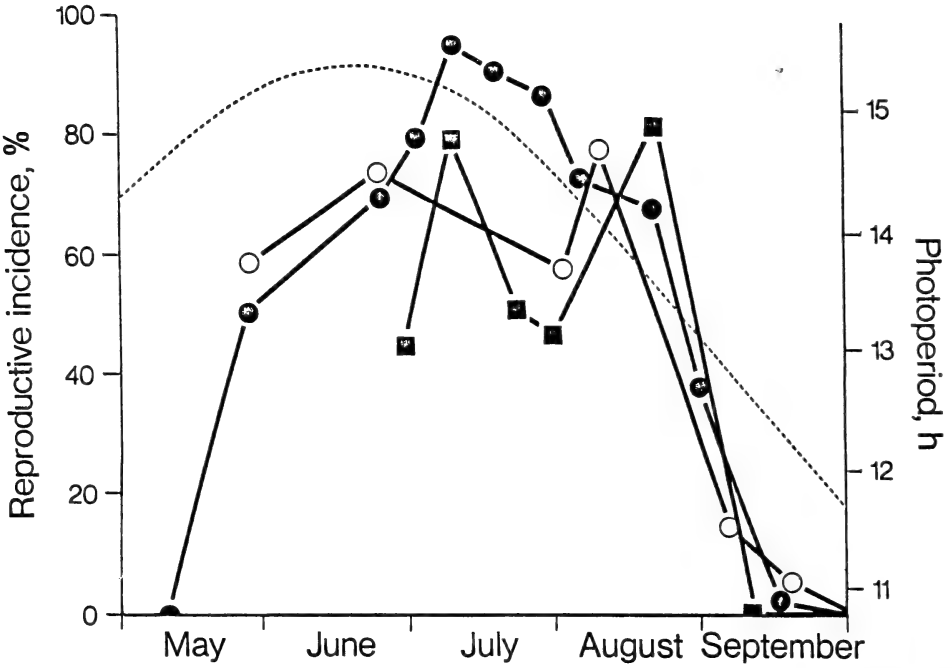

FIGURE 3. Reproductive incidence (fraction of females either ovipositing or having eggs visible through the abdominal integument) in captured *Sepedon fuscipennis* females in 1974 (■), 1975 (○), and 1976 (●), and photoperiod at the latitude of the study site (------). Except for the first 2 dates in 1974 (n = 11 and 10, respectively) and the first 2 dates in 1976 (n = 2 for each), percentages are based on 20-77 females.

noticed before by Peacock (1973) in the field, and demonstrated by Barnes (1976b) in the laboratory.

Capture-recapture estimation is usually reserved for populations that can be studied in no other way: cryptic, free-ranging, without synchronous generations, living in 3-dimensional habitats, or otherwise difficult to sample. The immense amount of skilled labor required to mark and release the animals, and to tabulate and analyze the data, has discouraged the use of recapture techniques whenever quadrat samping can be used, or when relative density estimates will suffice. This research suggests that much useful data can easily be obtained from capture-recapture studies in addition to the recapture statistics.

Acknowledgments

This research was supported by grants GB-32917X and BMS 75-10451 from the General Ecology Program, United State National Science Foundation, to Clifford O. Berg and by Cooperative Agreement 12-14-1001-400 between the Agricultural Research Service, United States Department of Agriculture, and the Department of Entomology, Cornell University.

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A GENERAL MATHEMATICAL MODEL FOR INSECT OUTBREAK

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Abstract

Elementary catastrophe models are well suited to represent insect outbreak dynamics. The model takes various control parameters into account and stresses the importance of stochastic inputs.

Forest tent caterpillar outbreaks may occur when populations escape from ecologically confining refugia and disperse over the entire habitat. Outbreak and refugia-contained populations may be represented by different parts of the attractor sheets of the elementary catastrophe cusp manifold, determined by $\epsilon\dot{x} = -(x^3 + ax + b)$. Slow equations for outbreak dynamics on the cusp are $\dot{a} = -c_1(x+3)^2 + c_2(b+3)^2$ and $\dot{b} = -c_3a(x+3) + c_4(x+3) - c_5(b+3)$.

Introduction

Insect pest outbreaks have aroused scientific interest for some time. While there have been many detailed studies on the outbreak dynamics of specific pests, there is at present no unifying or conceptual framework within which all outbreak phenomena may be described. In this report, we shall present a theoretical model which fulfills this criterion.

The pattern of outbreak in most insect species follows a similar course (e.g. Table I). All outbreaks are characterized by a rapid and extreme increase in population density, followed by a similarly rapid decline to endemic levels. For example, *Malacosoma disstria, Choristoneura fumiferana, Scolytus ventralis* and *Orygia pseudotsugata* all show increases in density of the order 10^3 or greater. In these and other species, there is little regularity in either the duration of an outbreak or the period of time between succeeding outbreaks. In all cases, a widespread outbreak is preceded by a local one.

Although the factors controlling an outbreak vary among species as well as among populations of the same species, the control factors for any outbreak fall into one or more of the following three categories: (1) resource-related factors such as quality of host plant and distribution of host in relation to species dispersal; (2) predation related factors including pathogens, parasites and parasitoids; (3) stochastic factors originating outside the system such as weather or the sudden influx of immigrants. The population dynamics of any outbreak species will be affected by factors in all three categories. However, the relative importance of each factor will vary from species to species (e.g. Table I).

In summary, the population dynamics of outbreak insects are substantially the same, despite specific differences in resource preference and control factors. The development of a general mathematical model to describe outbreak phenomena is therefore justified. We have found that the dynamics of insect outbreak can be adequately described by equations based on the simple cusp of Thom's catastrophe theory (Thom, 1969 and 1975). This model does not possess the precision inherent in the multiple factor hypotheses which have emerged from the studies of specific pests (e.g. Berryman (1973), Hodson (1941) and Rose (1975)). However, it does provide a valuable conceptual framework within which all outbreak phenomena may be described.

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TABLE I. Characteristics of population dynamics of 4 representative outbreak insects.

Insect	Life History	Duration of Outbreak	Period Between Outbreaks	Relative Increase In Density	Principle Host	Resource-Related Control Factors	Predator Related Control Factors	Stochastic Factors	Reference
M. disstria (Forest tent caterpillar)	univoltine	1-5 yrs	7-20 yrs	10^3-10^6X	Aspen		synchronous parasitoids nuclear polyhedral virus	weather	Hodson, 1941
C. fumiferana (Spruce budworm)	mainly univoltine	1-8 yrs	20-29 yrs	10^3-10^4X	Balsam fir	host quality and distribution intra-specific competition		weather	Morris, 1963
S. ventralis (Fir engraver)	univoltine	1-4 yrs	2-11 yrs	10^3X	true firs	distribution and susceptibility of host inter-specific competition	nematode parasitism		Berryman, 1973
O. pseudotsugata (Douglas fir tussock moth)	univoltine	1-3 yrs	7-12 yrs	10^3X	Douglas and other true firs	distribution of host intra-specific competition	nuclear polyhedral virus		Mason, 1974

Theoretical Basis of the Model

The cusp is a three-dimensional surface determining the nature of a gradient dynamical system's structurally stable equilibria when that system is subject to two control parameters (Thom, 1969 and 1975). The cusp is shown in Figure 1.

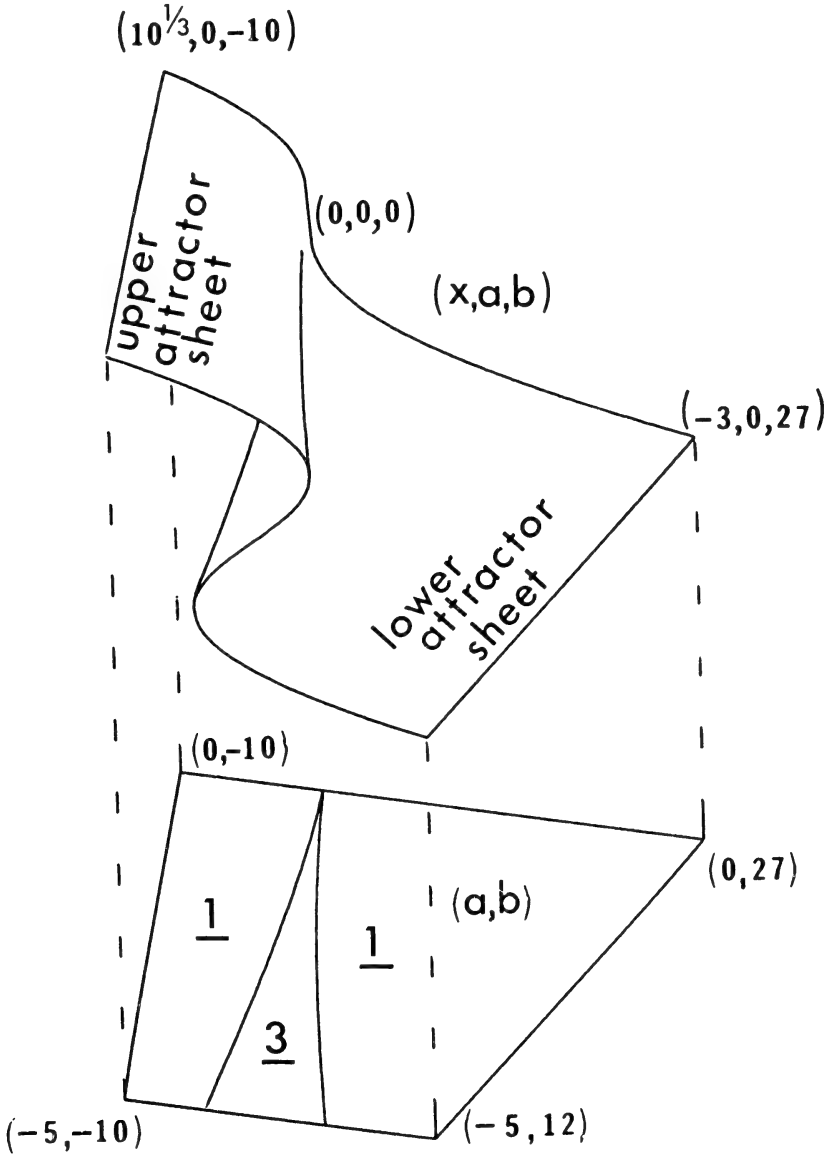

FIGURE 1. The canonical cusp for $0 \geq a \geq -5$, $x \geq -3$, $b \geq -10$. The surface is a manifold of equilibrium points for $\epsilon\dot{x} = -(x^3 + ax + b)$, obtained by setting $\epsilon\dot{x} = 0$ and solving over all values of a and b. Since the values of a and b determine the values of x at which there are equilibria, the control plane (a,b), shown below the manifold, specifies the equilibration along the x axis. The underlined numbers on the control plane indicate the number of equilibria determined by that region of (a,b).

The system state, x, is represented by the vertical axis. The control parameters, a and b, are represented by the two indicated horizontal axes. The depicted three-dimensional surface (Fig. 1) consists of solutions to the equation $x^3 + ax + b = 0$, for $0 \geqslant a \geqslant -5$, $x \geqslant -3$, and $b \geqslant -10$, in the (x,a,b) three-dimensional vector space. This surface is a manifold containing all equilibria for the system $\epsilon\dot{x} = -(x^3 + ax + b)$*, the canonical cusp equation, when a and b are allowed to vary. The ϵ parameter is small, constant, and positive. The upper and lower sheets of the manifold consist of asymptotically stable equilibria, or "attractors". The connecting sheet is made up of unstable equilibria, called "sources" or "repellors". The plane below the manifold is the "control plane", defined by (a,b). The projection of the surface's edges onto the control plane, called the "bifurcation set", demarcates the two different equilibration conditions. Within the region enclosed by the bifurcation set, there are two attractors and one repellor for each (a,b). Outside this region, there is but one attractor. In such cases, (x,a,b) approaches the manifold vertically with rapidity, and then changes only slowly on or near the attractor sheet. With (a,b) inside the enclosed region (x,a,b) vertically approaches the upper attractor sheet when it is above the repellor, the lower attractor sheet when below. If (a,b) passes through the bifurcation set on the right, and (x,a,b) was slowly moving on or near the upper attractor sheet, then x will suddenly be attracted to the lower sheet and decrease precipitously. This vertical movement is termed the "fast action". Movement on or near the manifold attractor sheets is termed the "slow action".

The simple cusp catastrophe is particularly suited to the representation of real-world systems where there are two such markedly different rates of change. Trajectories representing the dynamics of such systems remain on or near the manifold, except when a bifurcation occurs, and the system suddenly switches from one set of attractors to another. To simplify, the cusp catastrophe represents systems in which there are never more than two such attractor sheets, each representing a distinct stable system state.

When applying the catastrophe model to insect population dynamics, the system state, x, will be defined as the population density. The a axis represents resource-related control parameters; the b axis represents predator-related regulatory parameters. A set of three differential equations can be designed in order to produce a trajectory for (x,a,b) over time on the cusp. Stochastic elements can be added to any one, or combination of the equations so as to produce temporary deviations away from the cusp surface as well as allow random perturbations away from the determined trajectory on the attractor sheets.

Depending on the nature of the equations (i.e. on the biological composition of a and b, on their mutual interactions, and their interactions with x) five essentially different trajectories may be obtained. The most typical outbreak trajectory (Fig. 2 A) is represented by a relatively slow rise in population density from the lower attractor sheet to the upper, along the section of the cusp beyond the point of bifurcation. This is followed by a period of time on the upper sheet which is terminated in a sudden "discontinuity", or collapse onto the lower sheet, after which the cycle will repeat itself. Stochastic perturbation may result in (x,a,b) suddenly shifting from the upper to the lower attractor sheet at an earlier point in time than that determined by the basic set of equations.

The sensitivity of the system to stochastic perturbation allows the more extreme outbreak situation, represented in Fig. 2B. Here the trajectory never reaches beyond the bifurcation point. Yet, (x,a,b) can ascend from the lower

* The notation $\dot{x}$ is a short form for the more conventional $\frac{dx}{dt}$

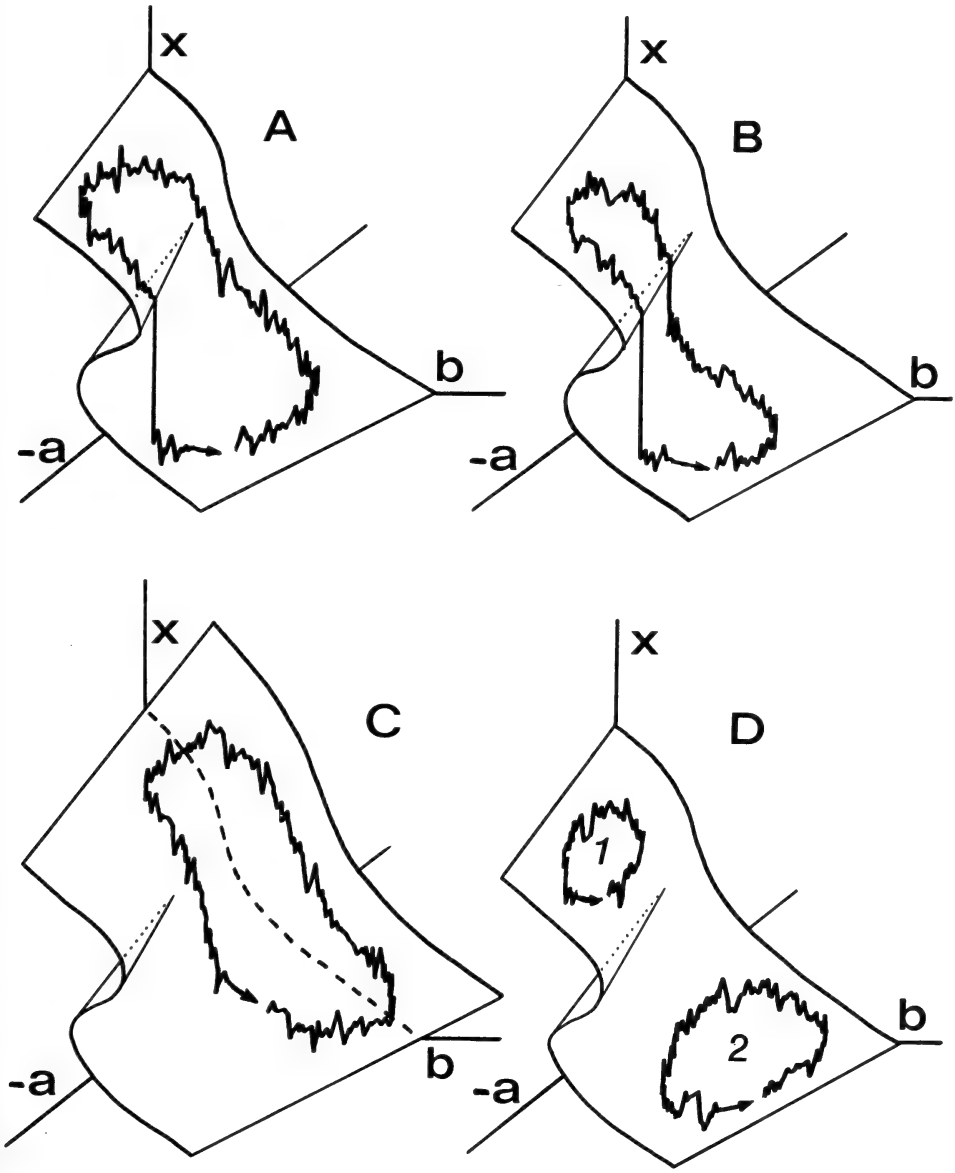

FIGURE 2. Typical dynamic trajectories of cyclical insect populations on a catastrophe model surface. The population density is plotted on the x axis, predation related control parameters on the b axis, and resource related control parameters on the a axis. All trajectories depicted here can be described with a set of three differential equations: $\epsilon\dot{x} = -(x^3 + ax + b)$, $\dot{a} = -c_1x^2 + c_2b^2$, $\dot{b} = -c_3ax + c_4x - c_5b$ plus a stochastic variable. Each depicted trajectory represents one complete cycle. A. The "typical" outbreak trajectory. B. The "extreme" and irregular outbreak trajectory. C. The mild outbreak trajectory. D. Non-outbreak low intensity cyclic populations, 1) at high density and 2) at low density. The importance of the stochastic input here is especially obvious in situation B, where the trajectory would be confined to the lower attractor sheet without the stochastic input. In situation A the timing of the collapse of the population, and in situation B the timing of both the collapse and ascent are highly dependent upon stochastic variables (e.g.—weather, migration).

sheet onto the upper sheet if and when a stochastic perturbation (e.g. immigration) pushes (x,a,b) upwards through the repellor sheet.

In Fig. 2C the entire trajectory takes place beyond the point of bifurcation, resulting in a relatively gentle cycle in population density. In Fig. 2D we see two steady state situations represented: D_1 is a population permanently on the upper sheet, while D_2 is permanently on the lower sheet. These situations may be the result of the populations' trajectories lying permanently to the left or right of the bifurcation. If stochastic perturbation causes the trajectories to penetrate the region of bifurcation, the stochastic perturbation is usually insufficient to carry (x,a,b) across the repellor sheet. Sometimes, man-made perturbations may be of such a magnitude as to shift the population trajectory from one attractor sheet to the other. Man's interference may also shift the arena of the species trajectory in the (a,b) field, allowing normally non-outbreak species to unexpectedly ascend onto the upper sheet.

Application of the Model to

Malacosoma disstria Hbn.

In the past seven years, we have developed a detailed simulation model describing outbreak in *M. disstria,* the forest tent caterpillar (Rose, 1975). Sensitivity analysis of this model indicated that the sensitivity function relating the model parameters to the simulated dynamics could be adequately approximated by equations based on the elementary cusp of Thom's catastrophe theory. We assume that the two major factors controlling *M. disstria* outbreak are (1) the degree of population dispersion relative to the resource distribution and (2) density-dependent regulation determined by parasitoids and viral epizootics. Stochastic factors such as weather may also influence the outbreak dynamics.

For the application of the cusp model to *M. disstria,* let $x + 3$ be the effective ecological density of the caterpillar, and let $-a$ and $b + 3$ be the degree of population dispersion and the effective density-dependent regulation, respectively. [The addition of constants and sign changes are for mathematical convenience.] Large positive values of x represent an extremely dense population. Large negative values of a represent a highly dispersed population. Large positive values of b represent high parasitoid densities and/or widespread viral epizootics. Given these definitions, (x,a,b) on the upper attractor sheet, with large negative a, represents an outbreak population, while (x,a,b) on the lower surface represents a between-outbreak population. When a is near zero, the population is confined to certain ecological microhabitats. The differential equations we developed for these variables are based on the results of the aforementioned simulation model sensitivity analysis. The complete equations are:

$$\epsilon\dot{x} = -(x^3 + ax + b)$$

$$\dot{a} = -c_1x^{*2} + c_2b^{*2}$$

$$\dot{b} = -c_3ax^* + c_4x^* - c_5b^*$$

where $x^* = x + 3$, $b^* = b + 3$, $x \geqslant -3$, $b \geqslant -3$, $0 \geqslant a \geqslant -5$, and all $c_i \geqslant 0$. The first equation is the fast equation, which restricts the system state largely to the manifold. Next are the two slow equations, each term representing a component feature of the simulation model sensitivity pattern. The $-c_1x^{*2}$ term represents the progressively increasing dispersion as population size increases. The c_2b^{*2} term represents the reduction in dispersion resulting from density-dependent regulation acting on low-density populations. The $-c_3ax^*$ term represents the increasing spread of viral epizootics with increased larval contiguity and defoliation attendant upon increased density. The c_4x^* term represents the numerical

response of synchronized parasitoid species. The $-c_5b^*$ term represents the negative feedback stabilization of regulation. The magnitude of each c_i determines the significance of the associated term in controlling the outbreak trajectories.

One outbreak trajectory is shown in Figure 3. It was obtained by numerical solution of the above equations for $c_1 = 2$, $c_2 = 2$, $c_3 = 3$, $c_4 = \frac{1}{2}$, and $c_5 = 3$. The trajectory approaches a limit cycle in x, a, and b. [It appears to be small, because the scale is arbitrary.] Numerical solutions, using the various corners of

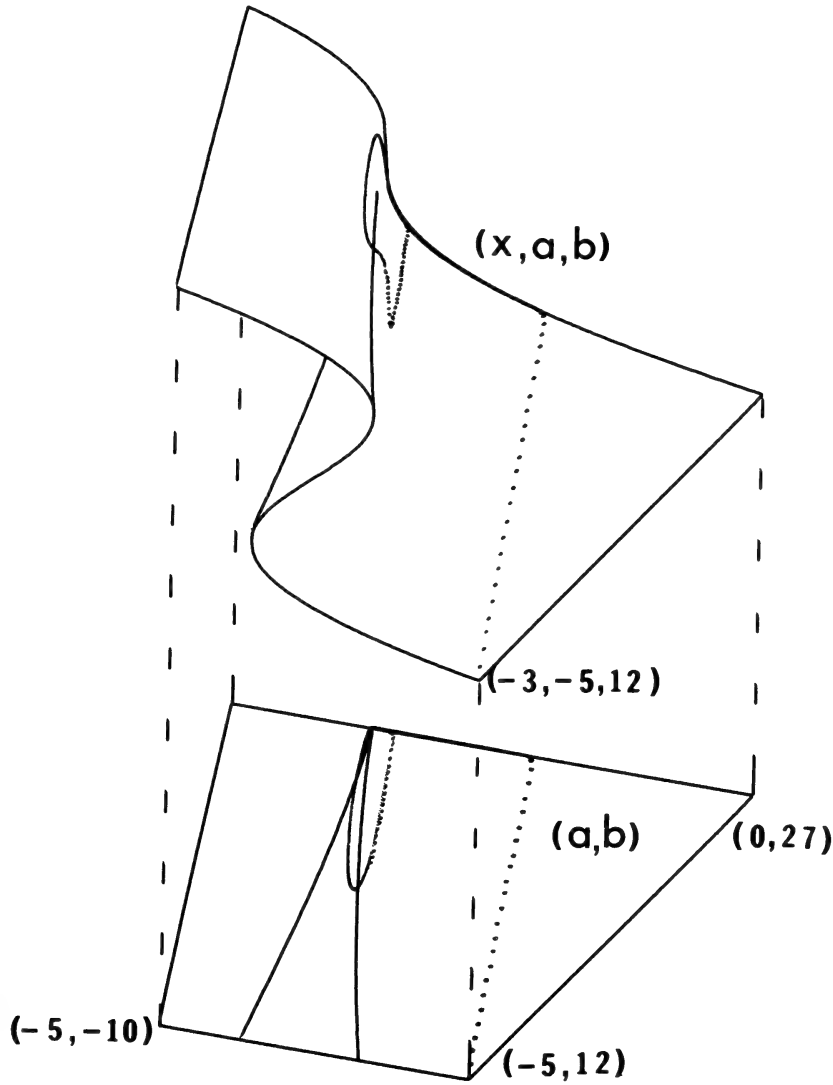

FIGURE 3. Numerical solution trajectory of the equations $\epsilon\dot{x} = -(x^3 + ax + b)$, $\dot{a} = -2x^{*2} + 2b^*$, and $\dot{b} = -3ax^* + \frac{1}{2}x^* - 3b^*$, where $x^* = x + 3$ and $b^* = b + 3$. The trajectory is shown in both (x,a,b) and (a,b) coordinates. The initial conditions are $(x_o,a_o,b_o) = (-3,-5,12)$. The motion is counter-clockwise. The limit cycle follows the hypothesized deterministic component of the forest tent caterpillar outbreak pattern.

the attractor sheets as initial conditions, all converge to the same limit cycle; indicating a possible global asymptotic solution. We suggest that this limit cycle, or one qualitatively similar represents the deterministic component of the forest tent caterpillar outbreak pattern. The actual trajectory, in (x,a,b), followed by the real-world system would differ due to the action of stochastic factors. For instance, when the trajectory is on the upper attractor in the equilibria region sudden heavy mortality, (perhaps due to weather), might push (x,a,b) below the repellor sheet, resulting in fast action to the lower set of attractors. With appropriate changes in the two slow equations (å, b̈) the cusp model may be used to describe the population dynamics of other outbreak insects.

Conclusion

In conclusion, the simple cusp model can account for both the similarities and the differences among outbreaks in diverse species. The model adequately describes the violent oscillations in population density which characterize all insect outbreaks. In addition, the flexibility of the control functions (represented by the å and b̈ slow equations) means diverse ecological factors may easily be accommodated within the model. Catastrophe theory, therefore, provides a general framework within which outbreak phenomena may be described.

The only other general population dynamic models based on ecosystem regulation (with or without stochastic inputs) are the Lotka-Volterra two-equation models or derivatives thereof (Rosenzweig and MacArthur, 1963). These models adequately describe our situations 2C and 2D (see Fig. 2); their trajectories would be very similar to the projection of our population trajectories onto the (x,a) plane or onto the (x,b) plane. Two-equation models, however, can not account for the sudden discontinuities observed in the dynamics of outbreak insects (our situations 2A and 2B), and must therefore be refuted as general structural hypotheses for insect population dynamics. The simple cusp catastrophe model, on the other hand, can account for all observed dynamics of insect populations. The strength of this new model will have to be assessed on the basis of its validity, or lack thereof, in a wide variety of specific field and/or laboratory studies.

Acknowledgements

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[1]DEVELOPMENTAL THRESHOLD AND DEGREE-DAYS TO ADULT EMERGENCE FOR OVERWINTERING PUPAE OF THE APPLE MAGGOT RHAGOLETIS POMONELLA (WALSH) COLLECTED IN ONTARIO

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Abstract

Apple maggot pupae were collected in the autumn from apples at Guelph, Ontario. The puparia were held in diapause for 16 weeks and then allowed to emerge at various temperatures. From the emergence data a developmental threshold of 8.7°C and a heat accumulation to mean emergence of 909 degree-days C, were calculated. The upper threshold for this insect appears to be near 31°C. These data were contrasted with comparable figures from pupae collected in New Brunswick.

Résumé

Des pupes de la mouche de la pomme ont été prélevées en automne dans des pommes de la région de Guelph, Ontario. Ces individus ont été maintenus en diapause pendant 16 semaines, après quoi on les a laissé éclose à différentes températures. A partir des données recueillies au moment de l'émergence on arrive à un seuil de développement de 8.7°C et une accumulation calorifique moyenne de 909 degrés-jours. Le seuil maximum se situe autour de 31°C. Ces valeurs diffèrent de données comparables obtenues au Nouveau Brunswick.

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Introduction

The apple maggot overwinters in the soil within a puparium, having developed to this stage in the autumn after the larva enters the ground (Dean 1942). The adult emerges from early July to September. It is perhaps due to this large spread in emergence times that neither developmental threshold nor number of degree-days to development has yet been published for field-collected individuals of this species. Emergence data will be of limited predictive value (e.g., for timing spray applications) since there is such wide variation in emergence dates. However, quantification of the developmental threshold of pupae and the number of degree-days to adult emergence could lead to the discovery of variation between local populations of the apple maggot. Such variation, if shown to have a genetic basis, perhaps could be utilized to identify physiological races or subspecies.

Materials and Methods

On September 17th and 18th, 1975, six one-bushel samples of fallen apples from six cultivars (Alexander, Snow, MacIntosh, Wolf River, Blenheim, and Northern Spy) were placed on sand indoors at 22-24°C. Puparia were collected from the sand and held at 26°C for one month to allow emergence of non-diapausing individuals. All remaining puparia were then held at 1°C (0.5-1.5°C) for a four-month period to break diapause (Neilson 1962). They were then

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placed individually in plastic snap-cap vials, and assigned randomly to six temperature treatments (10, 13.5, 19.5, 26, 29 and 31°C) in Schmitt insect storage boxes at *ca.* 70% R.H.

The four warm temperature treatments (19.5, 26, 29, and 31°C) were held to adult emergence and then per cent development per day was calculated as in Sawchyn and Gillott (1974). The two cool temperature treatments were held for 123 days at 10 and 13.5°C and then reared to emergence at 26°C. Their mean development time was compared with the original 26°C treatment to determine what proportion of their development had occurred at the lower temperatures. A temperature recorder probe was used to continuously record temperatures and the means were calculated by integrating the hourly deviation from the minimum temperature.

From mean emergence dates, mean per cent development per day was calculated and regressed against temperature. The developmental threshold and mean degree-days C required for development from diapausing pupa to adult were calculated using the resultant regression equation. The variation in emergence time which could be accounted for by sex, apple variety, and date puparia were formed was measured also but found to be insignificant.

Calculated mean degree-day accumulations necessary for adult emergence were compared with data on heat unit accumulations collected from the field (Environment Canada 1964). These comparisons were made for our site (Guelph, Ontario) and for the site used by Neilson (1962) (Fredericton, New Brunswick).

Results and Discussion

From more than 6,000 puparia held for one month at 26°C, only six adult apple maggots emerged (all within the first few days). Thus, only 0.1% of this sample consisted of non-diapausing individuals.

Too few adults (5) emerged from the 31°C treatment to yield a useful estimate of daily per cent development. The temperature of 31°C may be near the upper threshold for development of this population of apple maggots since all other treatments gave *ca.* 30% adult emergence except the 29°C treatment from which 23% emerged.

In Figure 1, mean per cent development per day and standard error of the means is plotted against temperature. The regression line drawn through the means gives a developmental threshold of 8.7°C and mean degree-days from diapause to adult emergence of 909 degree-days C. Trottier (1975) reported tentative results of 9°C for a threshold and 800 degree-days to maximum field activity for the apple maggot in Ontario. At Guelph, Ontario, our data correspond to a mean emergence date of August 11th which correlates with field data for the area, i.e., emergence generally begins in the first week of July and ends in September.

A single point may be plotted (Fig. 1) for the New Brunswick population sampled by Neilson (1962) which corresponds to a similar storage treatment of diapausing individuals. This point is far from the expected and requires either a treatment of over 6°C higher temperature or 24 days shorter development time. The data thus suggests a striking difference in developmental temperature and/or degree-days required for adult emergence between the populations from Ontario and New Brunswick.

The observed difference in these physiological population parameters is not surprising if we consider the marked climatic differences between Ontario and

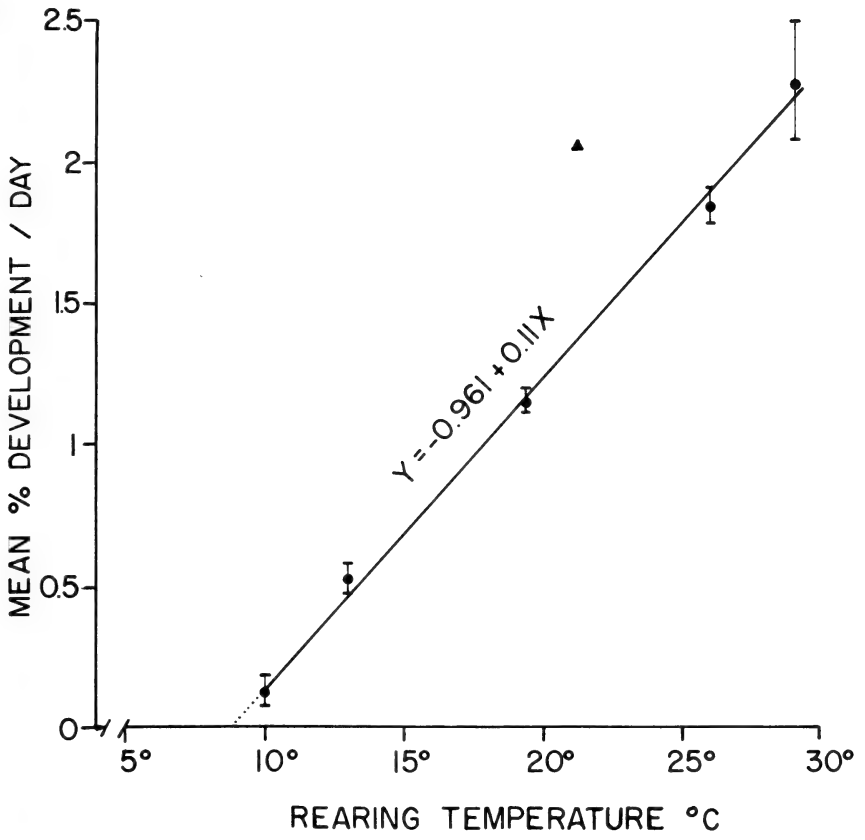

FIGURE 1. Mean per cent pupal development per day and standard error of the means plotted against rearing temperatures for Ontario-collected apple maggots, *Rhagoletis pomonella* (Walsh). ▲, a single point for the New Brunswick population studied by Neilson (1962).

New Brunswick, shown in Table I. The accumulated degree-days required to cause mean apple maggot emergence in Ontario are not present in New Brunswick until early September when emergence of the adult population is nearly complete. This difference in projected emergence date is accentuated by several years of data (Maxwell and Parsons, 1969; Neilson, personal communication) showing that New Brunswick apple maggots tend to emerge at the same time as Ontario populations.

TABLE I. Mean accumulated degree-days above 8.7° Centigrade and accumulated growing degree-days at Guelph, Ontario and Fredericton, New Brunswick (from CDS #8-64, CDS #6-64, and ARDA 1966).

	Accumulated degree-days Centigrade					
	May 30	June 30	July 31	August 11	August 31	Accumulated growing degree-days (yearly)
Ontario Guelph, O.A.C.	92.8	357.8	709.	909.	1,026.	3,250.
New Brunswick Fredericton, CDA	67.2	280.0	606.	704.	906.	2,750.

To obtain a more accurate measure of the variation between populations, simultaneous collections and degree-day experiments should be run on puparia from several areas. Such estimates could perhaps elucidate the adaptive strategies being employed by the insect to meet various environmental requirements. For example, in cooler environments does the insect reduce its spring and summer post-diapause heat accumulation requirement so as to have enough time for pre-diapause development, or is the developmental threshold lowered?

Differences in heat unit requirements between widely separated insect populations have recently been reported by Heron (1972) in the larch sawfly. The observed variation (some 30% in time required for the New Brunswick population to emerge at 21°C) reported here in the apple maggot may be evidence of a potentially valuable genetic difference between the two populations. Similar differences (Boller and Bush 1974) have led to the production of interracial sterile hybrids for insect release programs in the European cherry fruit fly, *Rhagoletis cerasi* L. (Boller *et al.* 1976). Such a technique also may be useful against the apple maggot, *R. pomonella.*

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FIELD STUDIES OF POTENTIAL PREDATORS OF THE APPLE MAGGOT *RHAGOLETIS POMONELLA* (DIPTERA:TEPHRITIDAE) IN ONTARIO

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Abstract

Many pupae of the apple maggot, *Rhagoletis pomonella* (Walsh), were destroyed by predators in two orchards on insecticide-free management programs. Few, if any, apple maggot larvae were attacked by predators. Potential predators of the pupae found in one orchard were sowbugs, *Oniscus laevis* (Koch) centipedes, *Lithobius forficatus* (L.), millipedes, *Oxidus rathkei* (Koch), ground beetles, *Calosoma calidum* F., and *Harpalus pennsylvanicus* DeGeer, and rove beetles, *Staphylinus badipes* Lec., in addition to crickets, previously determined to be predators of the pupae. Earwigs, *Forficula auricularia* L., were the only potential predators of the pupae found in the second orchard. The ability of these predators to detect and consume apple maggot pupae suggested that the predators contributed to the mortality of the apple maggot in the orchards. The distribution of the predators was apparently influenced by horticultural practises.

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Introduction

Biotic agents apparently have had little influence on the control of the apple maggot, *Rhagoletis pomonella* (Walsh), in commercial orchards. Insecticides and other management practices in general use by apple growers tended to eliminate parasites and predators of the apple maggot (Monteith, 1971c, 1972). Recently there has been an increased interest in integrated control programs in apple production. A study of control methods for the apple maggot, other than chemical insecticides was initiated in Ontario.

No predators of the eggs, larvae, or adults of the apple maggot were found (Monteith, 1971a, c, 1972). The only parasites found in any stage, attacked less than 3% of the mature larvae in restricted wild environments (Monteith, 1971b, c). By contrast, the pupae were severely attacked by predators. In an orchard on an insecticide-free program, crickets destroyed 54.5% of the pupae during the late summer and early fall in test lots buried in the orchard. Undetermined predators destroyed an additional 25% of the pupae in the late fall and spring (Monteith, 1971a). Prey-finding tests with potential predators indicated that seven species of arthropods, in addition to crickets, prey on apple maggot pupae and larvae in the laboratory (Monteith, 1976).

This is a report on field studies of potential predators of the apple maggot. The apparent influence of management practises on the distribution of these predators is discussed.

Materials and Methods

Test Orchards

Observations on the predators of apple maggot pupae during the current study were made in seven orchards of which the Rednersville orchard was described by Monteith (1971a) and the Smithfield orchards by Monteith (1973). The type and management of each orchard are described in Table I.

TABLE I. Environmental conditions in the orchards where the distribution and numbers of the predators of the apple maggot were measured.

Orchard	Condition	Pest management	Management during study
Rednersville	Commercial (Experimental). Sod medium thick. Humus on and in soil, medium.	No fungicides, insecticides, acaricides, or herbicides for 16 years.	Fungicides and fertilizers used. No herbicides. No insecticides.
Ayton	Commercial (Health food). Sod very thick. Humus content very high.	Fungicides. No insecticides, acaricides or herbicides.	Fungicides & fertilizers. No insecticides, acaricides or herbicides.
Campbell	Commercial. Sod very thick. Humus very high.	Full protective program of insecticides, acaricides, fungicides until 1969. Herbicides on restricted patches.	Fungicides & fertilizers. Insecticides and acaricides used as indicated by monitoring, at below label rates. No herbicides.
Smithfield 0-3	Commercial. Sod medium to thick. Humus medium.	Full protective program. Insecticides, acaricides, fungicides until 1970. Sod removed within 45 cm tree trunks by herbicides.	Fungicides & fertilizers. No insecticides, 1971-1973. No acaricides 1971-1975. Area under trees replanted, sod thick. 2 applications insecticides at reduced rates in 1974 and in 1975.
0-1	Similar to 0-3.	Similar to 0-3 except sod not removed around tree trunks.	Similar to 0-3.
0-2	Similar to 0-3.	Smiilar to 0-1.	Fungicides & fertilizers. No acaricides. Insecticides as indicated by monitoring, used at reduced rates.
Keeler	Commercial until 1969, then abandoned. Sod thick.	Full protective program of insecticides, acaricides, fungicides until 1969 but no herbicides used.	No pesticides or fertilizers. Not pruned or mowed.
Sydney	Abandoned, Sod medium. Patches of brambles. Humus medium. Much plant residue on surface.	Abandoned 12 years. No pesticides.	No pesticides or fertilizers. Not pruned or mowed.
Glen Miller	Hedgerows of wild apples and hawthorns. Much plant residue. Sod very thick along hedgerows.	No pesticides. Adjacent sod mowed and fertilized.	No pesticides. Sod fertilized and mowed.

All of the test orchards were comprised of mixed varieties of apples. Each orchard was surrounded by wild hedgerows, woodlands, or unmowed grasslands with scattered trees or clumps of trees. In each site, adjacent areas were inhabited by the arthropods that attacked apple maggot pupae and larvae in the laboratory (Monteith, 1971a, 1976).

Predator Sampling

The species and the number of potential predators of apple maggot pupae in the orchards were determined as follows:

(1) In the Rednersville orchard, two board-traps 90 x 15 x 2.5 cm were placed on the grass under each of 10 trees distributed through the orchard. One trap of each pair was placed close to the trunk of a tree, the other under the peripheral branches. Ten additional traps were placed between the rows of trees. Tanglefoot-bait traps hung in the trees to catch apple maggot adults also trapped millipedes.

(2) Soil samples, 0.1 m^2 and 8 cm deep, four in each quadrant of surface, were taken under each of five trees in each orchard on the dates that the orchard was sampled. Soil samples were taken and the board-traps examined on 19 days at Rednersville. Samples were taken on eight days at Smithfield and on two days at the other orchards when weather conditions appeared favourable for predators to be active under the trees.

(3) In all orchards the trunks of the trees, under which soil samples were taken, were examined for predators at the same time that the soil samples were collected.

Observations on and soil samples of the predators in the orchards were made in the following periods: Rednersville and Keeler, 1969-1973; Sydney and Glen Miller, 1970; Campbell, 1969-1975; Smithfield, 1970-1975; and Ayton, 1969 and 1971.

Results

Numbers and Distribution of Predators

Rednersville Orchard

Sowbugs, *Oniscus laevis* (Koch), centipedes, *Lithobius forficatus* (L), and millipedes, *Oxidus rathkei* (Koch), were the only potential predators of the apple maggot frequently found at the board-traps in the spring and late fall. The number of and the degree of activity by these predators on the soil surface under the trees varied considerably during the year (Table II).

The numbers of sowbugs, centipedes, and millipedes found at the board-traps between the rows varied more than the numbers at the traps under the trees. Numbers, equivalent to the highest found under the trees, gathered at the traps between the rows when the temperature and moisture between the rows were favourable for the arthropods. The changes in the numbers of predators at the traps suggested that the predators moved readily under the trees and from one row of trees to another.

Other species of arthropods found at the board-traps, on the tree trunks, or in the soil samples were not in sufficient numbers or did not exhibit prey-finding behaviour that would enable them to play major roles as predators of the apple maggot. Of these species, those that attacked pupae when tested (Monteith, 1976) were the adults of *Calosoma calidum* F. and *Harpalus pennsylvanicus* DeGeer (Carabidae) and *Staphylinus badipes* Lec. (Staphylinidae). Those that did not prey on the pupae were adult coccinellids, predaceous mites, spiders, ants, vespid

TABLE II. Average numbers of the three most common predators at 20 board-traps under trees in the Rednersville orchard during 1971.

Date	Sowbugs	Centipedes	Millipedes
Apr. 2-19	0	0	0
Apr. 20-27	0-T	0-T	0
Apr. 29	1.25	0.5	0
Apr. 30	13.15	0.35	0
May 3	9.9	0.75	0.5
May 4 a.m.	1.5	0.55	0.15
May p.m.	0.5	0.1	0.0
May 5	0.0	0.0	0.0
May 7	0.5	0	0.15
May 11 a.m.	0.35	0.25	0
May p.m.	0	0	0.5
May 13 a.m.	8.35	0.35	0
May p.m.	1.00	0.05	0.05
May 14	0.05	0	0.05
May 17	.75	.20	0
May 25	3.00	0.25	0
June 10	.75	0	.05
June 14-Oct. 5	0	0	0
Oct. 8	0.15	0.1	0
Oct. 15	0.3	0.2	0.1
Oct. 20 a.m.	2.0	0.5	0.5
Oct. p.m.	2.0	0.5	0.75
Oct. 21	2.0	0.5	0.5
Oct. 29	3.0	1.0	0
Nov. 8-22	0-T	0-T	0-T

T—on or adjacent to tree trunks.

wasps, harvestmen and praying mantids. Of these predators, *C. calidum, S. badipes* and some ants attacked mature larvae in the laboratory (Monteith 1976).

Sowbugs were the only arthropods frequently found on or in the soil samples in the Rednersville orchard. The number of sowbugs under the trees varied considerably during the season as shown by the average number in the soil samples during 1971:

21 Apr.	0	14 June - 30 Sept.	0 (11 dates)
7 May	7.0	8 Oct.	1.0
14 May	0.9	12 Nov.	1.5
31 May	0.2	19 Nov.	1.0
7 June	0.1		

Sowbugs, centipedes, and millipedes were very mobile. Two movement patterns were evident: (1) Seasonal—The predators were not found at the board-traps or in soil samples during most of April while the soil surface was very wet but they were active on or adacent to the trunks of the trees four days after the snow had melted under the trees (Table II). As the soil surface dried, sowbugs and centipedes moved from the trunks to the inner board-trap of each pair. Millipedes did not appear at the traps as early in the season as did the sowbugs and centipedes (Table II). During May and June, the three species spread into the area beneath the peripheral branches and between the rows of trees. It was during this period that the sowbugs were most common in the soil samples. The three species were not evident at the traps or in the soil samples from mid-June through September. With the advent of fall rains and cooler temperatures, the three species were found under the trees and were active until winter freeze-up. (2) Daily—The numbers of sowbugs and centipedes found under the trees changed from day to

day, and between the morning and afternoon of some days (Table II). Heavy rains, direct sunlight, or hot dry days stimulated these species to retreat to the shelter of the tree trunks or into the soil adjacent to the tree trunks. The predators returned to the traps and the surface under the trees when favourable conditions returned.

The ready mobility and the high populations of sowbugs and centipedes in the Rednersville orchard were indicated when a piece of tenting, 2 x 1.5 m, was blown, during a rain storm, onto the ground in an open area. When lifted the day after the storm, while the sky was cloudy, there were 25 centipedes, five millipedes, and hundreds of sowbugs under the cloth. The next day was warm and while the cloth was exposed to direct sunlight, no arthropods were found under the cloth or in the surface layer of soil beneath the cloth.

The mobility and the high population of the millipedes was further indicated by the number of millipedes caught in the tanglefoot traps in the trees. The number of millipedes ranged from 1-20 in various traps and averaged 3 per trap daily from August 29 through September 19 in 1970 and 1971. Millipedes were trapped in orchard trees and in wild apple and red cedar trees, *Juniperus virginiana* L., near the orchard. The millipedes moved into the trees during the night. None were found in the trees during the daytime. Sowbugs were found on the tree trunks on mild, damp days.

Abandoned Orchards

Sowbugs were the only common potential predator of apple maggot pupae found in the Sydney block or the Glen Miller hedgerows. The average number of sowbugs in the soil samples at the two sites on May 5 was 1.5 and 3.25, and on May 12, 1.2 and 2.0, respectively. Occasional centipedes, ground and rove beetles were found. The number of potential predators of the apple maggot found in the soil samples in the wild-type environment was less than ⅓ that at Rednersville on comparable days. These differences were evident although the amount of available prey appeared to be greater in the abandoned blocks where the percentage of apples damaged by the apple maggot and other pests was five times higher than that in the Rednersville orchard.

Insecticide-treated, Commercial Orchards

No predator of apple maggot pupae was found in the Campbell, Smithfield, or Keeler blocks during the years that a program of protective insecticides was applied. Predators were not found in the Campbell or the Smithfield 0-2 blocks during the five-year period during which insecticides were applied in reduced quantities.

Insecticide-free, Commercial Orchard

The earwig, *Forficula auricularia* L., was the only potential predator of apple maggot pupae found in the Ayton orchard. The earwig population averaged 2.0 and 4.4 in the soil samples on 21 June and 20 September, respectively.

The earwigs appeared to be well adapted as predators of apple maggot pupae. Present in large numbers from early May until late November, the earwigs were very mobile and apparently would have searched for prey throughout each season as indicated by their adeptness in detecting and destroying pupae in the laboratory (Monteith, 1976). The effectiveness of the earwigs as predators of the apple maggot was suggested by the condition of the crop at Ayton. Although the orchard was on an insecticide-free program and there were infested wild apple trees within easy flight range, there was only a trace of apple maggot damage in extensive

samples of apples from the orchard in 1966 and 1967 (Monteith, 1971b) and in 1969 and 1971.

Orchards Where Insecticides Were Discontinued

Keeler: Three years after the Keeler orchard was abandoned, the first predators were observed in the peripheral rows of the orchard. A few crickets each of *Gryllus pennsylvanicus* Burmeister, *G. veletis* (Alexander and Bigelow) and *Allonemobius fasciatus* (DeGeer) and an occasional ground beetle *H. pennsylvanicus* were found. In the fourth and fifth years, the same species were present, and though more generally distributed through the orchard than in the third year, only widely separated individuals were found. During the same period, predators thrived in the adjacent Rednersville orchard.

Smithfield: Three years after the use of insecticides was discontinued and the replanted grass and clover were growing well, crickets, *G. pennsylvanicus* and *G. veletis,* 1 per 10 standard trees, were found in the 0-1 and 0-3 blocks. However, the number of crickets in the two blocks did not increase during the fourth and fifth years. During the fourth year occasional ground beetles and rove beetles were found on the surface of the orchards. The same species and other ground beetles had been caught in light and tanglefoot traps in these blocks during the first three years of the study. However, their occurrence was apparently due to dispersal flights as the beetles were not yet established during the fifth year.

No sowbugs, centipedes, or millipedes were found in the Keeler or the Smithfield blocks by the end of the fifth year.

Discussion

The potential predators from the Rednersville orchard that detected, dug-up, and consumed apple maggot pupae in the laboratory (Monteith, 1976), in addition to the crickets, were sowbugs, centipedes, ground beetles, rove beetles, and to a lesser degree millipedes. Sowbugs, centipedes, and millipedes were the only predators of apple maggot pupae in the Rednersville orchard in sufficient numbers during the spring and late fall to destroy many pupae. As the millipedes destroyed few pupae during prey-finding tests, the sowbugs and the centipedes appeared to be the principal predators, other than crickets, in the orchard. Sowbugs and centipedes consumed .05 and .16 buried pupae, respectively, per predator daily in the laboratory. If these rates of predation by these species occurred in the orchard, through a life span of many weeks (Monteith, 1976), the high populations of these predators in the Rednersville orchard could have been responsible for most of the 25% mortality of buried pupae that occurred in the spring and late fall.

C. calidum and *S. badipes* destroyed more pupae per predator daily in the laboratory than any one of the other species tested, except crickets (Monteith, 1976). Ground beetles in agricultural lands are apparently capable of consuming considerable prey (Rivard, 1964). However, the low populations of *C. calidum, H. pennsylvanicus,* or *S. badipes* in the test orchards during the current study, minimized their contribution to the control of pests.

The activities of the sowbugs, centipedes, and millipedes appeared as though asynchronized with those of the crickets. The former were observed on the soil surface near the tree trunks a few days after the snow melted and dispersed under the trees during the spring. By the time crickets became active under the trees (Monteith, 1971a), the sowbugs, centipedes, and millipedes were not active on the orchard surface under the trees. In the fall, when the crickets had left the area under the trees, the sowbugs, centipedes, and millipedes were again evident

under the trees and were active until freeze-up. The absence of an overlap of the active period by the crickets with that by the other predators was primarily due to temperature and moisture conditions under the trees. However, the number and aggressiveness of the crickets probably had some influence, as sowbugs and centipedes did not become active under the trees on apparently favourable days during the "cricket season". A similar absence of arthropods, other than earwigs, was evident in the Ayton orchard where the earwigs were dominant.

Arthropod predators of the pupae are apparently the major potential biotic agents that would contribute to the control of the apple maggot. The mortality of naturally buried pupae by arthropod predators would probably have been higher than the 79.5% reported by Monteith (1971a). This mortality occurred during a period from mid-September to mid-June of the following year whereas under field conditions some pupae were exposed to predators before mid-September of the first year. Adults seldom emerged before mid-June, many during August or September, so that exposure of most of the pupae would have continued after mid-June of the second year. In addition, 7% of the pupae would have been exposed in the soil during a two-year diapause (Monteith, 1971a).

The importance of the mortality due to arthropod predators of the pupae is emphasized by several facts: Only 19% of buried pupae that were protected from predators died as a result of other factors (Monteith, 1971a). There was no evidence that rodents destroyed many pupae (Monteith, 1971a). There was little or no predation of the other stages (Monteith, 1972). The only parasites of the apple maggot (Monteith, 1971b, 1977) were of little value.

Few, if any, mature apple maggot larvae were attacked by predators in the orchard. The larvae generally remained in the fruit till it dropped. Observations in the laboratory indicated that mature larvae generally emerged from the lower surface of the fallen fruit. On a simulated orchard surface, the larvae quickly entered the soil. Therefore, any exposure of the mature larvae to predators in the orchard was brief. Hall (1940) after many years of observations, stated that he had seen ants, but no other predators, attack some larvae on the soil. However, during the 13 years covered by the current study, no predator has been observed to attack a mature larva, that was present naturally, in an orchard. Immature larvae in the apples appeared to be free from attack by predators.

Orchard surfaces with a high content of organic material, provided a more favourable environment for sowbugs, centipedes, millipedes, earwigs, and crickets than did orchards without such a surface cover. Most apple maggot larvae will, when they enter a soil high in organic material, pupate in or between the humus layer and the mineral soil beneath it. Thus, the orchard surface that favours the predators apparently predisposes the pupae to be more easily accessible to a potentially higher population of predators.

Predators were more numerous and apparently more effective against the apple maggot in well-managed but insecticide-free orchards than in abandoned or wild stands. This was the case when the numbers of predators and the percentage of the fruit infested by the apple maggot in the Rednersville and the Ayton orchards were compared with those in the Sydney or the Glen Miller blocks. It was also evident when the Rednersville and Ayton orchards were compared with adjacent wild stands of apples.

Soil-inhabiting predators did not become established where the use of insecticides was discontinued or greatly reduced. After five years the predators were not established despite the proximity of potential immigrants, the mobility of the predators, the physical suitability of the orchard surface, and an attractive undergrowth.

Insecticides and acaricides were the only agricultural chemicals applied in the orchards where the predators did not become established that were not used where the predators thrived (Table I). As the acaricides that were used were specific for mites, insecticides appeared to be the only residue that may have influenced establishment of the predators. Herbicides created environments unattractive to the predators. However, no herbicides had been applied in the Keeler block in which predators did not become established. Some insecticides will continue to be necessary in commercial orchards in the foreseeable future. The residues from these chemicals will probably influence the soil-inhabiting predators.

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THE SEASONAL OCCURRENCE OF *LITHOCOLLETIS BLANCARDELLA* (GRACILLARIIDAE), AND ITS MAJOR NATURAL ENEMIES IN ONTARIO APPLE ORCHARDS[1]

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Abstract

There are three distinct generations per year of *Lithocolletis blancardella* Fabricius (Lepidoptera: Gracillariidae) in the Meaford and Guelph areas of Ontario. Emergence from overwintering pupae occurs during the early part of May concurrent with the appearance of apple foliage. Populations are evenly distributed within the tree. Spring emergence of *Apanteles ornigis* Weed (Hymenoptera: Braconidae), a larval parasite of *L. blancardella,* is well synchronized with the presence of suitable hosts in the field. This parasite is most prevalent on first and third generation *L. blancardella* and along with several chalcidoid species is responsible for a high level of parasitism of *L. blancardella.*

* * * * * *

Introduction

A leaf-mining insect which attacked apple was first reported in 1940 from Nova Scotian orchards. It was identified as *Lithocolletis malimalifolliela* Braun and was said to be very common (Canadian Insect Pest Review (C.I.P.R.), 1941, Vol. 19). In 1952, a *Lithocolletis* sp. was found in some Quebec orchards. Parent and LeRoux found serious infestations of *L. malimalifolliela* in Southwestern Quebec in 1955 but also found that their numbers were reduced subsequently by the parasite *Apanteles ornigis* Weed (C.I.P.R., 1955, Vol. 33).

L. malimalifolliela was reported frequently in Quebec in 1959 and 1960. In 1961 it was found that what was identified as *Lithocolletis malimalifolliela* in Nova Scotia was in fact *Lithocolletis blancardella* Fabricius (Stultz 1962a, b). It is quite probable that the previous pest reports from Nova Scotia and New Brunswick which mentioned *L. malimalifolliela,* were in error and that this species was actually *L. blancardella.* In 1961 and 1962, *L. blancardella* caused severe damage to apple foliage in Quebec and was very numerous in Nova Scotia. It was labelled a "major pest" in Southwestern Quebec in 1964 (C.I.P.R., 1961-64, Vols. 39-42).

The first record of infestation of this species in Ontario was in Norfolk County in 1964 and it was reported in only one orchard (C.I.P.R., 1964, Vol. 42). An increase in numbers of *L. blancardella* was recorded in Ontario in 1970. In 1971, it was observed in orchards throughout Ontario and was severe in two locations on the Niagara Peninsula (The Agricultural Insect Pest Review, 1971, Vol. 49).

L. blancardella was reported by LeRoux (1960) as a secondary pest of minor importance yet, as early as 1964, it was referred to as a "major pest" in Southwestern Quebec (C.I.P.R., 1964, Vol. 42). In Ontario, The Agricultural Insect Pest Review (1972, Vol. 50) suggests that leafminer damage on leaves may hasten fruit maturity and reduce fruit size. Kremer (1963) noted that heavy

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L. blancardella infestations in Italy led to early leaf fall, reduction in terminal growth, stunting of fruit growth and reduction of fruit set the following year. Pottinger and LeRoux (1971) also noted a lowered effective photosynthetic area for the plant and a premature ripening and fall of fruit.

In North America the range of *L. blancardella* extends throughout the Maritime provinces, Quebec and Ontario as far west as Sault Ste. Marie. It has been noted in New York State, Vermont, New Hampshire and Maine (Pottinger and LeRoux 1971). *L. blancardella* is also found throughout the apple growing regions of Michigan (J. Dutcher, personal communication, 1975). We suspect that the reported distribution is the narrowest confines of the actual distribution and that the range may still be expanding.

The only complete study on life stages of *L. blancardella* is that by Pottinger and LeRoux (1971) in Quebec. Baggliolini (1959, 1960) found that *L. blancardella* completed three generations per year in Switzerland. Soenen and Aerts (1953) found three generations a year in Belgium. Kremer (1963) observed four and occasionally five generations a year in Italy. LeRoux and Parent (1956) state that *L. malimalifoliella,* later reported to be *L. blancardella* (C.I.P.R., 1962, Vol. 40), completed two full generations and a partial third generation in Quebec. Pottinger and LeRoux (1971) found three distinct generations per year in Quebec although some overlap can occur.

A comprehensive review of the natural enemies of *L. blancardella* in Europe was compiled by Janjua and Karl (1966?) for the Commonwealth Institute of Biological Control (Table I).

TABLE I. Parasites recorded from *L. blancardella* in Europe.

Parasite Species	Country
BRACONIDAE	
Apanteles bicolor Nees*	Germany
Apanteles blancardellae Beche*	Germany
Apanteles circumscriptus Nees*	Switzerland; Italy
Apanteles flavolimbatus Ratz*	Middle Europe
Apanteles lautellus Marsh	Italy
Apanteles sp.	Germany
EULOPHIDAE	
Achrysocharella formosa Westw.	Italy
Atoposomoidea lyncus Wlk.	Italy
Atoposomoidea unifasciata Forst.	From Alps to the Mediterranean region
Chrysocharis pubens Del.	Italy
Cirrospilus elegantissimus Westw.	Germany
Enaysma n. sp.	Germany
Pediobius saulius Wlk.	Germany; Italy
Pnigalio pectinicornis L.	Prealpine and Mediterranean region
Pnigalio sp.	Germany
Sympiesis dolichogaster Ashm.	Italy
Sympiesis gordius Wlk.	Switzerland
Sympiesis sericeicornis Nees	Italy Prealpine and Mediterranean region; Germany
Tetrastichus amethystinus Ratz.	Italy
Tetrastichus cyclogaster Ratz.	Italy
Tetrastichus platanellus Merc.	Italy
Tetrastichus xanthops Ratz.	Prealpine and Mediterranean region; Germany

* According to Janjua and Carl, Fahringer considers them as distinct species, but after Fulmek (1962) *bicolor* Nees, *blancardellae* Beche, *flavolimbatus* Ratz., are synonyms of *circumscriptus* Nees. Thompson (1953) in his Parasite Catalogue synonymises *circumscriptus* with *bicolor* Nees.

In Canada, the most frequently encountered parasites of *L. blancardella* are *Apanteles ornigis* Weed and *Sympiesis marylandensis* Girault although several other species of chalcidoid parasites also attack this leafminer (Pottinger and LeRoux 1971). *A. ornigis* overwinters as a naked larva, as a larva within a pupal cocoon or as a pupa within a cocoon and reaches its peak population during the first generation of *L. blancardella* (Pottinger and LeRoux 1971).

The chalcidoid species which attack *L. blancardella* are ectoparasites and their eggs, larvae and pupae remain exposed within the mines. Chalcidoids overwinter as larvae or pupae within the host mines. *S. marylandensis* has also been found to be a hyperparasite of other chalcidoid larvae (Pottinger and LeRoux 1971).

Very few predators of *L. blancardella* have been recorded. Egg predation does not seem to be a serious mortality factor. The only active predation of pupae from leaves on trees is by birds. Heavy predation of overwintering third generation pupae on the ground occurs possibly due to exposure of the contents of the leafmine by weathering (Pottinger and LeRoux 1971).

Materials and Methods

The dynamics, distribution and development of *L. blancardella, A. ornigis* and chalcidoid species were followed in an orchard near Meaford, Ontario (80° 35′W., 44° 35′N.) for the years 1973, 1974 and 1975. Additional observations on the development of *L. blancardella* and *A. ornigis* were recorded in the Guelph Research orchard (80° 15′W., 43° 25′N.) and the Patterson orchard (Thornbury) (80° 28′W., 44° 28′N.) in 1975. Sampling methods were modified over the period of this study to fit the objectives of the experiment. Only McIntosh apple trees were sampled in the three orchards. Five McIntosh trees were selected in the Meaford orchard which contained Spy, King, Delicious and Wolf River cultivars. Each tree was divided into an upper level (3 m) and a lower level (1.5 m) and each level was vertically subdivided into four quadrants corresponding to the north, south, east and west compass points. Three clusters were sampled weekly from each of the eight divisions in the tree for a total of 24 clusters per tree per sample. Clusters were used as a sample unit following the method of Pottinger and LeRoux (1971). This sample method was employed in 1973 and 1974. Parasites were identified by rearing to adults all larvae and pupae found inside leaf-mines.

During 1975 a large leaf sample was taken weekly at the 2 m level from the north, south, east and west quadrants because of low population levels of *L. blancardella.* Leaves were examined until at least 50 mines had been observed from each of the Meaford, Guelph Research and Patterson orchards and the contents of the leaf-mines were identified and recorded.

The population size and level of parasitism of *L. blancardella* were also recorded for several orchards in Ontario under different pesticide programmes by sampling 300 leaves from each orchard in October, 1974.

Field emergence of adults from overwintering pupae of *L. blancardella* and *A. ornigis* was studied with the aid of emergence cages similar to those of LaFrance and Perron (1955). Each cage covered 0.37 m^2 of ground surface. The number of adults emerged were recorded daily at 1600 h. To ensure that all emerging insects were captured, several minutes were spent searching inside each cage for adults resting on cage walls.

Observations were made in Meaford during the emergence periods of 1974 and 1975 on the sex ratio, flight, mating and oviposition of adult leafminers. Tree phenology was noted during the emergence periods.

The diel periodicity of emergence was studied with the first generation emerging adults. Leaves with advanced mines were gathered from the Meaford orchard in mid-June and the entire mine was cut from the leaf and placed, upper leaf surface down, on wet cotton in a petri dish. The petri dishes then were placed inside a screen cage 19.0 cm long x 19.0 cm wide x 38.0 cm high which was placed outside in a field cage. Throughout the period of emergence the dishes were checked hourly and emergence was recorded by counting the pupal skins sticking up through the leaf-mines.

Results and Discussion

Seasonal Life History

The life stages of *L. blancardella* are presented in Fig. 1, E-F. There are four life stages; egg, larva, pupa and adult. Eggs are laid singly on the under surface of the leaf. Egg counts are difficult because of their small size and few were found on very pubescent leaves. Eggs are not rigidly fastened to the leaf under surface and the shells disappear from the leaf shortly after the eggs hatch. There are five larval instars, three sap feeding and two tissue feeding. The spotted appearance of the mines (Fig. 1, G-H) is a result of the feeding of the last two larval instars. The larvae pupate inside the leaf-mines and adults emerge from the leaf-mines.

In the Meaford and Guelph areas of Ontario there are three generations of *L. blancardella* a year. Little overlap in generations of the leafminer was observed. However, second and third generation sap feeding larvae occurred in the field at the same time (Figs. 2 and 3). The second generation sap feeders were in the third instar (last sap feeding instar) and the blotch mine was conspicuous, whereas, the third generation sap feeders were in the first or second instar and the mine was not well-defined. The third generation pupae overwinter inside leaf-mines in leaves which have fallen to the ground. Emergence of adults from overwintering pupae of *L. blancardella* during mid-spring occurs (Figs. 4 and 5) just as the leaves are beginning to unfold on the earliest tree cultivar (King) (Table II). Emergence can occur at any time during the day, but hourly observations show that peak emergence occurs between 800 h and 1000 h (Fig. 6). Males emerge in larger proportion in the first 4-5 days of the emergence period, but the overall sex ratio at the end of the emergence period approaches 50:50 (Table III).

TABLE II. Leafminer development in relation to tree phenology.

Date		Stage of Tree	Stage of *L. blancardella*
1973	May 29	McIntosh-petal fall	1st instar larvae
1974	May 8	King-⅛" green McIntosh-green tip Spy-silver tip	First emergence of adults from overwintering pupae
	May 28	McIntosh-beginning petal fall	1st instar larvae
1975	May 9	King-½" green McIntosh-¼" green Spy-silver-green tip	First emergence of adults from overwintering pupae
	May 24	McIntosh-full bloom, some petal fall next day	1st instar larvae
	June 5	Spy-7 days after petal fall	Tissue feeding larvae

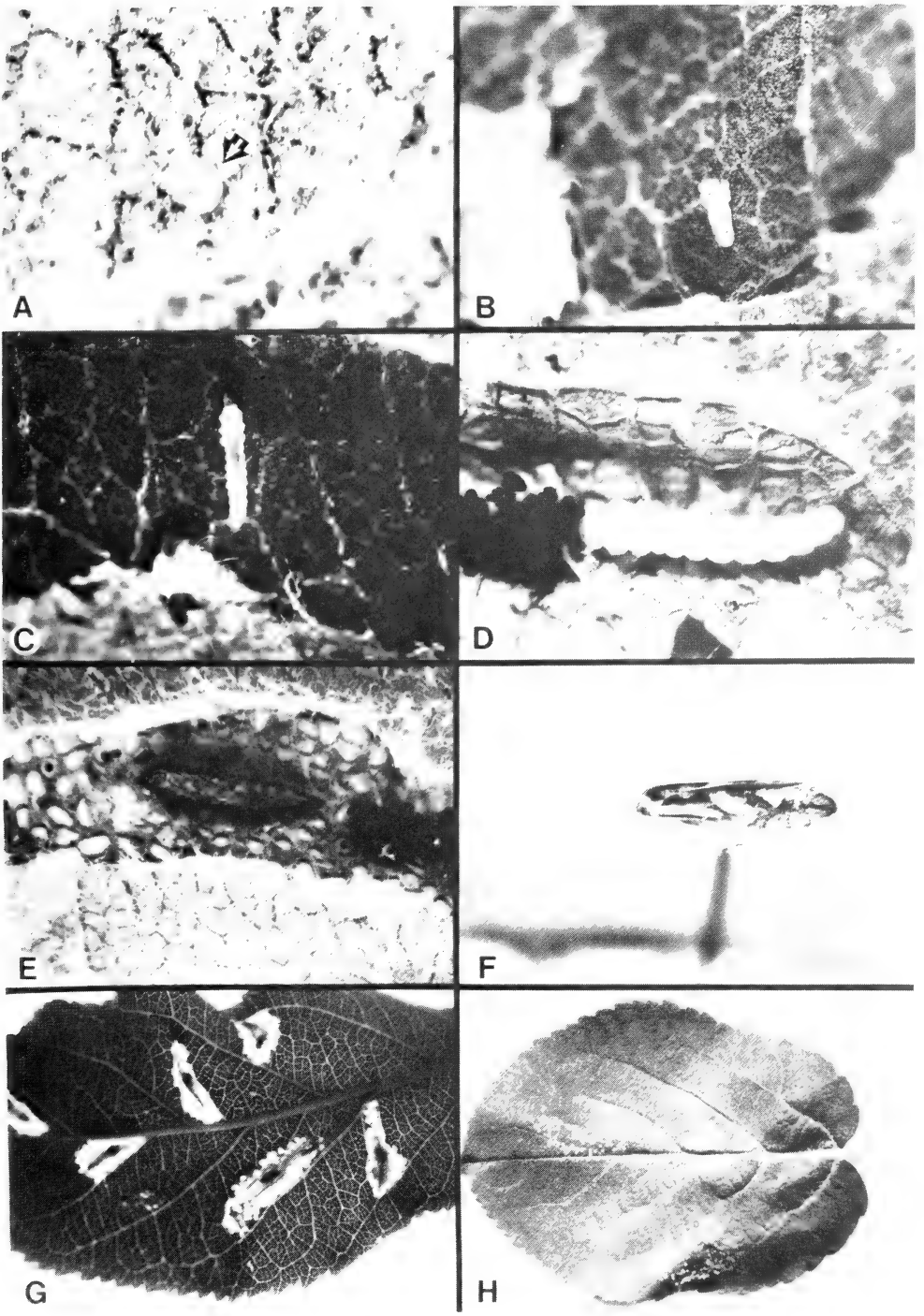

FIGURE 1. Life stages of *L. blancardella*. A, egg (x 30). B, first instar larva (x 16). C, third instar larva (x 12). D, fifth instar larva (x 11). E, pupa (x 7). F, adult (x 10). G, H, leaf-mines.

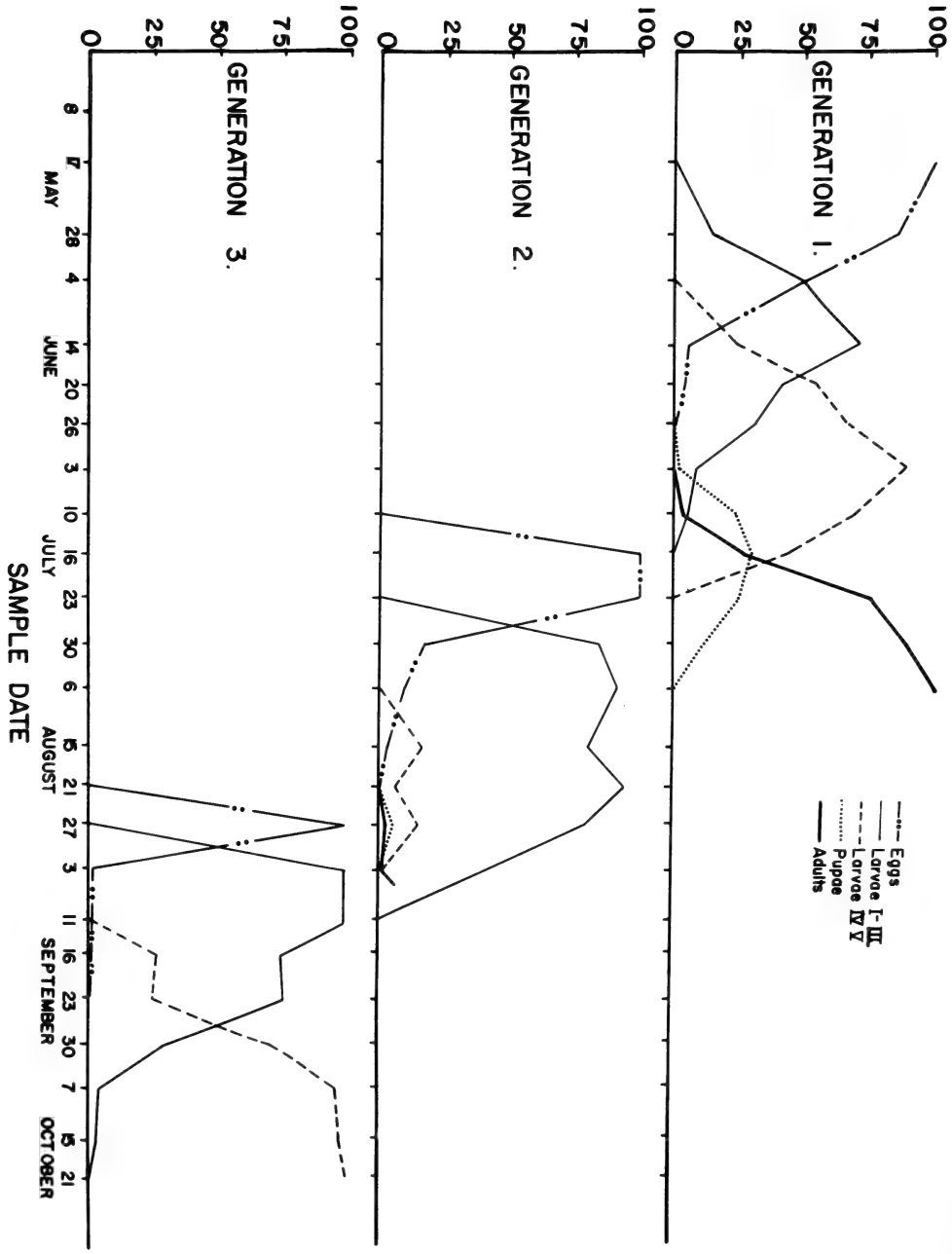

FIGURE 2. Seasonal development of *L. blancardella* in Meaford, Ontario during 1974.

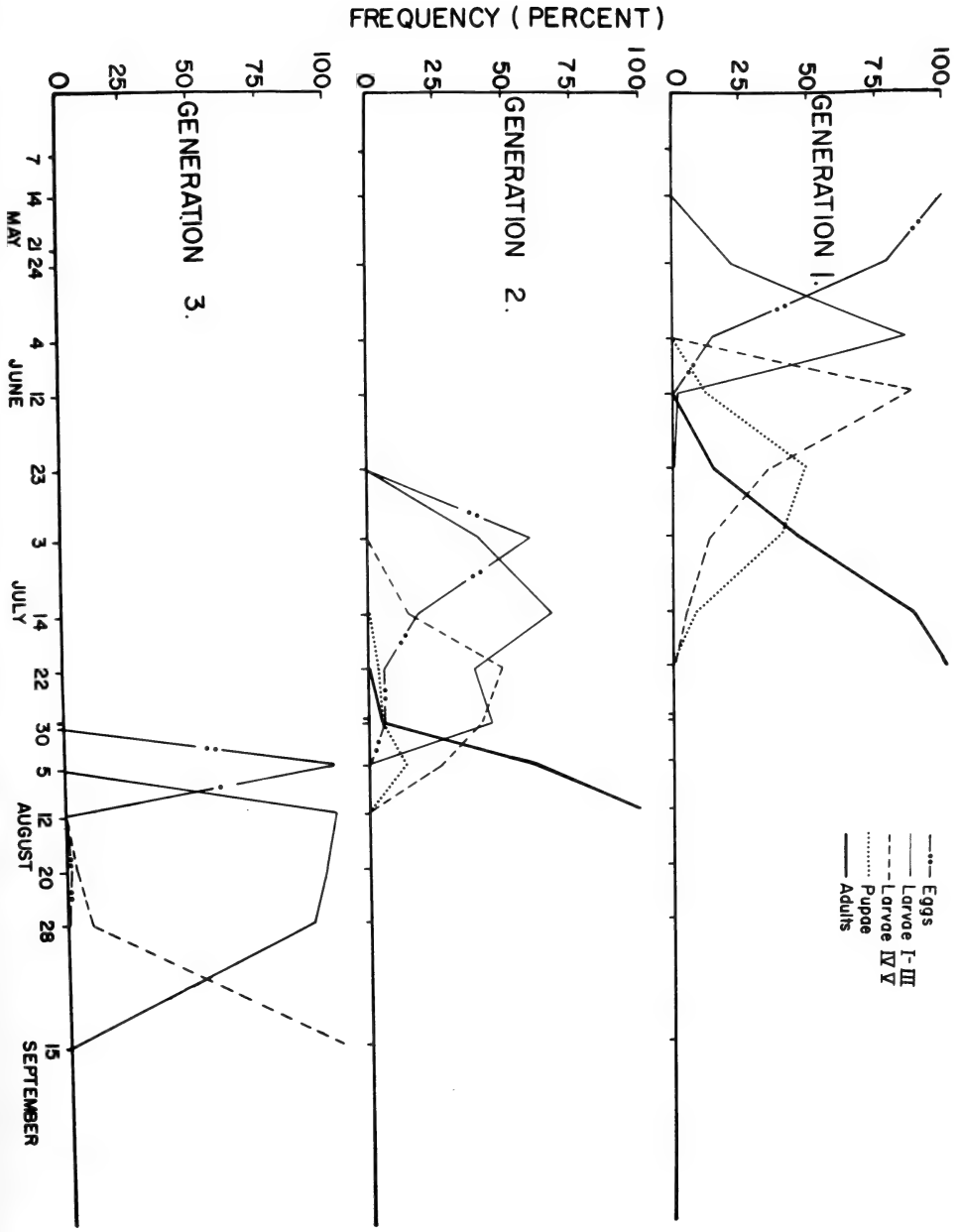

FIGURE 3. Seasonal development of *L. blancardella* in Guelph, Ontario during 1975.

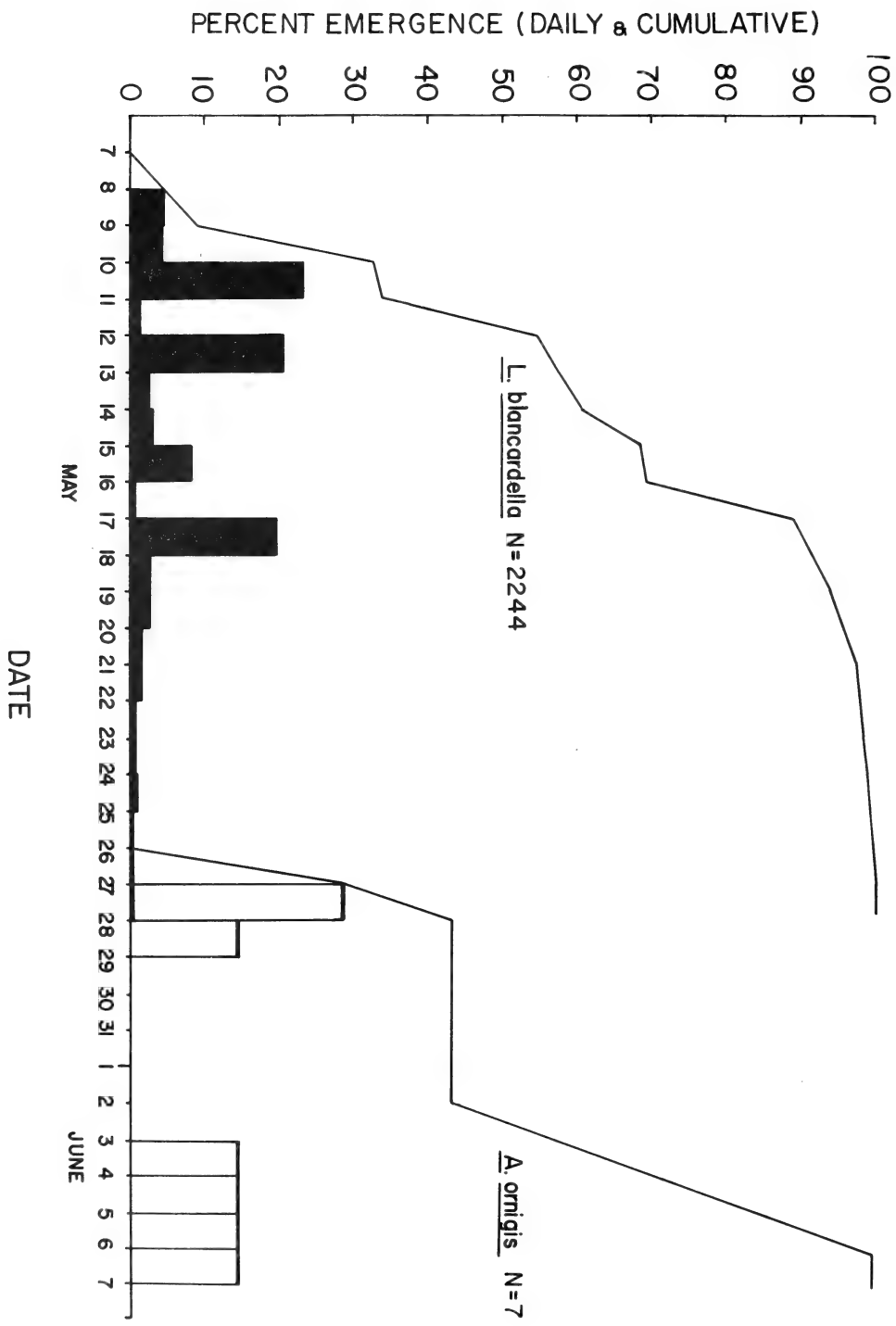

FIGURE 4. Emergence of overwintering *L. blancardella* and *A. ornigis* in Meaford during 1974.

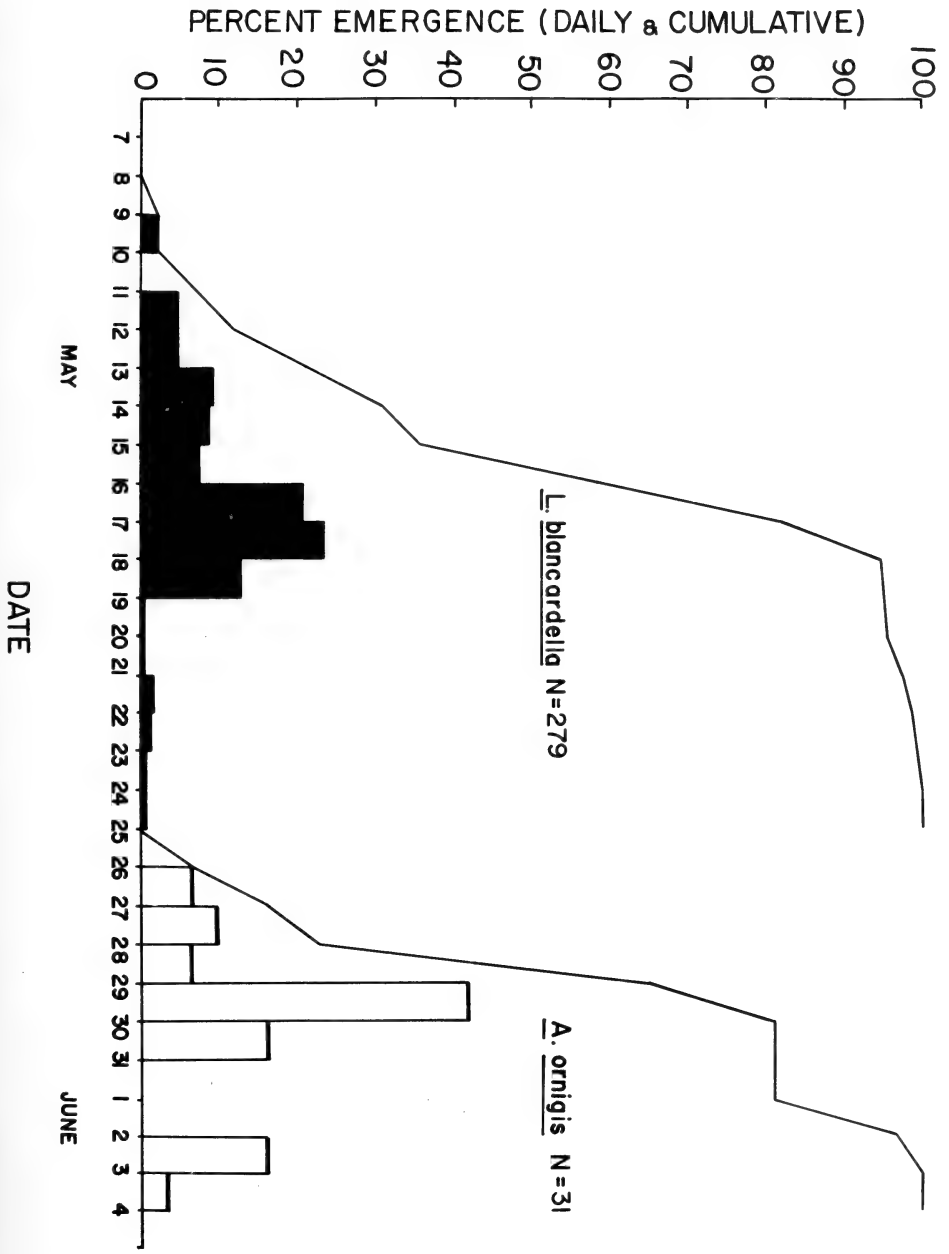

FIGURE 5. Emergence of overwintering *L. blancardella* and *A. ornigis* in Meaford during 1975.

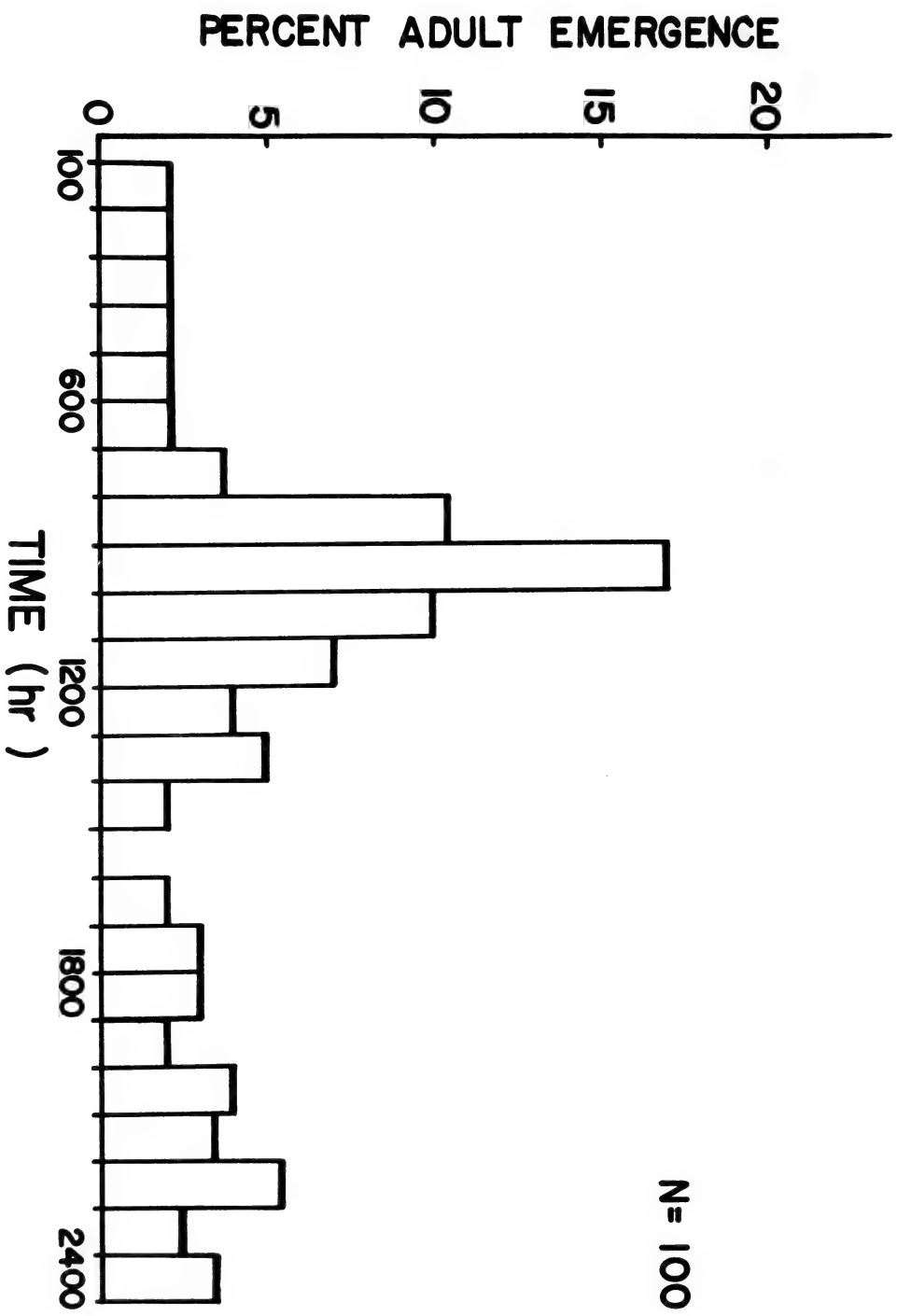

FIGURE 6. Diel periodicity of emergence for *L. blancardella*.

TABLE III. Sex ratio of adult *L. blancardella* from emergence cages in Meaford, Ontario.

Days of emergence	Number observed	1974 ♂ : ♀	Number observed	1975 ♂ : ♀
1-5	1222	3 : 2	59	7 : 3
6-10	768	2 : 3	205	2 : 3
11-15	187	2 : 3	13	1 : 5
16-20	67	1 : 4	2	0 : 2
Overall	2244	50 : 50	279	46 : 54

During the day adult *L. blancardella* emerging from overwintering pupae were observed on the orchard floor fluttering from blade to blade of the tallest orchard grasses. Moths were also seen on the trunks of major limbs of the trees as well as on leaves. The major flight of moths emerging from overwintering pupae occurred during the evening beginning at 1830 h, approximately 2.5 h before sunset. Flight times were similar to those recorded by Pottinger and LeRoux (1971). The adult moth swarms were greatest just after sunset (2100 h). Moths flutter uniformly throughout the tree, landing on leaves, twigs and branches. Adult moths walked from twigs onto leaves and from leaves back to twigs. They tended to walk over leaves for a matter of seconds and then flutter to another nearby leaf or twig. Flight was erratic and they appeared to be weak fliers.

On overcast and rainy evenings, no flight occurred in the orchard and moths were observed resting on the trunks of trees. A check was made of flight on a windy evening (winds approx. 30 kph) and no moths were seen. The greatest concentrations of swarming adults were noted on those trees having the most advanced leaf development. Copulation of *L. blancardella* was observed in this study on the same day as the first recorded emergence.

A. ornigis is a primary endoparasite of *L. blancardella* and parasites mid- and late-instar larvae present inside leafmines (Pottinger and LeRoux 1971) (Fig. 7, A-D). *A. ornigis* adults emerge from overwintering pupae about 20 days after the first emergence of *L. blancardella* adults (Figs. 4 and 5). By this time, first generation eggs of *L. blancardella* have hatched and within a week of the first emergence of *A. ornigis,* tissue feeding larvae of the host are present (Figs. 2 and 3). The level of parasitism by *A. ornigis* is highest on first generation larvae and lowest on the second generation. An increase in parasitism by *A. ornigis* from second to third generation *L. blancardella* was noted (Table IV).

TABLE IV. Percent parasitism of overwintering and first generation *L. blancardella* in Meaford.

Year	Generation	% parasitism *A. ornigis*	% parasitism chalcidoid species
1972*	Overwintering (III)	13.6	0.0
1973	First summer (I)	45.0	8.0
	Overwintering (III)	4.5	4.2
1974	First summer (1)	57.0	15.0
	Overwintering (III)	36.6	2.1
1975	First summer (1)	30.0	24.0

* Trottier, 1972 (unpublished data).

In this study, chalcidoid parasites (Fig. 7, E-G) were observed emerging from leaf-mines only a few days after first emergence of leafminers. Synchrony with *L. blancardella* is not imperative since most chalcids are not host specific.

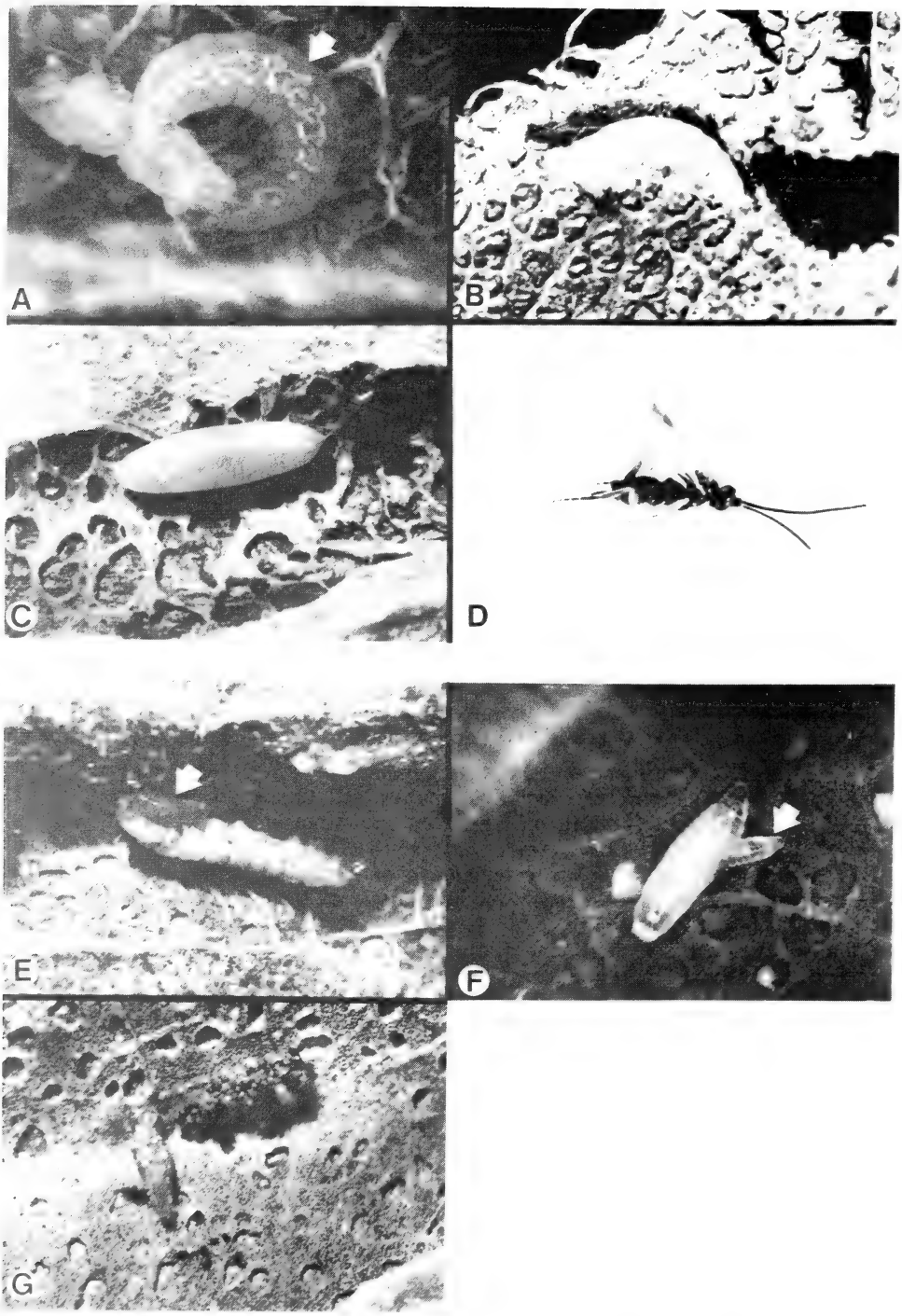

FIGURE 7. Life stages of *A. ornigis* and chalcidoid species. A, *Apanteles ornigis* mature larva leaving *L. blancardella*. B, *A. ornigis* larva beginning to spin cocoon (x 12). C, *A. ornigis* pupa (x 8). D, *A. ornigis adult* (x 7). E, Chalcidoid species larva on fourth instar *L. blancardella* (x 10). F, hyperparasitic chalcidoid species larva (x 10). G, Chalcidoid species pupa (x 10).

Sympiesis marylandensis, Sympiesis sericeicornis Nees, and *Pnigalio flavipes* Ashmead were found to be the most abundant chalcidoid species in the Meaford and Guelph orchards in 1975 (Table V).

TABLE V. The relative abundance of different chalcidoid* species found inside first generation and second generation leaf-mines in Meaford and Guelph, 1975.

	Meaford, 1975				Guelph, 1975			
	Gen. 1		Gen. 2		Gen. 1		Gen. 2	
	Total	%	Total	%	Total	%	Total	%
Sympiesis marylandensis Girault	22	15.0	9	60.0	13	19.4	7	41.2
Sympiesis sericeicornis (Nees)	96	65.3	2	13.3	23	34.3	7	41.2
Pnigalio flavipes (Ashmead)	23	15.6	3	20.0	22	32.8	3	17.6
Pnigalio uroplatae (Howard)	6	4.1	—	—	5	7.5	—	—
Chrysocharis cuspidogaster Yshm.	—	—	1	6.7	1	1.5	—	—
Closterocerus sp.	—	—	—	—	3	4.5	—	—
Total	147	100.0	15	100.0	16	100.0	17	100.0

* Det. C. M. Yoshimoto, Entomology Research Institute, Ottawa.

The results of this study indicate that *S. sericeicornis* is the most abundant chalcidoid parasite of first generation *L. blancardella*. *S. marylandensis* and *S. sericeicornis* seem to be the most abundant chalcidoid species parasitizing the second generation although numbers recovered from the latter are too low to conclude that one species is more prevalent than the other. The overwintering level of parasitism by *A. ornigis* and chalcidoid species (Table IV) indicates that parasitism increased from 1973 to 1975.

Population Size of L. blancardella in Meaford

The history of *L. blancardella* infestation prior to 1972 in the Agriculture Canada orchard in Meaford is undocumented. Samples in Meaford, Ontario, from 1972 to 1974 indicated that the population (total of generations 1, 2, and 3) increased from 1.0 mines/leaf in 1972 to 1.6 mines/leaf in 1973 but decreased to 0.7 mines/leaf in 1974. Density of the first generation moths decreased from 1974 to 1975, probably due to an increase in parasite populations (Table VI).

TABLE VI. Average numbers of mines/leaf of *L. blancardella* in Meaford, Ontario.

Year	Sample	Average number mines/leaf
1972*	Generations 1, 2 and 3	1.00
1973	Generation 1	0.20
	Generation 2	0.40
	Generation 3	1.00
	Generations 1, 2 and 3	1.60
1974	Generation 1	0.20
	Generation 2	0.10
	Generation 3	0.40
	Generations 1, 2 and 3	0.70
1975	Generation 1	0.10

* Trottier, 1972 (unpublished data).

The distribution in the tree of *L. blancardella* and parasitism by *A. ornigis* in the first generation (the only one with sufficiently large numbers to be able to measure distribution) in 1974 was uniform within the tree and significant differences were not associated with level or direction. However, significant differences ($P < .05$) between trees did occur.

In 1974, *L. blancardella* population levels were assessed in several orchards in Ontario (Table VII). Three hundred leaves were sampled from each orchard to determine the number of mines per leaf and percent parasitism. There were considerable differences in population levels between orchards from the same area. In the Milton area, orchard 5 had a population level of 4.09 mines per leaf, compared to the neighbouring 1, 3, and 4 orchards; 0.00, 0.09 and 0.43 per leaf respectively. In commercial orchards with an insecticide-fungicide (complete) programme, levels of parasitism by *A. ornigis* were low compared with orchards 6-9 receiving fungicide treatments only (Table VII).

TABLE VII. *L. blancardella* population levels and (%) parasitism from different localities in Ontario, 1974.

Orchard	Area	Pesticide programme	Average mines/leaf Gen. 1, 2 & 3	% parasitism *Apanteles ornigis* Gen. 3	% parasitism chalcidoid species Gen. 3
1	Milton	Complete	0.00	—	—
2	Guelph	Complete	0.02	0.00	0.00
3	Milton	Complete	0.09	0.00	0.00
4	Milton	Complete	0.43	5.70	0.00
5	Milton	Complete	4.09	0.00	0.12*
6	Guelph	Fungicide	0.09	7.27	10.90
7	Vineland	Fungicide	0.30	10.93	0.00
8	Meaford	Fungicide	0.60	14.16	2.10
9	Guelph	Fungicide	0.63	12.97	2.90

Samples taken October 21-25, 1974.

* Only one chalcidoid larva found.

Conclusions and Summary

L. blancardella is well established in Ontario, Quebec, New Brunswick and Nova Scotia. It was found in all areas of Ontario that were sampled but population sizes differed greatly between orchards only a few miles from each other. There are three generations per year in the Meaford and Guelph areas of Ontario. The third generation pupae overwinter inside fallen leaves and the adults emerge during the early part of May.

The major parasite of the first generation *L. blancardella* was *A. ornigis,* an endoparasite of the tissue feeding larvae. This parasite does not seem to be an effective control agent for second generation *L. blancardella* but numbers of *A. ornigis* rise again on third generation hosts. *A. ornigis* overwinters within a cocoon inside the leaf-mine.

The most abundant chalcidoid parasites were *S. marylandensis, S. sericeicornis* and *Pnigalio flavipes,* ectoparasties which attack late instar larvae. The number of chalcidoids attacking first generation *L. blancardella* increased from 1973 to 1975 in Meaford. Chalcidoids are abundant on second and third generation hosts and overwinter as naked larvae or pupae inside the leaf-mine. Further work on this chalcidoid parasite complex is needed for a better understanding of

the interaction between species and their effects on the population dynamics of the leafminer.

Decisions for control recommendations for *L. blancardella* can be made using the concept of "biological windows" (Haynes *et al.* 1974). These windows are defined as "time areas" within the seasonal life cycle of the pest where application of a control measure will not interfere with the natural control agents. In this study it was shown that such a biological window does exist. Spring emergence of *A. ornigis* occurs about 20 days after first emergence of *L. blancardella*. *A. ornigis* emergence is well synchronized with host development and appears just as the first generation *L. blancardella* are entering the fourth larval instar which is the stage preferred by ovipositing *A. ornigis*. Thus, when abundance of the leafminer makes chemical controls necessary, there is a period of time in which control may be applied without killing *A. ornigis*.

Acknowledgement

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THE PEST STATUS OF FOLIAR INSECTS ON SOYBEANS AND WHITE BEANS IN ONTARIO

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Abstract

Insect pests of soybeans and white beans were surveyed in 1975 and 1976 in southwestern Ontario. A sweep net was used to sample 31 fields at one- to two-week intervals, during the growing season. The potato leafhopper, *Empoasca fabae* (Harris), was the most abundant insect found on soybeans and white beans both years. Green cloverworms, *Plathypena scabra* (Fabricius); grasshoppers, *Melanoplus* spp.; Mexican bean beetles, *Epilachna varivestis* Mulsant, and aphids, previously described as pests of beans in Ontario, were not numerous during this survey. Of 10 fields located adjacent to alfalfa, two soybean fields were damaged by pests dispersing from alfalfa following second cutting. In both instances the fields were damaged by adults of alfalfa weevil, *Hypera postica* (Gyllenhal); meadow spittlebugs, *Philaenus spumarius* (Linnaeus) and tarnished plant bugs, *Lygus lineolaris* (Palisot de Beauvois). The destructive insects found on soybeans and white beans were identical except that the Mexican bean beetle was found only on white beans and the alfalfa weevil was found only on soybeans.

Both the insecticides applied at planting time and the foliar sprays currently recommended for control of potato leafhoppers on white beans by the Ontario Ministry of Agriculture and Food were effective but did not increase bean yield. Because the numbers of economically important insects were low, foliar sprays, applied when control became necessary, were better advised than treatments at planting time.

* * * * * *

Introduction

Production of white beans doubled and soybean production increased 50% in Ontario since 1956 (Ontario Ministry of Agriculture and Food, 1975). The 58,000 hectares of white beans and 156,000 hectares of soybeans grown in Ontario in 1975 were valued at 92 million dollars. This was a 5-fold increase in the value of soybeans and a 3-fold increase in the value of white beans in the last 20 years. Research on insect pests of beans in Ontario has been neglected and has not kept pace with the value of the crop.

Bereza (1974) listed the insects that caused damage to white beans in Ontario. These included the potato leafhoppers, *Empoasca fabae* (Harris); aphids; green cloverworm, *Plathypena scabra* (Fabricius); Mexican bean beetle, *Epilachna varivestis* Mulsant; and grasshoppers. Insects on soybeans in Ontario seldom cause yield reduction and control measures are warranted only against green cloverworms when prevalent (Ontario Ministry of Agriculture and Food, 1976). More must be known about the identity and pest status of the insects of beans before updating control measures.

In this paper, we report on a two-year project to: 1) determine the foliage feeding insects that occur on soybeans and white beans in southwestern Ontario; 2) record and evaluate the relative abundance of these insects throughout the two seasons; and 3) evaluate the efficacy and yield benefits of insecticides presently recommended for control of bean pests in Ontario.

Materials and Methods

Insect populations were sampled in 31 fields of soybeans and white beans in southwestern Ontario during 1975 and 1976 (Fig. 1). No insecticides were applied to these fields either year other than a diazinon and lindane seed treatment. Five main areas were sampled: Norfolk county, Huron and Perth counties,

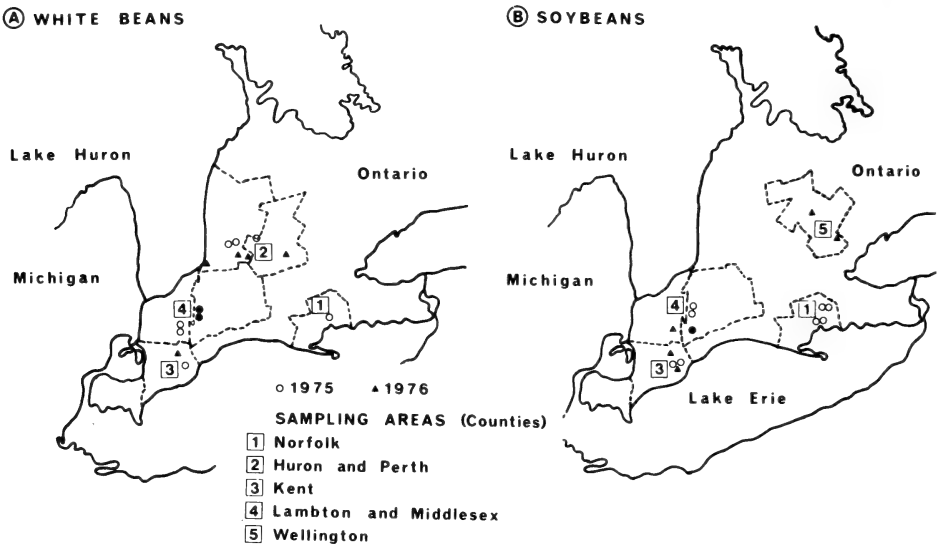

FIGURE 1. Locations of fields of white beans and soybeans sampled for insects in southwestern Ontario in 1975 and 1976.

Kent county, Lambton and Middlesex counties, and Wellington county. Eight fields sampled in 1975 and two in 1976 were purposely located next to fields of alfalfa so that the importance of pests dispersing from that crop could be assessed. Three plots, approximately 0.4 ha in size, were sampled in each field at one- to two-week intervals by taking 50 sweeps with a 38 cm (15 in) net. As recommended by Delong (1932) for collection of leafhoppers, two sweeps were taken over the same vegetation, one sweep on each side of the row. All samples were stored in 70% ethyl alcohol until sorted under a binocular microscope.

White beans, var. Sanilac, were planted at Kerwood, Ontario, on June 10, 1976, in a randomized, complete-block design of nine, three-row plots replicated four times. Immediately after planting, three granular insecticides were sprinkled directly over the seed row in a 15 cm band and raked 2 cm into the soil. Germination was determined weekly from June 28 to July 15 and again on Aug. 26 by counting the number of plants in 1.5 m of row in the middle of each plot. Plant height was checked weekly from June 27 to July 15 by measuring the height of the distal end of the petiole of the terminal trifoliate leaf of 20 plants from the middle row of each plot.

The efficacy of the granular insecticide treatments was determined by sampling each plot for potato leafhoppers on June 27 and July 8. The adult potato leafhoppers were collected from 10 sweeps in each plot, identified and tabulated. On July 15 and July 22, when nymphs were present, 20 trifoliate leaves were picked at random from each plot and the nymphs were counted and tabulated. Beans from the centre 5.4 m of the middle row were harvested on Sept. 17, threshed, dried to a constant weight, and reweighed to obtain yield data.

White beans, var. Kentwood, were planted at Elora, Ontario on June 4, 1976, and treated with the same rates of the granular insecticides. The residual toxicity of these insecticides was determined by caging potato leafhoppers on the leaves of treated plants. The cages were constructed from 236 ml styrofoam cups containing three, 1 cm holes; one in each side and one in the bottom. The terminal trifoliate leaf of a randomly selected bean plant was inserted through the bottom hole. Potato leafhopper adults collected from an adjacent field of white beans were

TABLE I. List of destructive insects collected on soybeans and white beans in southwestern Ontario.

Species	Common Name	Crop Where Collected	
		Soybean	White Bean
Scudderia spp.	bush katydids	✓	✓
Melanoplus spp.	grasshopper	✓	✓
Unidentified species of thrips		✓	✓
**Lygus lineolaris* (Palisot de Beauvois)	tarnished plant bug	✓	✓
**Adelphocoris lineolatus* (Goeze)	alfalfa plant bug	✓	✓
Acrosternum hilare (Say)	green stink bug	✓	✓
**Trigonotylus coelestiatium* (Kirk)		✓	✓
**Philaenus spumarius* (Linnaeus)	meadow spittlebug	✓	✓
**Empoasca fabae* (Harris)	potato leafhopper	✓	✓
**Macrosteles fascifrons* complex (Stal)	aster leafhopper	✓	✓
**Amplicephalus (Endria) inimica* (Say)	painted leafhopper	✓	✓
**Graminella nigrifrons* (Forbes)	blackfaced leafhopper	✓	✓
**Myzus persicae* (Sulzer)	green peach aphid	✓	✓
**Epicauta pennsylvanica* (DeGeer)	black blister beetle	✓	✓
Epilachna varivestis Mulsant	Mexican bean beetle		✓
**Systena* sp. prob. *blanda* Melsheimer	pale-striped flea beetle	✓	✓
**Longitarsus* spp.	flea beetle	✓	✓
**Systena frontalis* (Fabricius)	flea beetle	✓	✓
Hypera postica (Gyllenhal)	alfalfa weevil	✓	
Heliothis zea (Boddie)	corn earworm	✓	✓
Plathypena scabra (Fabricius)	green cloverworm	✓	✓
Trichoplusia ni (Hübner)	cabbage looper	✓	✓

* Identifications confirmed by Biosystematics Research Institute, Ottawa.

anaesthetized with CO_2 and placed into the cup through the top. A piece of nylon stocking was stretched tightly over the cup and tied to the leaf petiole. After 48 hours, the entire bean plant and cage were collected from the field and taken unopened to the laboratory where mortality counts were made. Six cages containing five potato leafhoppers each were placed in each plot at weekly intervals from June 25 to July 26 and also on the carbofuran plot and check plot on Aug. 6.

White beans, var. Kentwood, were planted at Elora, Ontario, on June 4, 1976, and later randomized in a complete-block design of six plots replicated four times. On Aug. 4, four plants from each plot were picked at random from a middle row and a pre-spray count of potato leafhopper nymphs (second- to fifth-stage nymphs), was made on all trifoliate leaves. Later the same day, five insecticides were applied to appropriate plots at the recommended rates (Ontario Ministry of Agriculture and Food, 1976) and replicated four times. Insecticides were applied with a boom-sprayer at the rate of 280 l of mixed spray per hectare at a pressure of 280 kPa (30 gal per acre at 40 psi). Counts of nymphs were repeated 2, 7 and 14 days post-treatment. Beans from the centre 5.4 m of the middle row were harvested on Sept. 29, threshed, dried to a constant weight, and reweighed to obtain yield data.

Results and Discussion

The injurious species of insects collected from soybeans and white beans were almost identical (Table I) and similar to what has been reported on soybeans (Deitz *et al.,* 1976). Two species described as pests of beans in Ontario were not found, namely, the fall armyworm, *Spodoptera frugiperda* (J. E. Smith); and the bean aphid, *Aphis fabae* Scopoli. Soybeans and white beans in Ontario have fewer insect pests than those grown in southern areas of North America.

The totals of the most numerous pest species collected at various locations in Ontario were tabulated. A comparison between soybeans (Table II) and white

TABLE II. Total numbers of some species collected on soybeans in Ontario; four samples of 150 sweeps each at 2 week intervals from July 1 to August 25.

County, Locality and Year	Tarnished Plant Bug	Other Mirid Species	Meadow Spittle-bug	Potato Leaf-hopper	Other Leafhopper Species	Leaf-feeding Beetles
NORFOLK						
1975						
Simcoe (1)	45	15	9	184	24	11
Simcoe (2)	115	160	39	86	65	14
Villa Nova (1)	10	15	23	83	22	9
Villa Nova (2)	19	23	17	283	12	13
KENT						
1975						
Ridgetown (1)	47	95	21	610	50	18
Ridgetown (2)	57	92	12	219	23	0
1976						
Ridgetown	8	8	11	1042	9	26
Thamesville	19	27	23	429	40	44
LAMBTON AND MIDDLESEX						
1975						
Kerwood (1)	74	96	75	492	48	16
Kerwood (2)	98	80	100	155	22	23
Glencoe	61	175	70	435	124	20
1976						
Aberfeldy	17	14	98	226	26	44
Glencoe	109	82	267	248	65	25
WELLINGTON						
1976						
Elora	11	48	223	1291	54	41
Arkell	294	270	700	320	84	42
TOTAL	984	1200	1688	6163	668	356

beans (Table III) can be made from the locations where both crops were sampled the same year. Such a comparison shows that pests, particularly potato leafhoppers, were more numerous on white beans Potato leafhoppers are influenced by host pubescence (Wolfenbarger and Sleesman, 1963; Broersma *et al.,* 1972). All the soybean varieties sampled during this survey were more pubescent than the white beans.

The potato leafhopper was the most abundant insect found during both years of the survey on both white beans and soybeans. Maximum numbers in

TABLE III. Total numbers of some species collected on white beans in Ontario; four samples of 150 sweeps each at 2 week intervals from July 1 to August 25.

County, Locality and Year	Tarnished Plant Bug	Other Mirid Species	Meadow Spittle-bug	Potato Leaf-hopper	Other Leafhopper Species	Leaf-feeding Beetles
NORFOLK						
1975						
Simcoe	60	89	4	919	84	17
HURON AND PERTH						
1975						
Kippen (1)	65	46	12	382	34	52
Kippen (2)	48	38	5	228	63	45
Dublin	22	48	12	177	276	14
1976						
Kirkton	33	66	54	638	74	15
Exeter	21	19	27	204	61	19
Grand Bend	43	31	12	554	58	113
Stratford	21	47	28	577	203	39
KENT						
1975						
Ridgetown	90	113	0	1451	98	11
1976						
Thamesville	116	17	10	489	52	86
LAMBTON AND MIDDLESEX						
1975						
Kerwood (1)	80	55	14	336	53	10
Kerwood (2)	154	79	14	674	70	14
Walnut	106	320	11	1038	41	10
Aberfeldy	77	100	4	416	91	12
1976						
Kerwood (1)	35	45	8	539	63	47
Kerwood (2)	40	19	11	871	274	25
TOTAL	1011	1132	226	9493	1595	529

each case occurred about mid-Aug. except on soybeans in Norfolk county where the maximum numbers occurred the first week of August in 1975 (Whitfield, 1977). The next most abundant species of insects on white beans was the tarnished plant bug and on soybeans the meadow spittlebug.

Leaf-feeding beetles, grasshoppers, green cloverworms, and aphids were not of pest status. The numbers of leaf-feeding beetles were low on both crops and were mainly flea beetles early in the season. Only one Mexican bean beetle larva was found during the entire two-year study. This species may occur in damaging numbers in some instances but this must be rare as we were unable to find any grower who had experienced damage by this pest. Grasshoppers and green cloverworms also occurred in low numbers on fields of beans sampled in both years and were not economically important. No grasshopper problems were reported on beans in Ontario in either 1975 or 1976. Only one species of aphid, the green peach aphid, *Myzus persicae* (Sulzer), was found on beans but was also not abundant enough to be considered a pest. This insect can transmit bean yellow mosaic virus but the disease was not reported on beans in Ontario during 1975 and 1976.

TABLE IV. Mean numbers of potato leafhoppers, height of white beans and bean yield following applications of granular insecticides to white beans at planting time.

Insecticide	Rate of Product kg/ha	Rate of Product (lb/A)	Mean Plant Height (cm) June 27	Mean Plant Height (cm) July 8	Mean Plant Height (cm) July 15	Mean No. of Potato Leafhoppers*/10 Sweeps June 27	Mean No. of Potato Leafhoppers*/10 Sweeps July 8	Mean No. of Potato Leafhoppers*/20 Trifoliate Leaves July 15	Mean No. of Potato Leafhoppers*/20 Trifoliate Leaves July 22	Yield (kg/ha)
DI-SYSTON 15G (disulfoton)	9.86	(8.75)	6.0a	11.8a	14.9a	2b	1b	3b	5b	1963.99a
FURADAN 10G (carbofuran)	11.21	(10)	6.7b	12.0a	18.1b	0c	0b	0c	1c	1953.89a
THIMET 10G (phorate)	11.21	(10)	6.4ab	9.5a	14.9a	2b	1b	1c	5b	1678.19a
UNTREATED CHECK			6.0a	9.9a	14.9a	6a	3a	16a	16a	1848.36a

* Data were transformed by square root ($x + \frac{1}{2}$). Means followed by the same letter are not significantly different at the 5% level as determined by Duncan's multiple range test.

Adjacent alfalfa fields had little effect on numbers or species of destructive insects on white beans and soybeans in 1975. However, in 1976, two soybean fields located next to alfalfa fields at Glencoe and Arkell, showed influxes of alfalfa weevil, *Hypera postica* (Gyllenhal); meadow spittlebug, *Philaenus spumarius* (Linnaeus); and tarnished plant bug, *Lygus lineolaris* (Palisot de Beauvois), after the second cutting of alfalfa. These two fields accounted for 57% of the meadow spittlebugs and 41% of the tarnished plant bugs from all soybean fields sampled in 1975 and 1976. Excluding the data of these two fields, meadow spittlebug numbers were low on both crops in both years. Populations of the alfalfa weevil were sufficiently high in early July on the soybeans at Arkell to warrant application of carbaryl (1.12 kg AI/ha). Six to ten alfalfa weevil adults per plant were present and three to four feeding-holes were visible per trifoliate leaf of soybean plants. Damage to pole-beans by alfalfa weevils was observed by Knowlton (1948) following extremely large populations on alfalfa during the season. Essig and Michelbacher (1933) and DeWitt *et al.* (1969) reported heavy feeding by adults of alfalfa weevil after caging them on soybean plants. This data showed that the planting of soybeans adjacent to alfalfa could lead to insect problems on soybeans. Foliar sprays may be necessary to control insects dispersing from alfalfa following cutting.

Efficacy of Insecticides

There were no significant differences in plant emergence among any of the treatments that were applied at planting time for potato leafhoppers and all the insecticide treatments provided good control up to July 22 (Table IV). However, only a small population of leafhoppers was present in this field and yields of treatments were not significantly different from each other or the check. White beans treated with carbofuran were significantly taller than were other treated beans and the check on June 27 and July 15. Phorate and carbofuran-treated plants were significantly taller than were check and disulfoton-treated plants on June 27. Moody and Bailey (1974) also reported an increase in plant height following in-furrow application of carbofuran at planting time but cautioned that the granular insecticide did not affect soybean production. The mortality of potato leafhoppers on plants treated with carbofuran was significant 52 days after application (Table V), and with disulfoton, significant up to 31 days after application. There was no significant difference in mortality among checks and plants treated with phorate before 21 days nor after 31 days. These results indicated

TABLE V. Percentage mortality of potato leafhoppers after 48 hours on white beans treated with granular insecticides at planting time.

Insecticide	Rate of Product kg/ha (lb/A)	Percentage Mortality No. of Days Following Treatment 21	31	38	45	52	63
DI-SYSTON 15G (disulfoton)	9.86 (8.75)	71.9bc	66.7b	13.4a	23.3a	16.7a	—
FURADAN 10G (carbofuran)	11.21 (10)	96.7c	96.7c	100.0b	66.7b	40.0b	10.0a
THIMET 10G (phorate)	11.21 (10)	50.0ab	43.4b	13.4a	23.3a	8.0a	—
UNTREATED CHECK		16.6a	10.0a	16.0a	23.3a	3.3a	10.0a

* Data were transformed by inverse sine. Means followed by the same letter are not significantly different at the 5% level as determined by Duncan's multiple range test.

plants treated with the relative persistence of insecticidal residues was carbofuran that the relative persistence of insecticidal residues was carbofuran > disulfoton > phorate. Webb *et al.* (1970) also suggested that the persistence of carborfuran was greater than that of phorate or disulfoton but that phorate was more persistant than disulfoton.

All the foliar treatments significantly reduced potato leafhopper populations on white beans for 14 days after application (Table VI). No treatments increased the dry weight of beans significantly at harvest. Azinphosmethyl and endosulfan significantly reduced yield but phytotoxicity was not observed.

TABLE VI. Mean number of nymphs of potato leafhopper and yield of white beans following applications of foliar insecticides, August 4.

Insecticide	Rate of Product /ha (/A)	Mean No. of Potato Leafhopper Nymphs/Plot* Pre-spray	Days After Treatment 2	7	14	Yield** (grams/plot)
CYGON 4EC (dimethoate)	1.05 l/ha (0.75 pt/A)	87a	0c	1b	2b	665.9a
GUTHION 2S (azinphosmethyl)	2.34 l/ha (1.66 pt/A)	92a	8b	1b	3b	576.4b
MALATHION 25% WP	4.48 kg/ha (4 lb/A)	104a	2c	1b	2b	709.3a
SEVIN 50% WP (carbaryl)	2.24 kg/ha (2 lb/A)	99a	0c	0b	3b	702.2a
THIODAN 4EC (endosulfan)	1.40 l/ha (1 pt/A)	93a	3bc	0b	2b	645.7b
UNTREATED CHECK		86a	74a	54a	45a	711.5a

* 4 plants counted per plot (data were transformed by square root $(x + \frac{1}{2})$).
**Yield data transformed by $\log_e$ before analysis. Means followed by the same letter are not significantly different at the 5% level as determined by Duncan's multiple range test.

Summary

The potato leafhopper was the most abundant insect found on soybeans and white beans in southwestern Ontario during 1975 and 1976. All the insecticides currently recommended for control of potato leafhopper on white beans in Ontario were tested and found effective in reducing leafhopper numbers. However, because populations of leafhoppers were low, neither the early nor late season control programs increased crop yield. Foliar sprays are preferable to planting-time applications of granular insecticides for the control of potato leafhoppers because their need can be established before application.

Green cloverworms, grasshoppers, Mexican bean beetles, and aphids, described as pests of beans in Ontario in the past, were not found to be numerous during the survey. These insects, however, could occasionally reach pest status in some fields and warrant a corrective control measure.

An influx of the adults of the alfalfa weevil, meadow spittlebugs, and tarnished plant bugs into soybean fields occurred after second cutting of adjacent alfalfa in two instances in 1976. Although this immigration may cause damage, requiring control in beans, it is not a common occurrence.

Acknowledgements

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LIGHT TRAP COLLECTIONS OF CERTAIN ECONOMICALLY IMPORTANT LEPIDOPTERA AT HARROW, ONTARIO

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Abstract

An ultraviolet light trap, operated from April to November for 6 years, provided information on seasonal distribution and annual variation of various Lepidoptera. The 7 species discussed and their average annual catch were: European corn borer, *Ostrinia nubilalis* (Hübner), (2573); armyworm, *Pseudaletia unipuncta* (Haworth), (1600); dingy cutworm, *Feltia ducens* Walker, (1155); variegated cutworm, *Peridroma saucia* (Hübner), (591); spotted cutworm, *Amathes c-nigrum* (Linnaeus), (560); black cutworm, *Agrotis ipsilon* (Hufnagel), (193); and corn earworm, *Helicoverpa zea* (Boddie), (107).

Only the dingy cutworm had a single peak of abundance. European corn borer, black cutworm, and spotted cutworm each had 2 or 3 generation peaks. Armyworm, variegated cutworm and corn earworm numbers were the most variable from year to year and support the hypothesis that at least a portion of these moths are migrants.

Two departures from the normal seasonal numbers of armyworm moths were tentatively suggested as indicators of the ensuing larval outbreak of 1976. In several instances, certain day-degree temperature accumulations were closely related to peak moth activity, and could be used as predictors.

* * * * * *

Introduction

Fluorescent ultraviolet light traps have proven very useful in entomological research. They provide occurrence records for many species of Lepidoptera, indicate the seasonal pattern of abundance, and over a number of years may serve to assess population changes. On a daily basis, light trap collections measure the suitability of the weather conditions for moth flight. If female moths are gravid, a good night for flight usually means there will be oviposition.

There are many factors which influence the number of a particular species of moth caught by a light trap. Assuming that a certain population level is present in the area, some species are attracted to the ultraviolet light more than others, there may be different levels of response between sexes, and both temperature and wind speed have a large influence. A full moon tends to decrease the moth catch.

Many of the above factors are averaged out if the light trap is run in the same place for a number of years, and the data become useful for comparison of a particular year with the average. A standard ultraviolet fluorescent light trap has been used at the Harrow Research Station since 1970, especially to record European corn borer moth flight, but other species were also tabulated for a number of years.

The peak of moth flight may be more closely related to the cumulative temperature than to the calendar date. If daily maximum and minimum temperatures are available, a simple day-degree accumulation may be calculated to compare peak times from year to year, or requirements for a complete generation (McLeod, 1976).

Methods

An Ellisco[1] general purpose 15 watt black light trap was used throughout the study. The bulb was a G.E. F15T8/BL, replaced at about 4 month intervals.

The trap site was at the Harrow Research Station on top of a gravel ridge which provided about 2 m elevation over the predominantly flat area. The ridge was not used for plots and the grass was kept mowed through the summer. The nearest crop was usually field corn 30.4 m away, and other crops within view of the trap site were soybeans, wheat, oats and white beans. Another ridge, 172 m to the west was wooded with mature red oak. A tobacco drying barn to the northwest was the only close building, and it blocked 17° of the light trap perimeter.

A dichlorvos strip in the collecting can provided quick death of the catch. The trap was emptied between 8 and 9 a.m. Monday to Friday and twice on weekends if moth flights were heavy. Selected species were sorted out, counted and some were sexed. The number recorded for a particular date was the previous night's catch. Data were tabulated as weekly totals to provide a smoother distribution curve, and for some moths the weekly catch was calculated as a proportion of the yearly total.

Temperature data from the Harrow meteorological records were used to calculate day-degrees above 10°C by the formula:

$$\text{Day-degrees} = \frac{\text{Daily max} + \text{daily min}}{2} - 10°\text{C}$$

Only positive values were used for seasonal accumulation.

Results

European corn borer *Ostrinia nubilalis* (Hübner)

The European corn borer has been monitored by a light trap at Harrow for many years. The records published by Wressell (1972) pertain to a "de Gryse" (incandescent) trap. McLeod (1976) used the "Ellisco" light trap data from Harrow, 1971 to 1974, for a comparison with other locations in southwestern Ontario, on a day-degree time scale. The weekly catches and mating frequency of females, from 1971 to 1975, are given in Elliott (1977). The average annual catch of those years was 2772.

In 1976 the total number of corn borer moths trapped was 1594, and as usual, over 90% of them were second generation moths. The date on which the first European corn borer moth was caught has only varied from May 29 to June 7 over the years 1971 to 1976. Peak moth catch occurs in the second generation, about mid-August. The highest number on a single night over the 6 years was 845 on August 14, 1971. The end of moth activity varied considerably, but was usually in October. When the evenings remained warm, corn borers were trapped as late as October 29.

The number of moths taken at the light trap provided a relative measure of oviposition that would follow, and if nightly catches exceeded 100 for several nights the interval between spray applications was decreased to 3 or 4 days rather than 5. Another use of these data was to indicate the gap between first and second generation flights. This enabled growers in the area to omit one or two sprays on sweet corn, on advice given by a recorded telephone message.

[1] Ellisco Inc., American and Luzerne Streets, Philadelphia, PA. 19140.

Armyworm *Pseudaletia unipuncta* (Haw.)

Armyworm moths were recorded each season from 1971 to 1976. The outbreak of armyworm in wheat fields of Essex and Kent counties in 1976 gave historical importance to the earlier light trap data. Other factors in addition to moth numbers are important in setting the stage for an epidemic and they should be evaluated if possible. Marcovitch (1957) links outbreaks with a scarcity of a major parasite, *Apanteles militaris* (Walsh), and a previous dry year.

The seasonal distribution of adult activity is illustrated in Fig. 1 by a graph of the weekly catch as a percent of the season total averaged over 6 years. Guppy (1969) stated that 575 day-degrees above a base temperature of 10°C was required for a complete generation of armyworm. The day-degree accumulations at Harrow ranged from 1382 to 1601 and averaged 1487. This would only allow 2 generations, so the 4 or 5 peaks of flight activity do not represent generations but are more likely due to moth migration from the south.

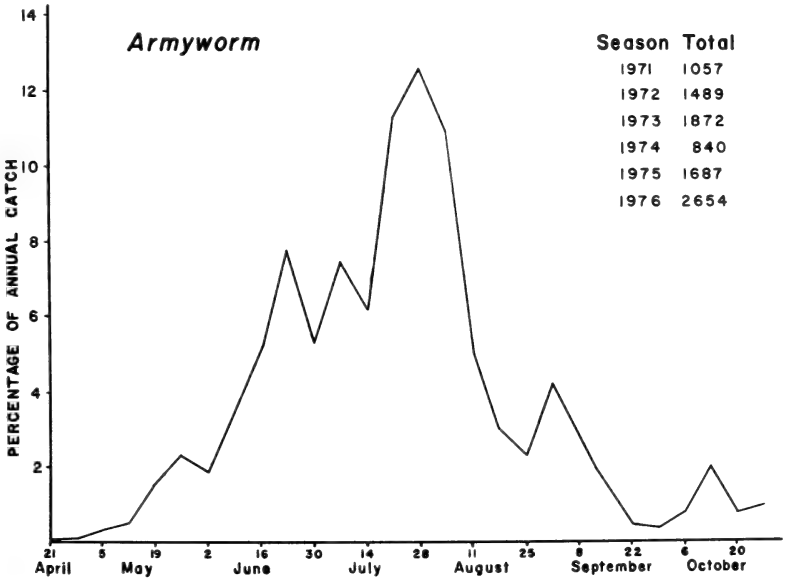

FIGURE 1. Weekly light trap catch of armyworm moths at Harrow, Ont., calculated as a percentage of the annual catch and averaged over 6 years.

There were two phenomena that may have been predictors of the 1976 armyworm outbreak. The fall of 1975 had moth activity later than usual with a November total of 87. Then in the spring relatively high numbers were caught in late April and early May. The cumulative total to May 12 was 63 while in other years it averaged 9 by that date. The survivors of the infestation resulted in many moths in July. The month's total light trap catch was 2217, and the record single night was 285.

Female moths outnumbered males in the collections in 1971 and 1976, the only two years in which armyworms were sexed. The ♂ : ♀ sex ratio of 41 : 59 was significantly different from an equal distribution at the 99% level of confidence.

Black Cutworm *Agrotis ipsilon* (Hufnagel)

The collections of black cutworm moths from 1971 to 1976 with the exception of 1974, were quite uniform from year to year. The 5-year average (Fig. 2) indicated 2 main peaks, one in mid July and the other in early September.

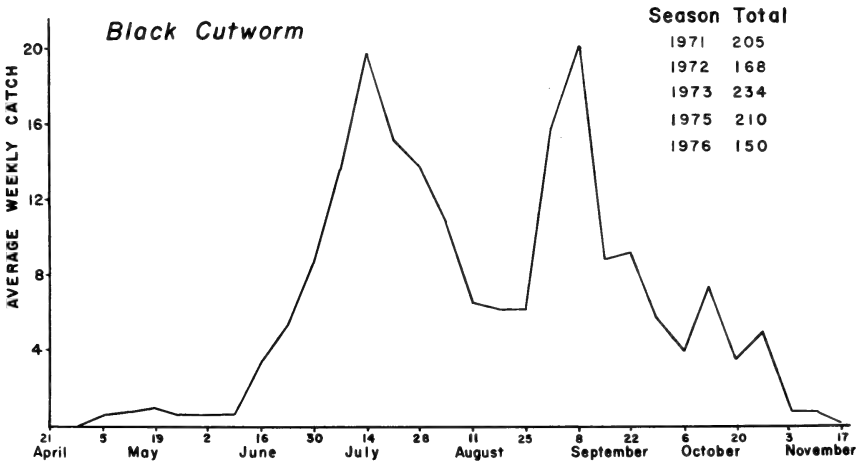

FIGURE 2. Average weekly catch of black cutworms over 5 years, at Harrow, Ont.

Adults were present early in the spring and late in the autumn. Record dates were April 30 and November 15 respectively. Apple (1967) suggested there was no diapause requirement for this species in Wisconsin. The overwintering generation did not produce many moths during May, and the rising numbers in June may have come from overwintering larvae rather than pupae. The period between peaks, 56 days, agreed closely with the laboratory life cycle of 54 days at 26°C (Harris *et al.*, 1962).

There was a moderate variation from year to year in the number of black cutworm moths trapped in the two main flight periods, and the peak heights were not as even as the average would indicate. The mid-August low level was quite pronounced, and in the 5 years of trapping no moths were taken on August 11.

Most moths were sexed and the overall ♂ : ♀ ratio was 45:55, but it was not consistent from year to year. In 1972 and 1973 there were more males than

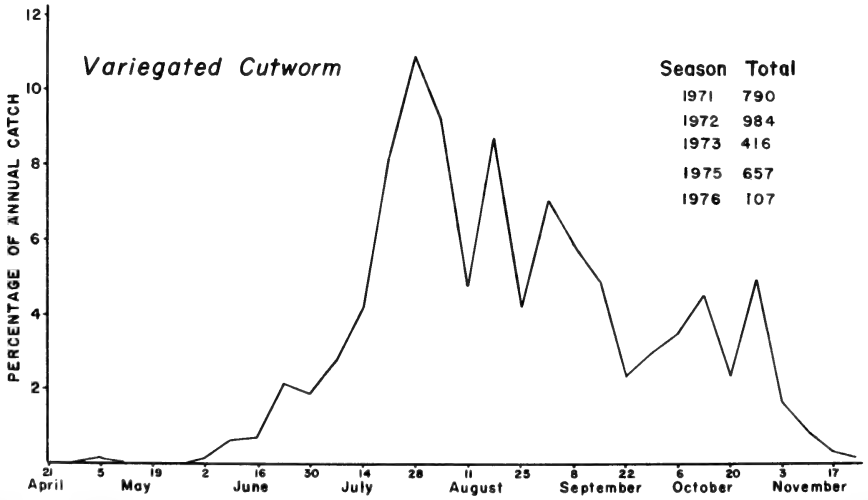

FIGURE 3. Weekly light trap catch of variegated cutworm moths at Harrow, Ont., calculated as a percentage of the annual catch and averaged over 5 years.

females. Only 1976 had a ratio significantly different from 50:50, and it was 31:69.

Variegated cutworm *Peridroma saucia* (Hübner)

This species has been a particular problem in fields of processing tomatoes in Essex County during some years. The light trap catches showed wide fluctuations through the season and also between years. A graph of the weekly catch on a proportional basis, averaged over 5 years, still did not eliminate this variability but indicated that the activity was mainly in July, August and September (Fig. 3).

A few specimens were caught early in the spring, for example, a moth was recorded April 17, 1972 and another the next night. The highest single night's catch was 48 on Oct. 10, 1972. As an indication of the variability encountered with this species, the previous week's total was 6, and the following week was 58. These rapid fluctuations support the hypothesis that the variegated cutworm is migratory. European studies have demonstrated that moth flight is south in autumn and north in spring (Poitout *et al.*, 1974). In favourable weather moths were caught between Nov. 15 and 19.

The ♂:♀ sex ratio (560 specimens) was 51:49, not significantly different from equal numbers.

Spotted cutworm *Amathes c-nigrum* (L.)

This cutworm has a wide range of hosts which includes many crop plants, but it is not often economically important (Beirne, 1971). The light trap records at Harrow confirmed that there were two generations a year. The average weekly catch, presented in Fig. 4, demonstrated a uniform activity. The bimodal peaks reflected variations in the average time of peak flight in different years.

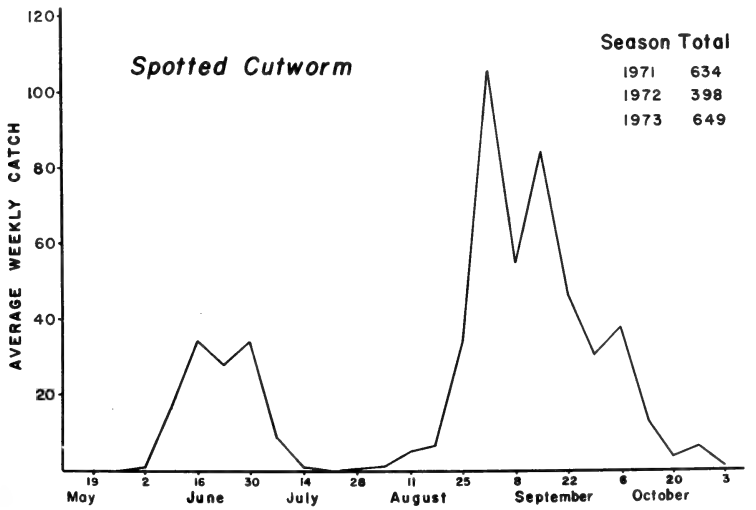

FIGURE 4. Average weekly catch of spotted cutworm moths, over 3 years, at Harrow Ont.

There was good agreement between day-degree accumulations and generation peaks in the 3 years of records. The first generation peak was at 258 ± 12.5[1] and the second at 1244 ± 28.5 day-degrees. Thus a complete generation required 986 day-degrees.

[1] Mean ± standard deviation.

The highest single night's catch of spotted cutworm was 69 on August 30, 1973, and the week ending Sept. 1, 1973 had a total of 269 moths.

Dingy cutworm *Feltia ducens* Walker

Specimens designated as dingy cutworm all appeared to be *Feltia ducens* Walker. Some of the very similar *F. subgothica* (Haworth) may have been present since it would be impossible to distinguish rubbed specimens.

A single generation was observed in the 3 years 1971 to 1973 (Fig. 5). The limits of the collecting period were July 25 and October 15. Record catches were set in 1971, centered on September 11 with 320 moths, and totalling 1074 for the week September 9-15.

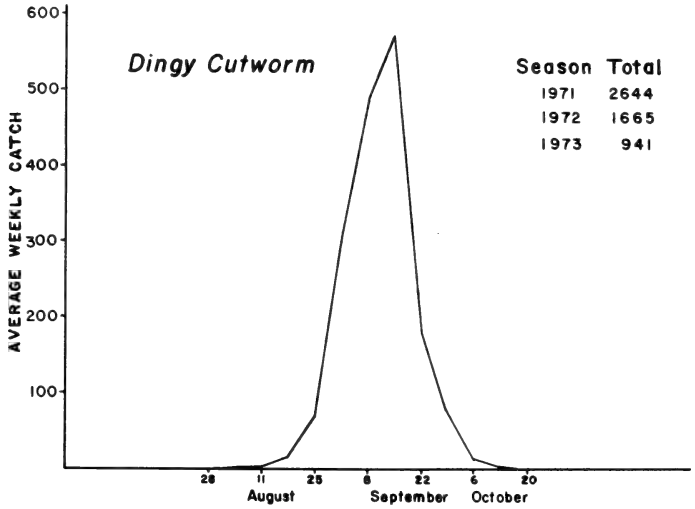

FIGURE 5. Average weekly catch of dingy cutworm moths, over 3 years, at Harrow, Ont.

The peak of activity in 1973 was about 10 days earlier than the two previous years. The day-degree accumulation was a better predictor with peak moth flight at 1253 $\pm$ 35.9. This was very close to the second generation peak of spotted cutworm.

Corn earworm *Heliocoverpa zea* (Boddie)

The corn earworm does not seem to be attracted to ultraviolet light traps as well as other species. In most years only an occasional moth is caught in July. There is enough infestation of sweet corn to indicate that moderate flights of migrant adults come into southwestern Ontario about then. The progeny of these migrants mature in the fall and higher numbers of moths are caught through September and October.

The 1971 peak flights occurred on the week ending September 15 with 113 moths recorded. In 1972 and 1973 the peaks occurred on October 6 with weekly totals of 23 and 91, respectively. There was no chance that these adults would find suitable oviposition sites in commercial crops that late in the season. Only 22 moths were trapped in 1974. The following year showed a moth flight of 72 between August 26 and September 16, and an equal number through October and early November. In 1976 only 6 corn earworm were taken in late August and September. The 6-year average annual catch was 107.

The main values of long term moth flight studies are the understanding of the seasonal life history, an assessment of the year to year fluctuations and, for some species, predictive information on the intensity of larval damage.

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A DISPOSABLE ADHESIVE TRAP FOR MONITORING THE CARROT RUST FLY

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Abstract

A disposable yellow adhesive bristol board trap was developed for capturing carrot rust fly, *Psila rosae* (F.), adults. In unsprayed, 0.02 ha plantings of carrots in the Holland Marsh, Ontario, the trap was as or more effective than wooden stake traps or Zoecon or Pherocon AM® traps. Captures of rust flies on bristol board traps mounted on stakes in a carrot planting with an emerging population of flies provided a record of the seasonal activity equal to that provided by emergence cages. The traps captured more flies when mounted at 15 cm than when mounted at 46 cm above the soil. Traps of orange yellow were more attactive than the sulphur yellow.

* * * * * *

Introduction

The carrot rust fly (CRF), *Psila rosae* (F.) has caused serious losses to carrots in the Holland Marsh, Ontario, on several occasions. Consequently, carrot growers use a protective spray program against this insect. Because the severity of attack varies considerably with location and from year to year, an effective method of monitoring seasonal activity of the adults can permit a more efficient use of insecticides. Bohlen (1967). Brunel *et al.* (1969), and Wakerley (1963) reported that flies responded to various colors but yellow was the most attractive. Stadler (1969) and Brunel (1971) employed yellow water traps and Wakerley (1963) and Stadler (1972) yellow glass plates to study fly activity. In the present study, yellow stake traps were employed initially. While they trapped flies effectively, they were bulky to transport and time consuming to clean. Reported here is a disposable adhesive trap developed for monitoring the CRF. Results of trials comparing the effectiveness of this trap and certain other traps also are presented.

Materials and Methods

The bristol board (BB) trap was constructed of yellow-painted bristol board 23 x 14 cm. Perforated lines were made with a casing wheel 0.5 cm from and on both sides of the centre line of the short axis to provide for folding of the trap. Tree Tanglefoot®[1] was applied from an aerosol can to an area 7.5 x 14 cm on each side of the 1-cm centre band, leaving a 3.5 cm wide margin without adhesive at each end of the trap. In transit and storage, the adhesive surfaces face inwards and the 1-cm band between the folded sides keeps the adhesive surfaces separated. In use, the adhesive surfaces face outwards when the trap is clamped with a Bulldog® clip (No. 1910) to a sidearm fastened to a wooden stake driven into the ground.

To construct the traps, sheets of white bristol board are painted and cut into strips large enough for 4 traps. The perforated lines are drawn and the adhesive applied before cutting into single traps. A wooden frame placed over the strip restricts the application of adhesive to the desired areas.

[1]The Tanglefoot Company, Grand Rapids, MI 49504.

Because a commercially available trap, if suitable, would be desirable, the Zoecon[2] trap described by Trottier *et al.* (1975) and the Pherocon AM®[2] trap also were tested. The Zoecon trap was obtained without the bait used for the apple maggot and, in 1974, it was modified further by cutting it in two to approximate the trapping area of the BB traps. In most tests the BB trap was painted with an orange yellow (Y1)[3]. In 2 trials, a sulphur yellow paint (Y2)[4] was tested that more closely resembled the color of the manufactured traps (Code No. not available). A trap similarly constructed from cellulose acetate (CA) and painted Y1 also was tested.

Most of the trials were conducted in plantings of carrots ca. 0.02 ha in area, located on commercial farms. The plots were being used to study the seasonal development of the CRF and were not treated with insecticide. Hence, CRF adults were usually emerging from the soil in or adjacent to the study plot when trapping trials were carried out.

A series of trials conducted during 1973-6 compared 2 or more types of traps. The traps being compared were usually fastened to the arms of a T-stake or placed on separate stakes within one m of one another. Pairs or groups of traps were placed at 5 sites within the plot, arranged in a pattern similar to the spots on dice. They were either left in place for 3 to 7 days and then removed for examination or the insects were counted *in situ* every 1 to 3 days and then removed from the trap.

In some cases stake traps, 61 x 7.5 x 2.5 cm with yellow trapping surfaces 15 x 7.5 cm on each face, were present for comparison although they could not be statistically compared with those of the test traps.

To determine the effect of trapping height, traps were mounted at each site on a single stake with sidearms located at appropriate heights above the soil.

To determine the efficacy of traps in detecting seasonal trends, traps were maintained in an unsprayed planting (exposed to attack by adults of the overwintered generation) throughout the emergence period of the 1st generation. Four emergence cages 1.5 m long, which covered 2 rows of carrots, were set up in the plot. Inside each cage, a stake trap similar to that already described was suspended from the apex of the cage. The numbers of flies trapped within the cages and on the field traps were recorded daily except on weekends.

Data from trials involving only 2 types of traps were tested for significance by a one-tailed, paired-sample *t* test (Zar 1974). Results of trials with more than two types of traps were analyzed by Fiedman's analysis of variance by ranks (Zar 1974).

Results

Traps varied in efficiency for capturing the carrot rust fly (Table I). In tests 1 and 2, the BBY1 trap performed as well as the stake traps ($P > 0.05$). In test 3, conducted when emergence of flies of the overwintered generation was practically complete and adult activity appeared to have declined, the BBY1 traps were more effective ($P > 0.05$) than the stake traps.

In tests 4, 5 and 6, conducted during the flight period of 1st generation adults, both BBY1 and CAY1 traps consistently captured more flies than did stake traps present in the same planting but not part of the experiment. In test 4,

[2]Manufactured by Zoecon Corp., Palo Alto, CA 94394.
[3]Code No. 6671, Sterling Varnish Co. Ltd., 5 Phillip St., St. Catharines, Ontario.
[4]Code No. 4239, Sterling Varnish Co. Ltd., 5 Phillip St., St. Catharines, Ontario.

Zoecon half-traps were as effective as BBY1 and CAY1 traps, but in test 6, they caught fewer flies ($P < 0.05$) than did the 2 homemade traps. Reasons for this variation in effectiveness are unknown. Test 7, later in the same season, showed that the Zoecon half traps were ($P < 0.01$) better than stake traps.

TABLE I. Mean daily catches of adult carrot rust flies on different types of traps in unsprayed carrot plots, Bradford, Ontario, 1973-1976.

Test No.	Trapping Periods	Mean number flies/trap/day[a] Stake trap	BBY1[b]	BBY2[b]	CAY1[b]	Zoecon	Pherocon AM
1	7-14/6/74	0.4x	0.5x	—	—	—	—
2	13-19/6/74	0.5x	0.7x	—	—	—	—
3	26/6-3/7/74	0.1x	0.6y	—	—	—	—
4	15-20/8/74	0.9[c]	3.0x	—	3.5x	3.3[d]x	—
5	20-27/8/74	1.9[c]	2.7x	—	2.3x	—	—
6	27/8-4/9/74	1.6[c]	2.3x	—	2.3x	1.2[d]y	—
7	4-10/9/74	0.8x	—	—	—	2.0[d]y	—
8	7/8-2/9/75	—	0.5x	—	—	0.6x	—
9	23/8-13/9/76	—	2.3x	—	—	—	1.7y
10	12-18/6/76	—	0.48x	0.25x	—	—	—
11	12-19/6/76	—	0.4x	0.1y	—	—	—

[a] Means within the same line followed by the same letter were not significantly different ($P > 0.05$).
[b] BB—Bristol board trap; CA—cellulose acetate trap; Y1—orange-yellow Y2—sulphur yellow.
[c] Stake traps were present in the same plot but not matched experimentally with test traps.
[d] Zoecon traps modified by cutting them in half.

In September 1975, test 8 showed that full-size Zoecon traps and BBY1 traps were equally effective ($P > 0.05$). In another test conducted between June 10 and July 17, 1975, the half-size and full-size Zoecon traps were compared; each type captured 1.7 flies/trap/day. In test 9, the Pherocon AM trap, which was structurally similar to the Zoecon trap, was less effective than the BBY1 trap ($P < 0.05$).

The sulphur-colored traps (BBY2) were not different ($P > 0.05$) from BBY1 traps when tested during the flight period of adults of the overwintered generation (Test 10) but were less effective ($P < 0.05$) during the following generation when adult numbers were lower (Test 11).

BBY1 traps maintained throughout the emergence period of 1st-generation adults in an infested unsprayed planting provided a record of seasonal activity comparable to that obtained by using emergence cages (Fig. 1). Although the numbers captured in field traps were not as high as the catches in the cages, they detected peaks of activity that paralleled peaks of emergence.

In 1974, BBY1 traps were placed 15 and 46 cm above ground in a young carrot planting with foliage not more than 15 cm high. Between June 13 and 25, catches were fewer ($P < 0.05$) at 46 cm (0.5 flies/trap/day) than at 15 cm (1.2 flies/trap/day). A similar test was conducted Aug. 11-20, 1975, when foliage was ca. 40 cm tall, and again more flies were captured ($P < 0.01$) at 15 cm (2.8 flies/trap/day) than at 46 cm (1.4 flies/trap/day).

Discussion

Several types of adhesive traps proved to be effective in capturing CRF adults in the field. In most trials, the BB trap developed at this station was equivalent to or better than the stake traps or the commercially manufactured traps.

The orange-yellow color (Y1) used on the BB traps was very similar to "buttercup yellow" in the RHS color charts.[5] Brunel *et al.* (1969) reported that the most attractive color to the CRF was "buttercup yellow". Y2, which resembled "sulphur yellow" on the RHS charts, was tested because it closely resembled the color of the manufactured traps. However, it was less attractive to the CRF than the orange-yellow, Y1.

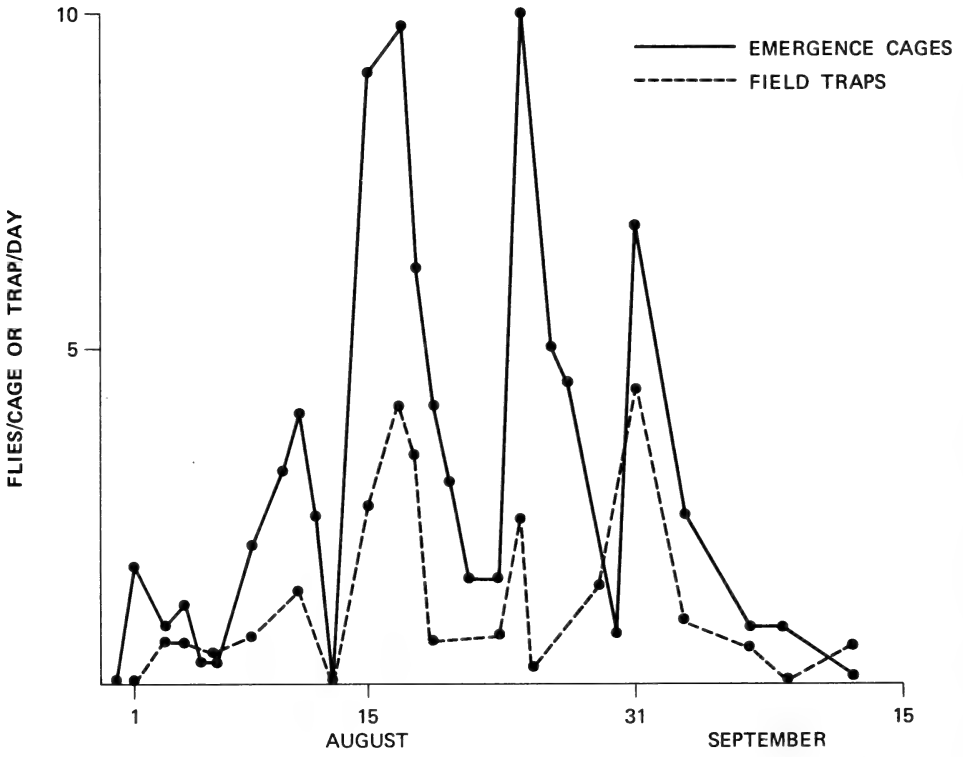

FIGURE 1. Seasonal activity of first generation adults of the carrot rust fly as determined by emergence cages and bristol board traps in an unsprayed plot of carrots. Bradford, Ontario. 1976.

The BB trap is especially useful for research purposes as it can be readily returned to the laboratory for examination without damaging the trapped insects. The cellulose acetate traps were more expensive to make and difficult to handle yet were no more effective than the BB traps so they were not used. Either BB or manufactured traps would be easily handled in a monitoring program. The BB traps could be made readily by growers should commercial traps prove too expensive.

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SEASONAL HISTORY OF THE CARROT WEEVIL, *LISTRONOTUS OREGONENSIS* (COLEOPTERA:CURCULIONIDAE) IN THE HOLLAND MARSH, ONTARIO

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Abstract

The seasonal history of the carrot weevil (CW), *Listronotus oregonensis* (LeConte), was studied in organic soil in the Holland Marsh, Ontario, in 1972-1976.

Egg-laying in celery transplants began as early as mid-May. From 1973-1976 the average date of peak oviposition in "set-out" carrot or celery was 6 June. In unsprayed plots of carrots seeded in early May, larval damage began to appear in early June and increased rapidly to reach a peak in early July. Mature larvae emerged continuously from infested carrots from about mid-July until the end of September.

First-generation adults appeared in late July and continued until November. There was normally one generation per year but in 1975 a partial second-generation occurred. The relationship between date of planting and damage in carrots and celery was determined.

Hibernating CW adults were recovered in November and again about 1 April from plant debris collected from sites where carrots were grown the previous season.

* * * * * *

Introduction

Since 1969, the carrot weevil (CW), *Listronotus oregonensis* (LeConte), has become an increasingly important pest of carrots and occasionally celery in the organic soils of the Holland Marsh, Ontario. Compounding the problem, the ban on the use of DDT in Ontario left the carrot growers with no insecticide registered for control of this insect. The biology of the CW has been studied in several states of the USA (Harris 1926, Boyce 1927, Pepper 1942, Wright and Decker 1958, Whitcomb 1965), where it has from 1 to 3 generations per year, and in Quebec (Perron 1971) where a single generation normally occurs. Although the CW was collected in Ontario in 1908 (Henderson 1940), no reports concerning its biology in this province have been published. A study of its seasonal history in the Holland Marsh during the years 1971-1976 is reported here.

Materials and Methods

The study was conducted on 3 commercial farms no more than 2 km apart, in an area of the Holland Marsh known to be infested by the CW.

To determine the onset and seasonal progress of oviposition, 10 or 20 carrot stecklings (1973-74) or celery seedlings ca. 10 cm high (1975-76), grown in a CW-free location, were transplanted into the soil in the study area. These trap plants were removed and examined after 3 to 7 days, and the numbers of infested plants, oviposition sites, and eggs deposited were recorded.

In 1973, the time of attack by the CW was determined by placing 60 x 13 x 10 cm boxes, containing carrot seedlings growing in muck soil in the ground in the study area for periods of 7 days between 22 May and 5 July. About 5 weeks after removal from the field the carrots were examined for CW damage, and retained in the laboratory until all larvae had left the roots. The soil was sifted to recover larvae or pupae that already had left the carrots.

Plots of carrots of ca. 0.02 ha in area, with rows ca. 24 m long, were seeded as early in May as possible during 1972-1974. Once the plants reached the first-true-leaf stage, the percentage infested (eggs or larval damage) was determined at 3- to 7-day intervals by collecting 100 carrots from each plot. Carrots severely damaged were often stunted and easily overlooked. Therefore, to minimize possible bias in sampling due to stunting, 5 consecutive carrots were collected at each of 5 sites selected at random within each of 4 quadrants of each plot.

When the carrots were 0.5 to 1 cm in diameter, samples of 100 were collected as described above at weekly intervals and placed in 2.2 liter plastic tubs with screened bottoms. Each tub was placed within a second tub containing a small amount of muck soil to collect maturing larvae. The carrots in tubs were kept in an insectary and the numbers of larvae leaving the infested carrots were counted every 3-4 days. The mature larvae were placed in muck soil in 14-cm petri dishes and retained in the insectary until the adults emerged.

The relationship between the severity of damage and dates of planting was determined experimentally. In one experiment, single-row plots of carrots, cv. Long Imperator, replicated thrice, were seeded at 2-week intervals beginning 23 May and concluding 17 July, 1972. On 3 October, 100 carrots were harvested from each plot and the percentage damaged was determined. Similarly, in 1973, plots of 20 plants of celery, cv. Utah, were planted at 7-10 day intervals from 10 May until 26 June. The plots were examined weekly and the numbers of dead, stunted, or chlorotic plants were recorded. On 24 July all surviving plants were pulled and the number having injury on the roots was recorded.

Because of the extensive damage due to first-generation larvae in the early-seeded study plots, it was not possible to determine whether any second-generation damage occurred. However, in 1972 and from 1974 to 1976, carrots from similar plots seeded in late June for carrot rust fly studies were examined for CW damage. To determine whether the first-generation adults maturing in the insectary oviposited during the current year, they were transferred to 0.5 1 plastic food containers, provided with pieces of carrot root as food and oviposition medium, and kept in the insectary until late autumn. In addition, adults were transferred to the laboratory and kept at 25°C and a 16-hr light period. In 1975 and 1976, the use of celery transplants previously described was extended until the end of August to detect any second-generation oviposition.

To determine sites of hibernation, 1-bu samples of plant debris (carrot foliage and weed material) were collected from the carrot study plots in November 1975 and in early spring of 1975-77. Portions of the debris were placed for 24 hr in a Berlese funnel separator similar to that described by Dietrick *et al.* (1959) to extract CW adults. None of the plots had been cultivated between harvest and time of collecting debris.

Results and Discussion

Oviposition by overwintered weevils in celery transplants began before the middle of May in 1975 and 1976 (Fig. 1). In 1973 and 1974, when carrot stecklings were first placed in the field 22 May, oviposition began before 25 May.

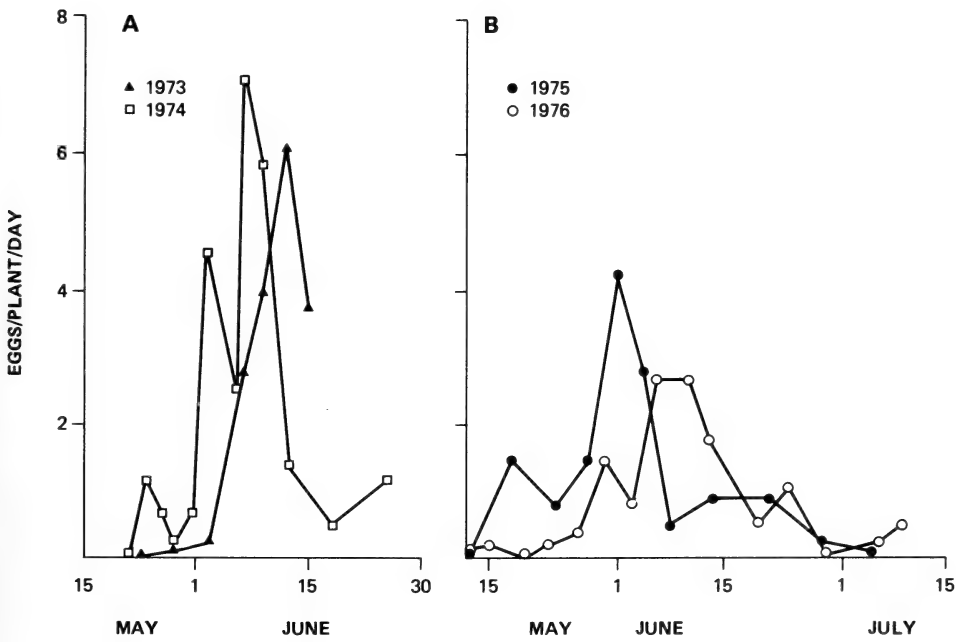

FIGURE 1. Daily rate of oviposition by the carrot weevil, Bradford, Ontario. A: Steckling carrots, 1973-74. B: Celery transplants, 1975-76.

In 3 of the 4 years, the rate of oviposition was maximal in the first half of June (Fig. 1). In 1975, however, the peak occurred before the end of May. Whitcomb (1965) reported that significant oviposition by CW adults occurred when maximum temperatures were at least 24°C. Therefore, the occurrence of a period of above-normal temperatures during the latter half of May 1975 probably explains the earlier peak observed in that year (Table I).

TABLE I. Dates of peak oviposition by the carrot weevil in relation to accumulated heat units and number of days with maximum temperature above 24°C[1]. Bradford, Ontario.

Year	Dates of peak oviposition[2]	Accumulated heat units (base 5°C) between 15 and 31 May	Days maximum 24°C or above	
			15-31 May	1-15 June
1973	8-12 June	108	0	11
1974	4-5 June	113	3	7
1975	26-29 May	222	10	2
1976	8-11 June	117	1	10

[1] Obtained from official records of the Atmospheric Environment Service, Springdale, Ontario, Station, located in the Holland Marsh.
[2] In steckling carrots (1973-74) and celery transplants (1975-76).

The early development observed in 1975 probably contributed significantly to the occurrence in that year of the partial second generation described below.

Exposure of carrot seedlings for various periods in 1973 showed that the intensity of attack by the CW, as determined by both the percent infestation and the numbers of larvae recovered, declined sharply after the third week of June (Table II).

TABLE II. Relationship between date of exposure of carrot seedlings and amount of damage by the carrot weevil. Bradford, Ontario. 1973.

Dates of exposure	Per cent damaged	Number carrot weevil larvae or pupae recovered
22-29 May	44.7	46
1- 7 Jun	32.3	46
7-14 Jun	28.0	32
14-21 Jun	34.0	36
21-28 Jun	6.5	1
28 Jun-5 Jul	3.8	5

The development of the CW infestation in the new seeded crop followed a pattern similar to that of oviposition (Fig. 2). In the study plots, generally seeded before 10 May, low levels of infestation were noted in early to mid-June. The percentage of infested plants increased rapidly during the last week of June and in early July. No separate records of foliar and root infestation were kept. However, in the early stages some of the infestation was limited to the foliage; later most of the injured plants had larval damage to roots as well.

In seeded carrots, little oviposition occurred until the carrots had developed beyond the first-true-leaf stage. Hence, the beginning and extent of the early stages of oviposition in a carrot planting will depend upon date of seeding and

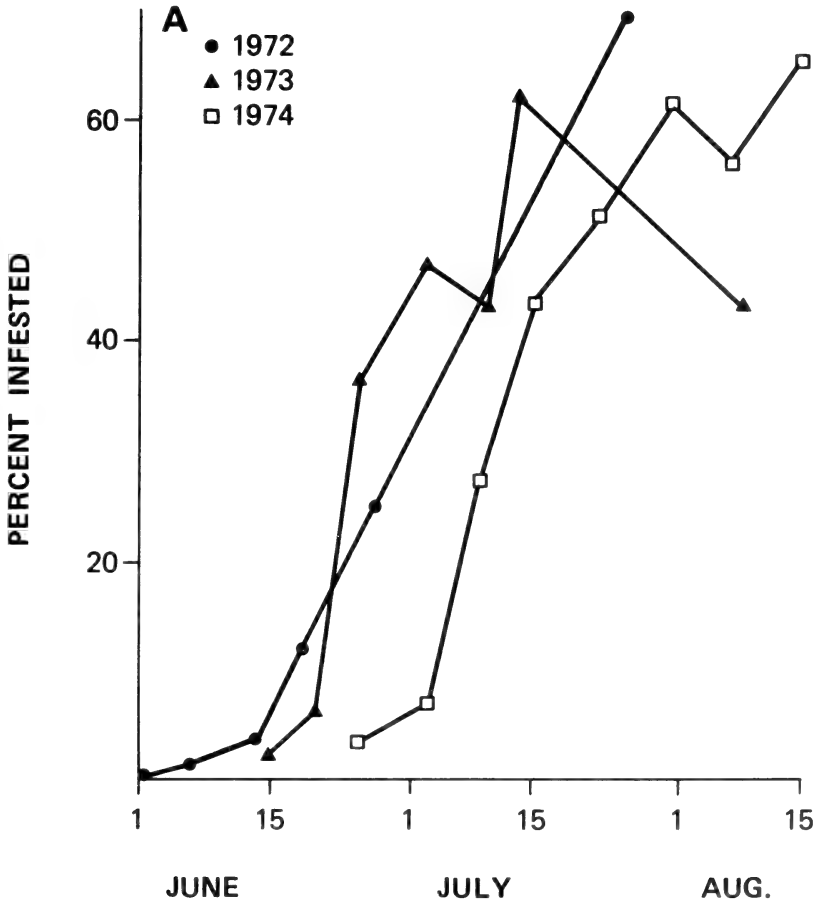

FIGURE 2. Seasonal increase in percentage of carrots infested by the carrot weevil. Bradford, Ontario. 1972-74.

growing conditions as well as upon climatic factors affecting the adult weevils. Celery, normally grown from transplants in the Holland Marsh, will be susceptible to attack immediately or very soon after transplanting. Volunteer carrots also would provide a host for oviposition as soon as environmental conditions are favourable.

In the insectary, mature larvae emerged from infested carrots from mid-July to early October (Table III). The sampling of 17 July yielded the most larvae. At this time oviposition was virtually complete and few mature larvae had emerged from the carrots. Thus this collection probably represented close to the maximum concentration of larvae that occurred in the field. Subsequent collections yielded fewer larvae because increasing numbers had left the carrots in the field before sampling. The continued decline in numbers of larvae recovered during the remainder of the season indicates that no second-generation attack occurred.

Adult emergence from the above collections began between 27 and 31 July and continued until early November. As an indication of the time required from larval maturity to adult eclosion, larvae recovered between 19 and 21 July pro-

duced adults from 4 to 25 August. Overall, the time from larval emergence to 50% eclosion ranged from 19 to 26 days.

The foregoing account described the conditions of development in the seeded carrot crop. However, carrot stecklings exposed in the field before 22-25 May yielded mature larvae in the insectary by 27 June. Hence, volunteer carrots in a field could result in an earlier development of the new generation of the CW.

TABLE III. Emergence of mature carrot weevil larvae from carrots collected from the field at various dates and incubated in an insectary. Bradford, Ontario, 1972.

Date of collection	No. larvae recovered[1]	Dates of recovery
27 June	32	13 - 31 July
8 July	98	14 - 31 July
17 July	158	18 July - 4 Aug
25 July	122	27 July - 22 Aug
31 July	104	3 - 29 Aug
9 Aug	43	11 - 31 Aug
24 Aug	33	28 Aug - 12 Sept
31 Aug	27	—[2]
11 Sept	10	—
19 Sept.	14	—
25 Sept	11	—
3 Oct	2	—
10 Oct	1	

[1] Samples of 100 carrots.
[2] After Sept 1, larval recovery containers were kept in an insectary at Vineland. Dates of recovery were no longer comparable.

In 1972 the relationship between date of seeding carrots and extent of infestation was as follows:

Date seeded:	23 May	5 June	20 June	4 July	17 July
Mean % damage:[1]	59.2a	46.0ab	29.6ab	21.9bc	2.6c

Date of planting also influenced the severity of CW damage to celery (Table IV). In 1973, celery seedlings transplanted in May and early June were moderately to severely damaged, while those transplanted later suffered some root damage but were not seriously affected above ground. In subsequent experiments, little or no above-ground damage occurred on celery despite infestation of the roots.

TABLE IV. Effect of date of transplanting on the severity of Carrot Weevil damage to celery. Bradford, Ontario. 1973.

Date transplanted	Number of plants killed	Survivors damaged	Total attacked by CW[1]
10 May	6	6	12
17 May	17	3	20
5 Jun	4	14	18
12 Jun	2	14	16
19 Jun	0	10	10
26 Jun	0	12	12

[1] 20 plants per date.

[1]Means followed by the same letter were not significantly different according to Duncan's Multiple Range Test ($P < 0.01$).

Apparently celery can tolerate a certain amount of root feeding without significant crop loss. Probably the condition of the transplants and growing conditions subsequent to transplanting are also important factors in determining the response of celery to attack.

In 1971, 1974, and 1976 no damage was recorded in the late-seeded study plots. Conversely, in 1973 some damage occurred in carrots seeded 25 June, but whether any of it was due to second-generation larvae could not be determined. In 1975, however, both oviposition by first generation adults and damage by the resultant larvae were confirmed. Oviposition in celery transplants was as follows:

Date set out:	30 July	6 Aug.	13 Aug.	20 Aug	28 Aug
Eggs/plant/day:	0	0.5	0.2	0.5	0

The relation between time of sampling and the percent infestation by second-generation larvae in samples of 100 carrots was:

Date of sample:	20 Aug	25 Aug	28 Aug	2 Sep	8 Sep
Percent damage:	5	5	23	19	30

However, there were no reports of economically significant second-generation damage in commercial plantings in the marsh in that year.

In 1975 first-generation adults that matured in the insectary before 5 August oviposited in the insectary but laid no eggs after 25 August. In the other years only very few eggs were laid in the insectary and then only by the adults maturing in early July.

First-generation adults oviposited soon after being transferred to the laboratory, indicating that diapause did not account for failure to oviposit in the insectary. Adults began laying eggs 5 to 12 days after transfer to 25°C in 16 hr daily light period, the varying interval probably depending on the age of the adults at the time of transfer. Similar results were reported by Whitcomb (1965) who found that summer adults did not oviposit in the laboratory unless exposed to longer periods of light and warmer temperatures than outdoors.

Hibernation behaviour of adults has been described. Boyce (1927) found hibernating adults in plant material on the site of a carrot crop of the previous year, but Pepper (1942) was unable to confirm this result. Wright and Decker (1958) reported that weevils hibernated in roadsides, ditchbanks and hedgerows near previously infested fields. Whitcomb (1965) reported on the movement of adults to and from hibernation but did not describe hibernation sites. In the present study, debris collected from carrot study plots yielded adults in both late autumn of the year of cropping and in early spring of the following year. Samples collected in November 1975 and early April in 1975, 1976 and 1977 yielded from 6 to 28 adults per bu of debris. Simultaneously, from 65 to 90% fewer adults were recovered from samples collected from the nearby ditches and headlands. These results showed that some adults overwinter in the crop site and their presence probably contributes to an early attack on a susceptible crop planted in that location the following year.

This study showed that there is normally one generation per year of the CW in the Holland Marsh, although a small number of eggs may be laid by the earliest first-generation adults. Occasionally, as in 1975, some second-generation damage occurs. Periods of unusually warm weather in May and the presence of early celery transplants or volunteer carrots favour such an occurrence. This is probably because the earlier development of first-generation adults results in their

exposure to temperatures and photoperiods favourable to oviposition. A similar situation exists in Massachusetts (Whitcomb 1965), while in more southerly areas climatic conditions favour more than one generation annually (Harris 1926, Boyce 1927, Pepper 1942, Wright and Decker 1958).

In the Holland Marsh most carrots are seeded early enough to be exposed to CW attack. Carrots seeded in May and early June are most severely attacked and have the greatest need for control measures. The time of attack by the CW coincides sufficiently with that of first-generation carrot rust fly, *Psila rosae* (F.), that chemical control programs for the two insects can be coordinated.

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A PRELIMINARY REPORT ON THE GYPSY MOTH AND ITS PARASITES IN SOUTHEASTERN ONTARIO

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Abstract

Gypsy moth, *Lymantria (=Porthetria) dispar* (L.), was common in several woodlots in the vicinity of Kingston, Ontario and, though rare in woodlots in Glengarry County, was common on roadside oaks there. Four species of parasites were recovered in these areas. Three of these, *Apanteles melanoscelus* (Ratz.), *Compsilura concinnata* (Meigen) and *Parasetigena agilis* (R-D), are exotic species already established on this host in the United States. The fourth parasite, *Pimpla pedalis* Cress., is a native species that has been recovered also in the United States. A fifth species, *Gelis tenellus* (Say), is a hyperparasite of *A. melanoscelus*.

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Introduction

Populations of the gypsy moth, *Lymantria (=Porthetria) dispar* (L.), have been found in Canada three times. On the first two occasions, in southwestern Quebec from 1924 to 1927 and in New Brunswick from 1936 to 1940, the outbreaks were isolated from the continuous distribution of the gypsy moth in the United States and were apparently eliminated (Brown 1968). The third invasion was noted first in southwestern Quebec in 1959 (Brown 1968, 1969). The gypsy moth has been present there ever since, and has been found also on Wolfe Island, Ontario since 1969 (Sippell *et al.* 1970), Howe Island and the adjacent Ontario mainland near Kingston since 1970 (Sippell *et al.* 1971) and in Glengarry and Prescott counties, Ontario, since 1971 (Sippell *et al.* 1972). In addition to being lengthier and more widespread than earlier invasions, these are no longer isolated populations but are extensions of the continuous distribution of the gypsy moth in the United States. Thus it appears that the gypsy moth may have become a permanent resident in southeastern Ontario, and the present survey is a necessary preliminary step to more extensive work against this potentially harmful insect.

Methods

The initial selection of areas to be searched for gypsy moth was made with the assistance of G. S. Brown of the Plant Protection Division of Canada Agriculture, who has been monitoring the gypsy moth in Canada since its most recent arrival. The areas selected were on Wolfe Island and near Eastview, both in Frontenac County, and in the Pine Hill-Glen Norman area of Glengarry County. Egg searches were made on ground debris and the lower 2 m of tree trunks in May and early September of each year. Because of the scarcity of eggs, a maximum of 4 man-hours of searching was allotted per plot, if approximately 50 egg masses had not been found already.

Collections of larvae were made in the same areas when larvae were nearing maturity, i.e., July 11-18, 1974 and June 20-26, 1975. Plots were set up in woodlots at the following locations:

Plot 1—0.4 km west of Eastview on Highway 2, Frontenac County;
Plot 2—Concession 11, Wolfe Island, Frontenac County;

Plot 3—0.8 km south of Glen Norman, County Road 26, Glengarry County;
Plot 4—Oak Point Road, Wolfe Island, Frontenac County;
Plot 5—0.8 km east of Kilburnie, County Road 16, Frontenac County;
Plot 6—6 km east of Pine Hill, County Road 18, Glengarry County;
Plot 7—3 km north of Williamstown, County Road 19, Glengarry County.

A plot consisted of 10 trees, each wrapped with a 30-cm-wide strip of burlap at breast height. The strips were fastened to the trees with cord so that half of the width hung down on either side of the cord. These strips serve to "trap" larvae which, during the late larval stages, feed at night and descend from the trees in the early morning to spend the day in sheltered sites on the trunk or on the ground (Leonard 1970). Plots were visited and the larvae removed from the burlap strips every second day. They were placed in paper bags which were sealed with masking tape and transported to Kingston, where they were reared at Queen's University through the courtesy of Dr. G. R. Wyatt of the Biology Department. These samples were left in Kingston until September when the fall egg survey was made, at which time parasites were brought to Sault Ste. Marie for further rearing or examination.

Burlap strips were placed on trees of the following species: basswood (*Tilia americana* L.), sugar maple (*Acer saccharum* Marsh.), red oak (*Quercus rubra* L.), white oak (*Q. alba* L.), beech (*Fagus grandifolia* Ehrh.), trembling aspen (*Populus tremuloides* Michx.), shagbark hickory (*Carya ovata* [Mill.] K. Koch), bitternut hickory (*C. cordiformis* [Wang] K. Koch), black cherry (*Prunus serotina* Ehrh.), hop hornbeam (*Ostrya virginiana* [Mill.] K. Koch), white elm (*Ulmus americana* L.), white ash (*Fraxinus americana* L.), black ash (*F. nigra* Marsh.). In the text and tables that follow, the two species each of oak, hickory and ash are grouped, both to simplify the results and because the members of each pair were found to be in the same food preference class by Mosher (1915) in his study of food plants of the gypsy moth.

Results and Discussion

A total of 230 egg masses was obtained in collections made in the spring and fall of each year (Table I). Egg masses from spring collections were reared immediately at room temperature in quarantine; those from fall collections were reared at room temperature for approximately 2 months, then stored at 2°C until

TABLE I. Number of gypsy moth egg masses collected in southeastern Ontario in 1974 and 1975.

Plot	1974		1975	
	Spring	Fall	Spring	Fall
1	36	25	14	—
2	53	25	12	25
3	1	1	0	1
4	—	—	—	24
8[a]	—	—	—	13

[a] Roadside oaks, Glengarry County.

spring when they were again reared at room temperature. Emergence was normal in both groups of gypsy moth when they were incubated in the spring. This rearing regime was designed to recover adults of both of the exotic egg parasites established on the gypsy moth in the United States. One of these species, *Anas-*

TABLE II. Numbers of gypsy moth larvae obtained from various tree species sampled in southeastern Ontario in 1974 and 1975.

Tree species	Year	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	Plot 6	Plot 7
Oak	1974	200 (5)[a]	345 (8)		68 (7)	0 (8)		
	1975	0 (4)	260 (5)		326 (2)	1 (5)	0 (1)	
Basswood	1974	17 (1)		3 (5)	0 (1)	0 (2)	0 (1)	0 (5)
	1975			0 (4)	9 (1)	1 (5)	0 (1)	0 (2)
Beech	1974				2 (1)			
	1975		144 (1)	0 (1)	23 (1)			
Aspen	1974						0 (4)	
	1975						4 (3)	
Maple	1974	68 (1)		0 (5)	0 (1)		0 (3)	0 (2)
	1975			0 (2)	1 (1)		0 (3)	0 (2)
Hickory	1974	67 (3)	93 (1)					0 (3)
	1975	0 (6)	62 (3)					0 (1)
Cherry	1974		65 (1)					
	1975		27 (1)					
Hornbeam	1974							
	1975				46 (2)			
Elm	1974							
	1975			0 (1)			0 (2)	
Ash	1974							
	1975			0 (2)	7 (3)			0 (4)
	1974	352 (10)	503 (10)	3 (10)	70 (10)	0 (10)	0 (8)	0 (10)
	1975	0 (10)	493 (10)	0 (10)	412 (10)	2 (10)	4 (10)	0 (9)

[a] Numbers in brackets are the numbers of trees sampled.

tatus disparis Ruschka, overwinters as a mature larva within the gypsy moth egg chorion and emerges as an adult in spring. The other species, *Ooencyrtus kuwanai* (How.), overwinters as an adult which has emerged from a gypsy moth egg in the fall (Burgess and Crossman 1929). No specimens of either species were obtained from these collections.

Substantial numbers of larvae were obtained from the three plots in Frontenac County (Plots 1, 2 and 4) in 1974 and from two of them in 1975 (Plots 2 and 4) (Table II). The absence of larvae from Plot 1 in 1975 was the result of a spraying operation carried out there by Agriculture Canada. Very few larvae were obtained from the plots in Glengarry County (Plots 3, 6 and 7) (Table II), but this appears to have been caused, at least in part, by the absence of favored food plants rather than of gypsy moth, since many moths were found when roadside oaks in the same area were examined. Ten such oaks were examined on 4 days in 1974 and 56 larvae and pupae were found. Fifteen roadside oaks examined on 4 days in 1975 provided 264 larvae.

In the 4 plot years during which 350 or more gypsy moth larvae were obtained under burlap strips (Plot 1, 1974; Plot 2, 1974, 1975; Plot 4, 1975), all trees sampled produced larvae on at least one sample day. In order to make comparisons between tree species possible, differences in tree circumference were compensated for by converting daily recovery under burlap strips to daily recovery per linear 30 cm of strip. Then data for each tree species were grouped for all four plots and the mean number per species was calculated (Table III). When

TABLE III. Number of gypsy moth larvae obtained per day per 30 cm of burlap strip, Plot 1, 1974; Plot 2, 1974, 1975; Plot 4, 1975.

Tree species	Mean[a]	Number of sample days	Number of trees
Beech	12.8	8	2
Cherry	5.0	8	2
Oak	2.9	96	20
Hickory	2.2	37	7
Maple	1.9	10	2
Basswood	0.5	11	2
Ash	0.2	12	3

[a] None of the means joined by the same line is significantly different by Duncan's Multiple Range Test.

means were compared by Duncan's Multiple Range Test, it was found that significantly more larvae and pupae were collected from beech than from all other tree species. None of the other differences between tree species was significant.

Four species of parasites were recovered as adults from rearings and these were identified at the Biosystematics Research Institute, Ottawa (Table IV). However, only one of them, *Compsilura concinnata* (Meigen), was common. This species is of European origin and was introduced successfully into the United States against the gypsy moth in 1906 (Dowden 1962) and into Canada against the satin moth, *Stilpnotia salicis* (L.), and other species in 1913 (McGugan and Coppel 1962). Since then it has been recovered from over 200 host species in the United States (Dowden 1962) and from 41 species in Ontario by the staff of the Forest Insect and Disease Survey, Great Lakes Forest Research

TABLE IV. Parasites recovered from gypsy moth in southeastern Ontario in 1974 and 1975.

	Year	Plot 1	Plot 2	Plot 4	Plot 8[a]
Gypsy moth collected[b]	1974	352 + 0	496 + 7	70 + 0	45 + 11
	1975	0 + 0	493 + 0	412 + 0	264 + 0
Parasites recovered					
Braconidae					
Apanteles melanoscelus	1974	0	11	0	0
	1975	0	16	4	2
Ichneumonidae					
Gelis tenellus	1974	0	1	0	0
	1975	0	0	0	0
Pimpla pedalis	1974	0	0	0	6
	1975	0	0	0	0
Tachinidae					
Compsilura concinnata	1974	65	46	0	0
	1975	0	19	17	25
Parasetigena agilis[c]	1975	0	9	6	3
Diptera puparia[d]	1974	9	9	5	0

[a] Roadside oaks, Glengarry County.
[b] Numbers are for larvae and pupae, respectively.
[c] No adult emergence, based on puparial characteristics (Tigner 1974).
[d] Not examined.

Centre, Sault Ste. Marie, Ontario. It is a larval parasite and has from two to four generations per year on various hosts.

Apanteles melanoscelus (Ratz.) was almost as widely distributed among the samples but was not nearly as common as *C. concinnata*. It is also a European species successfully introduced into the United States against the gypsy moth (Dowden 1962) and into New Brunswick, Newfoundland and British Columbia against the satin moth (McGugan and Coppel 1962). It was not introduced into Ontario and this is believed to be the first recorded recovery of this species here. It probably arrived with the gypsy moth since Tigner *et al.* (1974) suggest that primary dispersal occurs when the parasite is inside first-instar gypsy moth larvae which are dispersed by the wind. *Apanteles melanoscelus* is a larval parasite that has two generations per year on the gypsy moth. In the United States hyperparasitism greatly reduces the effect of this species. *Gelis tenellus* (Say), which was recovered in the same plot as *A. melanoscelus* in 1974, is one of these hyperparasites (Muesebeck and Dohanian 1927). It is a native species and has been recovered from 27 hosts in Ontario by the Forest Insect and Disease Survey.

The fourth species obtained, *Pimpla pedalis* Cress., is a native species, recovered from seven hosts by the Forest Insect and Disease Survey in Ontario. It is a pupal parasite and this may account for its rarity in this study, since few gypsy moth pupae were collected.

The fifth species, *Parasetigena agilis* (R-D), was identified by developmental and puparial characteristics presented by Tigner (1974), since no adults were produced. It is a European species established on the gypsy moth in the United States (Dowden 1962). It was not introduced into Ontario and this is believed to be the first recorded recovery of this species here. It is a univoltine larval parasite.

Pimpla pedalis, the only native primary parasite obtained from the gypsy moth in this study, is recovered rarely in the United States (Campbell 1963).

The three exotic parasites now known to be established on gypsy moth in southeastern Ontario—*C. concinnata, A. melanoscelus* and *P. agilis*—are all common species on the gypsy moth in the United States, but assessments of their regulatory influence either do not exist or are contradictory. Both Bess (1961) and Campbell (1967) point out in their studies of gypsy moth populations that *C. concinnata* may be a very common parasite of late larvae, but the latter author also states that it is ineffective in population regulation in spite of its abundance. Reardon (1973) obtained this species from high populations of gypsy moth on Cape Cod, Massachusetts in 9 of 10 plot years, but the maximum attack there was 8%. He obtained *P. agilis* in all five plots in both years and found parasitism by this species to be from 4% to 33%. However, neither Bess (1961) nor Campbell (1967) mentions this species. *Apanteles melanoscelus* is often common in the United States but hyperparasitism is usually extreme. Burgess and Crossman (1929) recorded up to 95% of the second generation destroyed; Proper (1934) found 39% of the first generation and 89% of the second generation attacked. Thus it would be unwise to assume that these species will prevent the buildup or dispersal of the gypsy moth in Ontario and work on the establishment of more beneficial species is necessary.

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SOWBUGS AND WATER-SLATERS (ISOPODA) OF DUNN TOWNSHIP HALDIMAND COUNTY, ONTARIO, CANADA

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Abstract

Collections of water-slaters and sowbugs were made in 1976 in Dunn Township, Ontario, Canada. Species collected were *Asellus forbesi* Williams, *Tracheoniscus rathkei* (Brandt), *Porcellio spinicornis* Say, *Cylisticus convexus* DeGeer, *Oniscus asellus* L., *Porcellionides pruinosus* (Brandt) and *Armadillidium vulgare* (Latreille). *A. forbesi* was found only on rocky points on Lake Erie. *T. rathkei* was the commonest species. Numbers of eggs in the brood pouches of female *T. rathkei* ranged from 6 to 52, averaging 27.8 per female. Other species were rare and more local.

* * * * * *

Introduction

In earlier publications an account was given of the distribution of butterflies (Judd 1963b, 1970) and dragonflies and damselflies (Judd 1968) in Dunn Township, Haldimand County, Ontario. In 1976 it was determined to study the distribution of sowbugs and water-slaters in the township which has recently been annexed to the town of Dunnville as Ward 1 of that town. A description of the physical features of the township is included by Judd (1963b). The map (Figure 1) shows the township, bordered on the north and east by the Grand River, on the south by Lake Erie and on the west by the road separating it from South Cayuga Township. It also includes a grid system (lettered A to L at the left; numbered 1 to 12 at the bottom) which was used in defining collection localities, e.g. the aerodrome of Dunnville is located in grid-squares G10 and G11. There are two communities in the township, Port Maitland at the mouth of the Grand River (I12) and Byng about five miles upriver (E8).

Methods

From July 3 to September 2, 1976 collections of sowbugs and water-slaters were made throughout the township in eighty-six grid-squares, each grid-square being examined on at least one day during the period. They were looked for under trash at roadsides, under bark of trees and logs, in rotting logs, in fallen vegetation in ditches, around debris and manure piles in and about buildings, at edges of stream beds and the Grand River and along rocky ledges of Blott Point, Low Point and Grant Point on Lake Erie. They were identified by using keys in Richardson (1905), VanName (1936), Walker (1927, 1928) and Williams (1970). Specimens of the seven species collected are deposited in the collection of the Department of Zoology, University of Western Ontario.

The numbers of specimens actually collected were: *Asellus forbesi*—31, *Tracheoniscus rathkei*—518, *Porcellio spinicornis*—68, *Cylisticus convexus*—15, *Oniscus asellus*—5, *Porcellionides pruinosus*—8, *Armadillidium vulgare*—34.

Account of Species Collected

Asellus forbesi Williams—This water-slater was found only on the three rocky points, Blott Point, Low Point and Grant Point (J3, K5, K7) on Lake

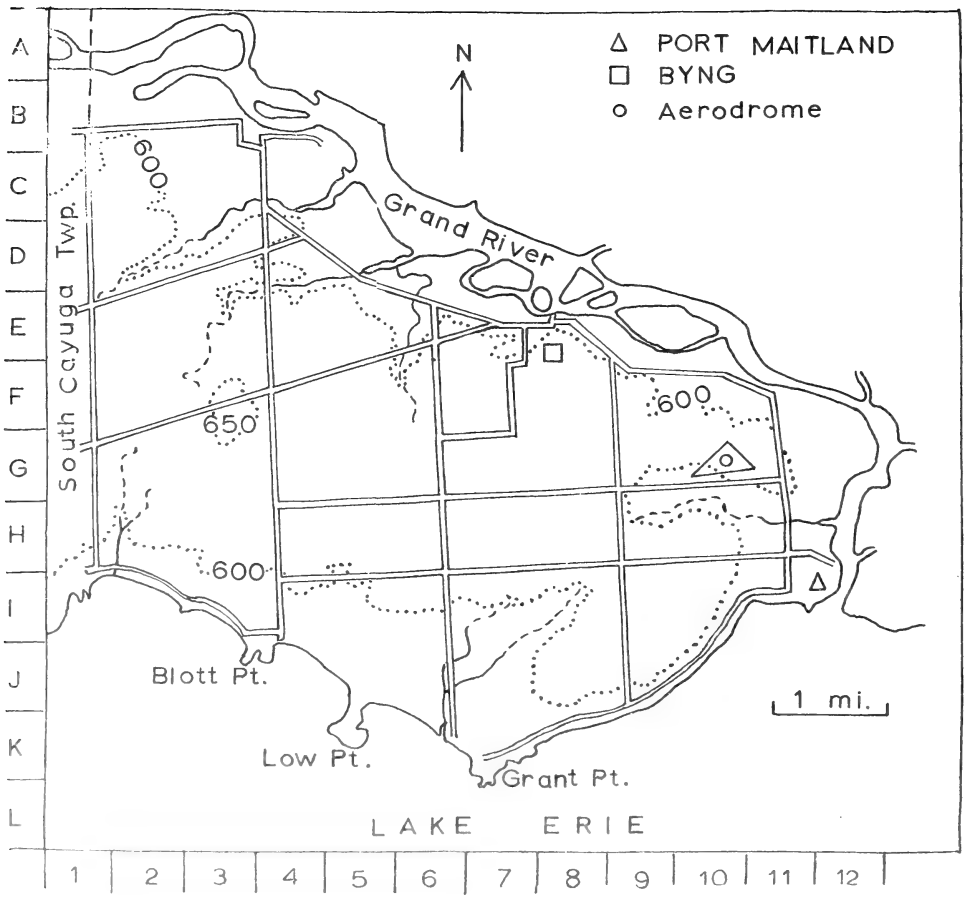

FIGURE 1. Map of Dunn Township, Haldimand County, Ontario.

Erie, occurring at the outer margins of the points under rocks and in pockets in the rocks where open water was present owing to washing of the rocks by waves. *A. forbesi* is an abundant species, distributed over the east-central United States and in southern Ontario (Williams, 1970).

Tracheoniscus rathkei (Brandt)—This species was by far the commonest one, found in eighty-four of the eighty-six grid-squares, from comparatively dry edges of fields and woods to damp locations along the Grand River and in ditches. Much of the area of Dunn Township in 1976 was planted with corn with consequent reduction of concentrated shelters for sowbugs, but wherever a clot of turf, a loose board or a sizable rock was present at the perimeter of a field a few *T. rathkei* could be expected. It was thus the only sowbug found in well cultivated areas. Over the past decade most of the white elms in the township have been killed by Dutch Elm disease and twenty-five collections of *T. rathkei* were made from beneath the loose bark of elm stubs and branches lying on the ground. The presence of this sowbug in a bird's nest (I2) is in accord with the observation by Judd (1963c) who found it in three cardinal nests at London, Ontario. *T. rathkei* is widely distributed in eastern United States and Canada (Judd 1965; VanName 1936; Walker 1927).

From July 3 to 11 the numbers of eggs in the brood pouches of 22 females were counted. They ranged from 6 to 52, averaging 27.8 per female. These figures fall within the range, 6 to 62, averaging 23.4, found in *T. rathkei* in the Byron Bog at London in 1961 by Judd (1963a). Gravid females were found throughout the collection period July 3 to September 2. In a female collected on July 3, 13 of the 16 eggs had hatched, an observation in accord with that made by Judd (1963a) that the first females had hatched young in the pouches as early as June 22 in the Byron Bog.

Porcellio spinicornis Say—This species was collected from ten sites, most of which were at abandoned barns and sheds, e.g. F3, G6, H7, E8, I8, F11, I12. It is widely distributed in eastern North America (Judd 1965; VanName 1936; Walker 1927).

Cylisticus convexus (DeGeer)—This species was collected at four localities (E1, F3, I8, I12), most of which were at abandoned buildings. It is widely distributed in eastern North America (Judd 1965; Richardson 1905; VanName 1936; Walker 1927).

Oniscus asellus L.—This species was found at only two localities (F12, G12) under logs at the edge of a marsh. Its occurrence there, near the community of Byng and the Dunnville aerodrome, is in accord with the report of VanName (1936) that it is found in the vicinity of human settlement.

Porcellionides pruinosus (Brandt)—This species was found at only three sites (E1, F3, I8), the first of which was a dead white elm and the others around barns. Its occurrence around barns is in accord with the observation by Judd (1967) that it is associated with human settlement. VanName (1936) reports it as widely distributed across the United States but rarer in Canada.

Armadillidium vulgare (Latreille)—This species was found at four localities (I10, F11, G12, I12). Two of these, F11 and I12, were about a shed and root-house, an observation which accords with the report of VanName (1936) that *A. vulgare* is most numerous about human habitations.

The greatest concentrations of species, three or four together, occurred at sheltered sites involving human habitations, e.g. F3, E8, I8, F11, I12, including the ubiquitous *T. rathkei* together with *Porcellio spinicornis, Cylisticus convexus, Porcellionides pruinosus* and *Armadillidium vulgare.*

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III. INDEX

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HISTORICAL NOTES

I. THE SOCIETY

IN MEMORIAM

The following Canadian entomologists died during 1977. Those identified by an asterisk, were members at some time of our Society.

***R. E. (Buck) Bellamy** (-1977) died February 7 in Saskatoon, Sask. He was primarily interested in biological control and came to the Belleville Institute from California, as Research Scientist, not long after the new building was completed. When the Belleville staff was dispersed in 1971, he was transferred to the federal Entomology Research Laboratory on the campus of the University of Saskatchewan.

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***William J. Brown** (1903-1977), Ottawa, Ont., died on May 15. One of Canada's leading coleopterists and widely known for his work on the systematics of the scarabaeids, elaterids, and chrysomelids. An obituary written by Dr. E. C. Becker, was published in the Bulletin of the Entomological Society of Canada 9(3): 100-101, 1977. Reference to it will provide much additional information.

* * * * * *

Barney Flieger (-1977), Fredericton, N.B., died on March 24. Early in his career he was a faculty member of the University of New Brunswick and at the time of his retirement was manager of Forest Protection Ltd., Montreal. He was a pioneer in forest insect control by aircraft.

* * * * * *

R. G. Glendenning (-1977), Agassiz, B.C., died in March. Honorary member and held various offices in the Entomological Society of British Columbia.

* * * * * *

***Gordon A. Hobbs** (1916-1977) contributed much to entomology through his studies on forage crop pests and pollinators. After demonstrating that honey bees were of little value in pollinating alfalfa in western Canada, he devoted his attention to leafcutter and bumble bees. An alfalfa seed industry developed in western Canada as a direct result of his efforts. He died in Lethbridge on March 23, 1977, after a prolonged illness. Dr. N. D. Holmes prepared an obituary which was published in the Bulletin of the Entomological Society of Canada 9(2): 70, 1977.

* * * * * *

Georges Maheux (1889-1977), Quebec, Que., Faculty of Forestry, Laval University, Quebec. Teacher, administrator, research worker, editor and an important contributor to the development of entomology in Quebec and in Canada as a whole.

*__Kenneth E. Stewart__ (1895-1977), one of Canada's pioneers in forest entomology, served for many years with the federal civil service in both western and eastern Canada. Officially retired in 1960, he continued as a consultant for three years with the Ontario Dept. of Lands and Forests and served for another five years at the Shade Tree Laboratory, Faculty of Forestry, University of Toronto. Mr. C. S. Kirby, a former colleague, prepared an obituary which was published in the Bulletin of the Entomological Society of Canada 9(2): 71, 1977.

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*__Walter H. A. Wilde__ (1923-1977) died September 3 in Vernon, B.C. Research scientist (1950-1963) with Canada Dept. of Agriculture at Summerland, B.C., where his research interests were the virus-vector relationships in stone fruits, and population and control studies on fruit pests. Came to the University of Guelph in 1963 and introduced ULV (ultra low volume) spraying in Ontario orchards, and continued research on other fruit problems. He returned to British Columbia in 1973 and was a consultant on orchard production problems.

ESTABLISHMENT OF *UROPHORA CARDUI* L. (DIPTERA: TEPHRITIDAE) ON CANADA THISTLE IN SOUTHERN ONTARIO

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Urophora cardui was released for control of Canada thistle, *Cirseum arvense* (L.) Scop., during June 1975, near Belwood, Ontario. Thirty-seven females and 44 male flies, received from P. Harris, Agriculture Canada, Regina, Saskatchewan, were placed on caged, flowering, host plants in the field for one week then released from the cages. Successive observations during 1975-78 indicate that this fly has become established and has spread several hundred meters from the original release site. Approximately 40% of the host plants around the release site contained galls of *U. cardui* in the fall of 1978. Only two of several hundred plants in the release area, which contained galls, had mature seed heads.

HISTORICAL NOTE

THE ENTOMOLOGICAL SOCIETY OF ONTARIO — 1899

In the 30th Annual Report of the Society, reports from a number of Sections and Branches are recorded. Sectional reports included those of the Botanical, Geological, Microscopical and Ornithological Sections. The annual reports of Branch Societies (Montreal, Toronto and Quebec) are included also and as well the report of the Entomological Society of Ontario to the Royal Society of Canada. Obviously, our Society at that time and for many years was actually a natural history society, and Canadian rather than provincial in coverage and scope.

These Society Reports from earlier years make interesting reading.

Editor

II. SUBMITTED PAPERS

ECOLOGY

ADDITIONAL RECORDS AND THE ROLE OF THE PARASITES OF THE APPLE MAGGOT *RHAGOLETIS POMONELLA* (DIPTERA: TEPHRITIDAE) IN ONTARIO

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Abstract

Additional records of parasites of the apple maggot, *Rhagoletis pomonella* (Walsh), in Ontario are listed. Populations were low and all species were found in abandoned shrubby sites. The parasites appear unlikely to play an important role in the control of *R. pomonella* in commercial orchards.

Introduction

Parasites of the apple maggot, *Rhagoletis pomonella* (Walsh) have been reported at irregular intervals from a large area of North America (Monteith, 1971b, c; Rivard, 1968). When the parasites were found, they were generally present in low numbers. The parasites were not found in successive years at most sites (Monteith, 1971c).

Only two species of parasites, *Opius melleus* Gah. and *O. lectus* Gah. were found during a 4-year survey, 1963-1966, made throughout southern Ontario (Monteith, 1971b). They were found in small sections of the Niagara Peninsula. The parasites were restricted to a wild-type of environment where they attacked less than 4% of the *R. pomonella.*

Each year after the survey, larvae of *R. pomonella* were collected at some of the sites sampled during the survey and in adjacent areas for use in experiments. Unexpectedly, parasites emerged from *R. pomonella* collected at sites where the parasites were not found during the survey or previous experiments.

The additional records of parasites of *R. pomonella* are listed in this paper. Their probable role in the control of *R. pomonella* is discussed.

Materials and Methods

Apples infested by *R. pomonella* were collected when many of the larvae were nearly mature. Five to 100 boxes of hanging and fallen fruits were collected at each site, depending on the crop in a particular site. Each site was comprised of abandoned or wild trees with the exception of the Rednersville orchard. The latter was a well-managed experimental orchard on an insecticide-free program (Monteith, 1971a, 1977). However, this orchard was adjacent to a hillside on which there were many wild apple trees infested by *R. pomonella.*

Collections of *R. pomonella* on which the current report is based were made at 15 sites in the towns of Niagara-on-the-Lake and Lincoln in the Regional Municipality of Niagara and in the counties of Hastings, Northumberland, and Prince Edward. The collections were made each year from 1968 to 1975, inclusive. The sites are listed with the results.

The methods of collecting mature larvae from the fruit, winter storage of the pupae, and propagation of adult *R. pomonella* and, therefore, the parasites, were described by Monteith (1971b).

Results

Parasites of *R. pomonella* were found in the collections from 10 of the 15 sites. However, parasites were only found in the collections made in 1972 and 1973. The additional records of parasites, species and sites, were:

Opius melleus Gah.
Rednersville.

O. lectus Gah.
Niagara-on-the-Lake: Niagara Parkway at E.W. Line and at 3rd Line. Rednersville. Murray Township: Murray Canal West (Conc. B & C Lot 19W) and East (Conc. B Lot 8E), Higgens Estate (Conc. 2. Lot 12).

O. lectoides Gah.
Rednersville. Murray Township: Murray Canal West, Higgens Estate.

O. alloeus Mues.
Niagara-on-the-Lake: Niagara Parkway at E.W. Line and at Queenston Escarpment, Conc. 4 at Line 1. Lincoln: Jordon Station. Murray Township: Murray Canal West.

O. ferrugineus Gah.
Niagara-on-the-Lake: Niagara Parkway at the E.W. Line, at the 2nd Line, and at the Queenston Escarpment, Conc. 4 at Line 1. Lincoln: Jordon Station. Rednersville, Murray Township: Murray Canal West, Higgens Estate.

No parasites were found during the current study at two sites in Niagara-on-the-Lake: Conc. 1 at E.W. Line and Conc. 1 at 4th Line where *O. lectus* was found during the survey. Parasites have yet to be found at three of the sites sampled during the current study in Central Ontario: Murray Township, Conc. C Lot 12. Brighton Township: Conc. 3 Lot 31. Cramahe Township: Conc. 1 Lot 13.

In addition to the records of parasites from the current study and the survey, specimens from the Can. Nat. Collection provide two additional records for Lincoln: Vineland; *O. ferrugineus* by Ross in 1918, and *O. alloeus* by Stevenson in 1962 (Unpub. data).

The percentage of *R. pomonella* parasitized by the *Opius* was low. Although no count of the pupae obtained from the collections was made, the percentage parasitism was obviously below 4%, as it was during the survey (Monteith, 1971b).

Discussion

Parasites of *R. pomonella* were found at some sites where no parasites were taken in previous collections and additional species were found at other sites. These records increase the area where parasites are known to be present and the number of species found in Ontario. The fact that one or more species of parasites were found in 1918, 1962, 1963-1967, and 1972-1973, suggests that the parasites, though difficult to find, have been present through a long period.

Although parasites may have been continuously present, their occurrence appeared sporadic. This was evident when the parasites or their absence in the collections made in successive years during the current study, the survey, and by previous authors (Monteith, 1971b) were reviewed. For example, at Niagara-on-the-Lake, Monteith (1971b) found *O. melleus* and *O. lectus* each year for four consecutive years, 1963-1967, at some sites. In 1972 and 1973, additional species of *Opius* were collected at some of the same sites, and *O. lectus* was found where it was not previously recorded. On the other hand, *O. lectus* was not found at two sites during the current study where it had been collected during the survey. Further evidence of the sporadic appearance of the parasites is the fact that although Ross collected *O. ferrugineus* in 1918, and Stevenson found *O. alloeus* in 1962 in the town of Lincoln (Vineland-Jordan), Hall (1933-1940) found no parasites in massive collections of *R. pomonella* from the same area. Later at the same sites, Monteith (1971b) collected *O. melleus* and *O. lectus* in the years 1963 to 1967, inclusive, and during the current study, four species of *Opius* in 1972 and 1973.

There are several factors that probably influenced the number of parasites found in commercial orchards.

1. The environments were not suitable. All of the parasites collected during the current study and the survey were from wild or abandoned blocks of apple trees with one exception during each study. However, in each case, the Rednersville and the Nezezon orchards during the current study and the survey (Monteith 1971b), respectively, abutted stands of wild trees. These orchards had been sampled for 10 and two years, respectively, before parasites were obtained. During a further two-year period after parasites were collected in the Nezezon and one year (the final sample) at the Rednersville orchard, none was found in those orchards although they were present in adjacent wild stands. Apparently, only infrequently did the parasites disperse from wild sites into adjacent commercial orchards.

2. Populations of the *Opius* were generally low in the wild sites. At no time during the survey or the current study was the parasitism as high as 4%, it was generally 2%, or less. Apparently there were not sufficient parasites in the wild sites to disperse into adjacent orchards in sufficient numbers to influence an infestation by *R. pomonella.*

3. Soil-inhabiting predators thrived in orchards on insecticide-free programs (Monteith 1971a, 1977). These destroyed both parasitized and non-parasitized *R. pomonella* pupae. As the predators were present in successive years and destroyed most of the host pupae, parasites did not become established in such orchards.

4. In orchards where insecticides were used, both the host and the parasites were eliminated. However, as adult *R. pomonella* are stronger fliers than the *Opius,* the pest returned to the treated orchards more quickly and, apparently, from greater distances, than did the parasites. A sanitation zone, free of the food plants of *R. pomonella,* as maintained by many growers around their orchards, appeared to be more detrimental to the entry into those orchards by the parasites than by the pest.

5. Apparently, there were undetermined factors in some wild stands of apples that influenced the establishment of the *Opius* species. In each of three areas there were examples that when two wild sites, similar as to geographic location, number and type of apple trees, ground cover, host population, and the

absence of predators were sampled, parasites were found at one but not the other site.

6. Factors that influenced the number of *R. pomonella* had a direct influence on the populations of the parasites. Populations of the host fluctuated severely as to the period of activity, the number of adults, and the number of larvae in the fruit at different sites in any one year or at the same site in successive years. Populations of *R. pomonella* were influenced by the crop of wild apples which varied considerably in successive years. The wild crop failed completely in some areas during some seasons. This eliminated most of the potential hosts for the parasites during such years in the affected sites and reduced the population of parasites.

Probable Role of Parasites

Current horticultural practices are such that the parasites did not become established in any commercial orchard sampled during a 14 year period. Further, a resident population of *R. pomonella,* sufficient to maintain a reservoir of parasites could not be tolerated in a commercial orchard as the pest attacks the fruit. The parasites did not disperse from wild sites into commercial orchards in sufficient numbers to influence the populations of *R. pomonella.* Though, insecticides and predators removed both the pest and the parasites, the *R. pomonella* returned more quickly to sprayed or unsprayed orchards than did the *Opius.* Therefore natural populations of the parasites were unable to play a significant role in the control of the apple maggot in commercial orchards.

The parasites will probably play a minor and indirect role in the control of *R. pomonella* in orchards. The parasites are well adapted to survive in wild, shrubby stands of apple and hawthorns, *Crataegus* spp. (Monteith, 1971b). As stands of wild and abandoned apples, hawthorns and other food plants of *R. pomonella* are profusely scattered throughout the apple-growing areas of Ontario, there are many sites where the *Opius* may be or could become established. As soil-inhabiting predators were seldom active in such environments (Monteith, 1971b, 1977), the parasites appeared to be the principal biotic agents attacking *R. pomonella* in those sites. As such, the parasites would destroy some *R. pomonella* that might emerge as adults and disperse into commercial orchards.

Acknowledgment

I thank Dr. W. R. M. Mason, Biosystematics Ottawa, for instructions on the identification of the parasites and the use of specimens identified by him.

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PEST POPULATION BUILDUP IN APPLE ORCHARDS FOLLOWING OMISSION OF INSECTICIDE AND ACARICIDE SPRAYS

By

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Abstract

In three successive years following the omission of insecticide and acaricide sprays from two blocks of mature apple trees, at Smithfield, Ontario, the codling moth, *Laspeyresia pomonella* (L.) was the most important pest. In the 1st year several species of leafrollers and fruitworms and the tarnished plant bug, *Lygus lineolaris* (Pde B), were also important. The eye-spotted bud moth, *Spilonota ocellana* (D&S), the lesser apple worm, *Grapholitha prunivora* (Walsh), and the plum curculio, *Conotrachelus nenuphar* Herbst., caused some fruit damage in the 2nd and 3rd years following omission of the pesticides. Damage due to the apple maggot, *Rhagoletis pomonella* Walsh, and the European red mite, *Panonychus ulmi* (Koch), was negligible.

Introduction

Glass and Lienk (1971) showed that when insecticidal and acaricidal treatments were omitted from a 1-acre block of apples in which cyprex and captan were applied for disease control, the fruit were commercially worthless after the first year. Damage was due mainly to the apple maggot, *Rhagoletis pomonella* Walsh; the codling moth, *Laspeyresia pomonella* (L.); the plum curculio, *Conotrachelus nenuphar* (Herbst).; and the red-banded leafroller, *Argyrotaenia velutinana* (Walker). *R. pomonella* was the most serious pest accounting for 75% of the fruit infestation each year after the 2nd non-insecticidal season. Some damage was also caused by the lesser appleworm, *Grapholitha prunivora* (Walsh), and the European red mite, *Panonychus ulmi* (Koch), was relatively unimportant. In studies in Ohio, Hall (1974) reported that two years after cessation of insecticide, acaricide, and fungicide applications, *C. nenuphar* and *L. pomonella* were the most important fruit pests. The tarnished plant bug, *Lygus lineolaris* (Pde B), several fruitworms *(Amphipyra, Lithophane* and *Orthosia* spp.) and the oblique-banded leafroller, *Choristoneura rosaceana* Harris also caused some damage. Populations of *A. velutinana* and *R. pomonella* were low in the test plots in both years.

In 1971-73 a similar study was undertaken in two 2 ha blocks of mature apple trees in an orchard at Smithfield, Ontario. Insecticides and acaricides were omitted from the spray program and pest populations monitored to determine the rate at which pests would invade the area and the species that would become of major importance with reduced pesticide pressure. The data obtained were of considerable importance in relation to the implementation of a pest management program in which it was anticipated that pesticide applications would be considerably reduced.

[1] Smithfield Experimental Farm, Box 340, Trenton, Ontario K8V 5R5.

Materials and Methods

The two blocks of mature trees used in this study at the Experimental Farm, Smithfield, were comprised mainly of 23-year old McIntosh, Northern Spy and Red Delicious trees which had been intensively sprayed with pesticides (Table 1). They

TABLE I. Example of protective spray program applied to orchard blocks A and B prior to 1971 at Smithfield.

Date	Pesticide	Rate/ha (kg)
April 30	Captan (50% WP)	6.8
May 11	Captan (80% WP)	4.2
May 16	Captan (80% WP) + Mercury	4.2 + 1.1 litre
May 22	Captan (80% WP)	4.2
May 26	Captan (50% WP)	6.8
June 5	Captan (50% WP) + Guthion (50% WP)	6.8 + 2.2
June 12	Captan (50% WP) + Guthion (50% WP)	6.8 + 2.2
June 23	Captan (50% WP) + Guthion (50% WP)	6.8 + 2.2
June 30	Captan (50% WP) + Guthion (50% WP)	6.8 + 2.2
July 12	Captan (50% WP) + Guthion (50% WP) + Tedion (25% Tetradifon)	6.4 + 2.2 + 7.1 litre
July 22	Captan (50% WP)	6.4
Aug. 6	Captan (50% WP) + Sevin (50% WP) + lead arsenate + Tedion (25% Tetradifon)	6.4 + 3.6 + 6.4 + 3.6 litre
Aug. 29	Omite (30 W)	4.9

were located in an area of approximately 200 ha of commercial orchards in which pest control was obtained under a protective chemical program and in which pest pressures were low. Cultivation practices (pruning, fertilization, weed control etc.) were carried out as in a commercial orchard.

Codling moth and red-banded leafroller adult populations were monitored with sex pheromone traps (Sectar 1) baited with Codlamone and Redlamone attractant caps, respectively (Zoecon Corp., Palo Alto, California, U.S.A.). The apple maggot was monitored in block A with yellow prebaited traps (Trottier *et al.* 1975), and in block B with yellow sticky boards to which was attached a jar containing a solution of protein hydrolysate (Still, 1960). Twigs and fruit clusters were examined during the season and at harvest to determine the abundance and degree of damage caused by species attacking both the foliage and fruit. Phytophagous and predacious mite populations were determined from leaf samples using a Henderson and McBurnie mite brushing machine (Henderson and McBurnie, 1943). In both blocks apple scab was controlled with 10-12 fungicide sprays mainly cyprex 65% WP applied at .85-1.7 kg/ha.

Results and Discussion

In 1970 visual observations in the blocks indicated that the only fruit damage (<2%) was due to spring feeding caterpillars. In the first year (1971) in which no pesticides were applied, leafrollers, and the tarnished plant bug, *L. lineolaris,* caused the most fruit damage in block A, and the codling moth and fruitworms in block B (Table 2). In both New York and Ohio the plum curculio and the codling moth were the most important pests in the 1st year. In the 2nd (1972) and 3rd (1973) years, the numbers of codling moths increased (Table 3) and this insect was the most important pest accounting for about 49% and 39% fruit damage in the 3rd year in blocks A and B, respectively. Damage due to the plum curculio was of importance only in the third year after the cessation of sprays. *R. pomonella*

TABLE II. Percent fruit damage at harvest in blocks A and B at Smithfield from 1970-1974.[1]

Block	Year	Total No. Fruit Exam.	Percent Fruit Damage at Harvest due to: Codling moth	Apple maggot	Plum Curculio	RBLR	OBLR	Bud-moth	Pl. Bug	LAW	Fruitworms	European scale	Total % Fruit Damage
	1970												<2.0
A	1971	594	Nil	Nil	0.5	2.0		1.0	2.0	Nil	Nil	Nil	5.5
	1972	850	5.6	0.1	0.1	0.7	1.6	3.5	0.5	0.2	Nil	Nil	12.6
	1973	626	49.2	5.3	6.5	0.3	0.2	3.7	0.9	1.0	8.0	Nil	69.0
	1974	750	Nil	Nil	0.3	Nil	1.3	Nil	1.7	Nil	1.7	Nil	5.1
B	1971	200	5.3	Nil	Nil	Nil	Nil	Nil	1.8	Nil	2.9	1.8	8.0
	1972	800	8.5	Nil	Nil	1.8	3.0	Nil	Nil	1.8	Nil	Nil	14.6
	1973	800	38.8	Nil	3.8	0.9	2.2	0.6	6.7	5.1	1.9	Nil	53.7
	1974	875	1.8	Nil	0.7	1.4	0.6	Nil	0.5	Nil	1.1	Nil	6.4

[1] RBLR — Red-banded leafroller; OBLR — Oblique-banded leafroller; Pl Bug — Tarnished plant bug; LAW — Lesser apple worm.

TABLE III. Total number of adult insects taken in traps in blocks A and B during 1971-1974.

Species	Orchard Block A				B			
	1971	1972	1973	1974	1971	1972	1973	1974
Codling moth	1(5)[1]	122(5)	317(5)	142(8)	—	—	86(5)	47(5)
Red banded leafroller	—	136(5)	214(5)	121(8)	—	—	75(5)	51(5)
Oblique-banded leafroller[2]	—	—	95	5	—	—	80	10
Apple maggot	1(5)	7(5)	1(5)	3(10)	0(4)	0(4)	4(20)	6(20)

[1] Total number traps per block.
[2] Adults taken in pheromone and on sticky board traps.

populations were generally very low (Table 3) and appreciable damage occurred mainly in the 3rd year in block A. This result was surprising in view of the generally large maggot populations in unsprayed orchards in the area and the observations made by Glass and Lienk (1971) in New York. However, the low populations may have resulted from the use of lead arsenate in the blocks for many years. Fruit damage due to undetermined species of fruitworms and the eye-spotted budmoth, *Spilonota ocellana* (D&S), in block A, and to *G. prunivora* and *L. lineolaris* in block B, was fairly extensive in the 3rd year. Although the red-banded leafroller, *A. velutinana,* occurred in relatively large numbers (Table 3), fruit damage was not extensive. The green apple aphid, *Aphis pomi* De Geer, was present in relatively large numbers especially in block A in the first year when 35% of the shoots were infested.

Neither *P. ulmi* nor the rust mite, *Aculus schlechtendali* (Nalepa) were important in either block of apples. Highest red mite numbers of 8.1 eggs and 1.8 mature forms/leaf were recorded from cv. Red Delicious in the 1st year. In the 3rd year, 15.0 eggs and 4.0 active stages occurred in plot A on August 15 and 18 respectively; while in block B, an average maximum of 99.2 eggs and 67.5 active stages occurred on 28th June and 12th July, respectively. Rust mites were also present in both blocks in the 3rd year reaching an average maximum of 94/leaf in block A on 2 August and 233/leaf on 25 July in block B. Very low populations of predacious mites were observed in both blocks, but the predator-prey ratios (1: 11.5) were favourable for control of the phytophagous species.

In 1974, insecticides were applied (Table 4) to reduce the pest populations as total fruit damage exceeded 50% in both blocks in 1973 (Table 2). Sprays were aimed primarily for control of *L. pomonella.* In block A, zolone (30% WP, 3 lb/ac.) followed by two imidan (50% WP, 2 lb/ac.) sprays gave good control of all pests (Table 2). Two guthion (50% WP, 1.25 and 1.0 lb/ac.) sprays in block B generally gave a similar degree of control except against late 1st and 2nd generation codling moth larvae. No acaricide sprays were required in either block.

It is apparent from the above observations that the pesticide 'load' in an orchard on a protective chemical program can be reduced without a sudden, large increase in pest abundance. Also, effective apple insect control could be obtained by the application of 2 or 3 properly timed sprays. This knowledge contributed largely to the implementation of a pest management program, based on monitoring pest activity, in several apple growing areas in Ontario. Although the number of sprays and quantity of pesticides have been considerably reduced there has not been any decrease in fruit quality due to insect and mite pests.

TABLE IV. Pesticides applied to blocks A and B in 1974.

Date	Block A Material	Rate/ha (kg)	Block B Material	Rate/ha (kg)
April 24	Cyprex (65% WP)	1.7	Cyprex (65% WP)	1.7
May 8	Ferbam (76% WP)	3.4	Polyram (80% WP)	4.5
May 13	Cyprex (65% WP)	1.7	Cyprex (65% WP)	1.7
May 18	Cyprex (65% WP)	1.7	Cyprex (65% WP)	1.7
May 23	Cyprex (65% WP)	1.7	Cyprex (65% WP)	1.7
May 31	Cyprex (65% WP)	1.7	Cyprex (65% WP)	1.7
June 10	Zolone (30% WP)	3.4	Guthion (50% WP)	1.4
	Cyprex (65% WP)	1.4	Cyprex (65% WP)	
June 17	Cyprex (65% WP)	1.4	Cyprex (65% WP)	1.4
June 20	Cyprex (65% WP)	1.4	Guthion (50% WP)	1.4
			Cyprex (65% WP)	1.4
July 3	Cyprex (65% WP)	1.4	Cyprex (65% WP)	1.7
July 16	Cyprex (65% WP)	1.7	Cyprex (65% WP)	1.7
	Imidan (50% WP)	2.8	Cyprex (65% WP)	1.7
July 24	Cyprex (65% WP)	1.7	Cyprex (65% WP)	1.7
August 8	Cyprex (65% WP)	1.1		
	Imidan (50% WP)	2.8		

Acknowledgments

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DEVELOPMENTAL THRESHOLD OF *EUROSTA SOLIDAGINIS* (FITCH) (DIPTERA: TEPHRITIDAE)

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The larvae of *Eurosta solidaginis* (Fitch) cause the formation of ball-shaped galls on various species of goldenrod with *Solidago altissima* L. reported to be the preferred host (Miller, 1959). *E. solidaginis* overwinters as a prepupa within the gall and the adult fly emerges in late May or early June through a previously prepared exit (Uhler, 1951). From September 1976 to February 1977, 2,350 galls of *E. solidaginis* were collected from *S. altissima* and *S. canadensis* L. in abandoned fields near Guelph, Ontario and placed in cold storage at 2°C until March 10. The galls then were placed in clear plastic containers in groups of ten and transferred to controlled environment chambers kept at six different temperatures, 13.5, 16.2, 18.4, 19.8, 26.3 and 28.4°C. A photoperiod of 16L: 8D was maintained with a relative humidity between 80 and 95%.

The developmental rate was calculated from first emergence of the 1,301 flies which successfully emerged and regressed against temperature. The developmental threshold and degree-days (dd) C required for development from diapausing larvae to adults were calculated from the resultant regression equation of $y = -0.04271 + .00424x$, using the method of Campbell *et al.* (1974). Extrapolation of the regression line shows a developmental threshold of 10.1°C with an SE of 0.9°C. The degree-days from diapause to first adult emergence for all temperatures is 235.8 dd C with an SE of 18.4 dd C. Emergence of *E. solidaginis* ranged from 210 to 600 dd C with ca. 50% of the adult flies emerging when 270 dd C had been accumulated. At Guelph, heat unit accumulations from the field for 1977 correspond to a first adult fly emergence on May 23 which agrees with observed field activity. Uhler (1951) reports first adult emergence at Varna, N.Y. to be May 16 for 1941, May 29 for 1947, and May 31 for 1948.

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PIPELINE CONSTRUCTION — IMPACT ON SOIL MICRO- AND MESOFAUNA (ARTHROPODA AND ANNELIDA)[1] IN ONTARIO

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Abstract

A survey, comparing arthropod and earthworm (Annelida) populations in an area disturbed by major pipeline construction one year previously with an adjacent undisturbed area, revealed significant differences in soil faunal populations. Earthworm populations were significantly reduced in the construction zone while some elements of the arthropod fauna increased.

Since World War II the number of large diameter pipelines used to transport water and petroleum products in Canada has increased enormously, particularly in the fertile farmlands of Ontario that lie south of a line between Sarnia and Toronto. This increase has been due to urbanization and industrialization. Strings of farms have been used repeatedly as a right - of - way for these pipelines. A combination of heavy machinery used to lay the pipeline, of inadequate drainage techniques during construction, and of failure to restore soil, particularly topsoil, to its former place and condition, usually results in a low quality soil for agriculture. This low soil quality in the area of the construction reduces hay yields. I suspected that soil animal populations were also affected by the construction. Certain components of the soil fauna (Annelida, Acari, Collembola, Insecta) in a construction zone and in adjacent undisturbed areas were compared.

Materials and Methods

Site Description

Soil animal populations were sampled on Larigmoor Farm, 1 mile east of Bryanston, Middlesex Co., Ontario. The pipeline right-of-way was a 27.4 m strip of land and during a 25-year period (1957, 1967, 1975-6) 3 pipelines had been installed in this area. The right-of-way, marked by parallel series of red posts along its axis, passed through a managed pasture which had been used for production of hay crops. The vegetation over the right-of-way in this pasture was sparser and weedier than in the adjacent undisturbed area. Along the right-of-way there were several large, bare patches where the pale subsoil was not covered by the darker clay loam topsoil typical of the area. In the spring, low areas in the right-of-way became shallow ponds up to several meters in diameter. These ponds were probably due to soil compaction by machinery and improper restoration of drainage tile. There were no similar ponds in the undisturbed parts of the field.

Earthworm Sampling

Earthworms were sampled on June 20, July 14, Aug. 8, and Oct. 14 by the formalin expellant method (Raw 1959). Quadrats 0.36m^2 were randomly placed in mown, hand-raked strips and two consecutive treatments of 4.6 l of dilute formalin solution (25 ml of 40% formaldehyde in 4.6 l of water) were poured into each quadrat with a sprinkling can. Worms that surfaced were placed in pint mason jars (one for each quadrat) containing a 10% formalin solution and were

1) Contribution No. 725

identified, weighed, and counted later. Twelve quadrats were sampled on the first 3 dates, and 24 on the October sampling date.

Soil Arthropod Sampling and Extraction

Equal number of soil cores 5 cm diam. and 15 cm deep were taken from both the control and the right-of-way areas and each core was transferred to a numbered aluminum tube with air-tight cap. The total number of cores taken varied from 16 to 48 over the five sampling dates (June 15, June 20, July 14, August 8, and October 14).

Soil arthropods were extracted in modified Tullgren funnels in a room with a constant temperature of 15°C. Each soil sample was spread over a sieve to a depth of approximately 5 cm. The temperature at the soil surface was maintained at approximately 30°C producing a temperature gradient of 15°C between the soil surface and the sieve. Extraction was completed in 72 hours with the arthropods being collected in 5% glycerol in 70% aqueous ethanol solution. The arthropods were subsequently counted and identified (usually to family level for Collembola and order for Acari) with a stereomicroscope.

Results

Since earthworm populations tend to be aggregated, numbers were log-transformed to stabilize the inter-sample variance for subsequent analyses of variance. Results of the earthworm samples are in Table I.

TABLE I. Comparison of earthworm numbers between right-of-way (RW) and undisturbed (Control) areas of the field (Larigmoor Farm, 1977).

Sampling Date		No. of quadrats	Mean No. of Worms/quadrat
June 20	RW	5	2.6
	Control	7	8.6
July 14	RW	5	3.8 a
	Control	7	15.9
Aug. 8	RW	6	0.3 b
	Control	6	29.8
Oct. 14	RW	12	9.4 b
	Control	12	34.4

[a] Means were significantly different from control ($P \leq 0.05$).
[b] Means were significantly different from control ($P \leq 0.001$).

TABLE II. Biomass of *L. terrestris* and the total biomass of earthworms per sample from right-of-way (RW) and undisturbed (Control) areas of the field (Larigmoor Farm, 1977).

Date	Sampling Site	Biomass *L. terrestris* (gm)	Total Earthworm biomass (gm)	% Biomass of *L. terrestris* (gm)
July 14	RW	6.6	7.6	87
	Control	19.5	24.6	79
Aug. 8	RW	0.6	0.9	67
	Control	30.9	38.5	80
Oct. 14	RW	105.4	142.3	74
	Control	286.7	395.8	72

TABLE III. Mean number of arthropods/core for various taxa where significant differences between right-of-way (RW) and undisturbed (Control) areas were observed on 2 or more sampling dates (Larigmoor Farm, 1977).

Sampling Date	No. of Cores		Mean No. of Arthropods/Core: All Arthropods	Mesostigmata: Rhodacaridae	Mesostigmata: Other Gamasina	Acari: Astigmata	Acari: Cryptostigmata	Collembola: Poduridae
June 15	RW	8	211	0.4	7.8	113	3.1	13.4
	Control	8	106	1.5	7.6	3.4 [a]	6.1	0.1 [b]
June 20	RW	17	203	1.9	13.4	44.1	13.8	20.7
	Control	12	142	2.3	5.7 [a]	1.3 [c]	9.8	0.1 [c]
July 14	RW	18	177	0.2	18.7	74.6	2.6	4.3
	Control	18	55 [b]	1.1	2.8 [b]	0.7 [b]	6.3	0.2
Aug. 8	RW	12	143	0	27.6	32.0	3.8	8.8
	Control	12	118	1.8 [c]	11.8	5.4 [c]	10.0 [b]	0.2 [b]
Oct. 14	RW	24	214	0.3	14.7	18.1	20.0	22.8
	Control	24	69 [c]	3.9 [b]	4.0 [b]	0.9 [c]	6.3 [a]	0.3 [c]

a, b, c — Significant difference between control and right-of-way, a: $P \leq 0.05$; b: $P \leq 0.01$; c: $P \leq 0.001$.

The earthworms were identified to species, two of which dominated samples from this field; *Lumbricus terrestris* Linnaeus and *Aporrectodea tuberculata* (Eisen). Numerically, *L. terrestris* represented 41-50% of the total worm population over the 4 sampling dates and there was no apparent difference in the proportion of *L. terrestris* in samples from the right-of-way compared to control. Since *L. terrestris* characteristically has a greater mass than *A. tuberculata,* the total biomass of *L. terrestris* represents 67-87% of the total earthworm biomass (Table II).

Several arthropod taxa were also enumerated. Significant differences were determined by analysis of variance on data transformed by the formula "log $(X + 1)$" where X = number actually observed. Log transformations were required to stabilize the high variances due to the apparent aggregative nature of many of these arthropods. Differences were not consistently significant between control and right-of-way samples and total numbers of arthropods differed significantly on only one sampling date. The most obvious difference was the large astigmatid mite population from cores taken in the right-of-way. The species was identified as *Rhizoglyphus echinopus* (Fumouze & Robin) (Astigmata: Acaridae) by Dr. E. E. Lindquist (Biosystematics Research Institute, Ottawa). Rhodacarid mites were enumerated separately from other gamasine mites and are included in Table III. Significant differences between right-of-way and control populations per core were respectively noted for the collembolan families Sminthuridae on June 20 (2.6 and 5.1: $P<0.05$); Onychiuridae on August 8 (1.1 and 5.1: $P<0.005$); Isotomidae on August 8 (18.5 and 38.4: $P<0.025$); Prostigmata (Acarina) on June 13 (33.1 and 11.4: $P<0.05$); and Pauropoda (Myriapoda) on August 8 (0 and 1.0: $P<0.005$). Entomobryids (Collembola) were enumerated but mean numbers per core were very small and no significant difference between the two areas was apparent. Myriapods such as Symphyla, Diplopoda, and Chilopoda, and terrestrial isopods (Isopoda) were counted. Mean numbers were typically less than one per core, but these were found almost exclusively in the control area on all 5 sampling dates. Numbers of Insecta (Protura, Diplura, Thysanoptera, Hemiptera, Hymenoptera, Coleoptera, and Diptera) were found in both areas, but again in very low numbers and no differences were apparent.

Discussion

The pipeline construction had a marked effect on earthworm populations by reducing the numbers of the two dominant species. May, June, and July were abnormally dry in southwestern Ontario in 1977 and this is reflected in the relatively low number of worms/quadrat in the June and July samples. Neither worm species appeared to have a selective advantage in recolonizing the pipeline zone, since the biomass proportion of *L. terrestris* was approximately the same in both the control and right-of-way areas. Earthworms dominate the faunal biomass of soil, representing 50-70% of the biomass in deciduous mull (Bornebusch 1930). In clay soils, they probably represent an even higher proportion of the biomass of soil fauna because of the reduced significance of nematodes. The highly reduced numbers ($P \leq 0.01$) of earthworms in the right-of-way suggest that normal soil processes, such as decomposition, humification, and turnover will be greatly reduced in that area, possibly for several years (cf. Ch. 6, Edwards and Lofty 1977).

The results of the arthropod survey are more difficult to interpret. The most apparent difference was the large population of astigmated mites which had built up in the right-of-way. The species involved, *R. echinopus* (bulb mite), was

probably feeding on surface litter that probably accumulated because of reduced earthworm populations. The generally larger gamasine mite population found in the right-of-way probably was preying on the large population of astigmatid mites. The podurid springtails (phytophagous and/or fungivorous) had significantly larger populations on the right-of-way on 4 of 5 sampling dates. Presumably they were taking advantage of some food source or were under reduced pressure from predation compared to the control area. In general, there were substantial differences in components of the arthropod fauna between the control and right-of-way areas.

Acknowledgments

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INSECTS ATTACKING WHITE SPRUCE CONES IN THREE HABITATS

by

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Expanded requirements for seed in forest regeneration have highlighted the importance of reductions in seed yield resulting from attack by cone-feeding insects. Little is known about environmental factors likely to influence the abundance of the several species which attack cones. Hence, a small survey was undertaken in the summer of 1977 to determine the incidence of attack by spruce cone insects on trees in three different habitats.

The three habitats sampled in the Upper Ottawa Valley, Ontario were as follows: pure white spruce or white (75%)/black (17%) spruce (22-34 years) growing on gravelly sandy loam; spruce-fir-hardwood consisting of less than 5% white spruce (25-30 years) 90% mixed hardwoods and 5% balsam fir growing on well-drained Monteagle Rock complex; and old field open-grown trees (27-30 years) on clay-rocky phase or gravelly sandy loam.

Although the cone crop was very poor, 10 to 20 cones from each of 5 trees under 10 m in height in each habitat were collected on July 18-19. Cones were sliced in half along the axis and damage was attributed to *Choristoneura fumiferana*

(Clemens), *Laspeyresia* sp., *Pegohylemyia* sp., *Dasineura rachiphaga* (Tripp), or *Dioryctria* sp., on the basis of their distinctive feeding habits (Tripp and Hedlin 1956).

The percentages of cones damaged by these insects are shown in the following table. Damage by all of the insects is evident but there is a marked difference in

	% of cones infested by				
Habitat	*Laspeyresia* sp.	*Pegohylemyia* sp.	*Dasineura rachiphaga*	*Dioryctria* sp.	*Choristoneura fumiferana*
Old-fields	77	24	19	1	22
Spruce-fir-hardwood	31	54	23	0	14
Spruce stands	7	92	14	3	32

attack by *Laspeyresia* and *Pegohylemyia* in the different habitats. Over 75% of cones from isolated old-field trees were damaged by *Laspeyresia* whereas little damage was evident in spruce stands. By contrast, most of the cones from the spruce stands had been attacked by *Pegohylemyia* and a much smaller percentage of cones was attacked in old-field trees. In the spruce-fir-hardwood mixture both are present at intermediate rates of infestation.

It has been suggested that open-grown red pine trees with large crowns tend to be more prone to attack by seed and cone insects than are closely-grown trees (Stiell 1971; Mattson 1976). For white spruce, our data suggest that the abundance of certain insects varies with stand conditions. These differences will have to be considered when developing strategies to prevent damage.

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MICROORGANISMS ASSOCIATED WITH *RHAGOLETIS POMONELLA* (TEPHRITIDAE: DIPTERA)[1] IN MASSACHUSETTS

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Abstract

Adults, larvae and puparia of *Rhagoletis pomonella* (Walsh) (Tephritidae: Diptera) were collected from an orchard in central Massachusetts. Diseased appearing individuals were chosen from the samples obtained and examined for the presence of pathogenic microorganisms. Several potential pathogens (e.g. *Pseudomonas aeruginosa, Bacillus cereus, Streptococcus* sp.) were isolated from larvae and puparia. Nematodes of the genus *Neoaplectana* were also found in *R. pomonella* puparia.

Introduction

While a fair amount is known about parasitoids and predators of the apple maggot, *Rhagoletis pomonella* (Walsh) (Rivard 1967, Monteith 1971, 1972, Dean and Chapman 1973, Cameron and Morrison 1977, Prokopy and Webster 1978), little is known about its pathogens. Jaques et al. (1969) isolated 16 species of bacteria associated with a bloating disease of laboratory-reared apple maggot adults but did not determine the principal causal organism. To our knowledge, no pathogens have been reported from field populations of the apple maggot.

Here, we present results of a study of microorganisms associated with diseased apple maggot larvae and puparia collected in a central Massachusetts apple orchard.

Methods and Materials

The orchard was located in Northborough and consisted of ca. 30 unsprayed (for more than 10 years) Yellow Transparent apple trees. In 1977, these trees harbored several thousand apple maggot adults (as indicated by monitoring traps — Prokopy 1968) and bore a large crop of maggot-infested apples. Samples of living adults on tree foliage, fallen rotting apples (for larvae), and soil (for puparia) were taken from 11 of the trees. Sampling was done in mid-July, when adults, larvae, and newly formed puparia were simultaneously present. Ground cover consisted of various grasses and weeds, including heavy growths of poison ivy.

Sixty-five living adults that were collected (by aspirators) were placed in cages with food (enzymatic yeast hydrolysate and sugar) and water, taken to the laboratory, and examined after 7 days for the presence of possible pathogens.

Over 100 fallen apples were examined for larvae. Approximately 50 out of 250 larvae collected appeared diseased (motionless or dark in color) and were immediately surface sterilized with a 5% solution of sodium hypochlorite. They were then opened and some fat body transferred with a fine sterile forceps to a culture medium of nutrient agar (for bacteria) or Sabouraud dextrose agar with yeast extract (for fungi).

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The soil samples were dry-sieved, and the 500 puparia found placed in a beaker of water. The 20 puparia that sank to the bottom (most healthy pupae float) were surface sterilized and transferred to one of the above culture media. The culture tubes were taken back to the Insect Diagnostic Laboratory at Berkeley and the isolated microorganisms identified as precisely as possible.

Results

No pathogens were found associated with any of the 65 living apple maggot flies collected. Indeed, all flies appeared healthy. No dead flies were observed on the trees. If diseased, dead flies did exist, it is possible they were quickly consumed by ants that were present in the orchard. A *Pseudomonas* sp. was isolated from crushed heads of adult flies but apparently had no pathogenic effect on the insect.

Microorganisms isolated from diseased larvae and puparia of *R. pomonella* are listed in Table I. All of these organisms are being maintained in the Insect Pathogen Culture Collection at Berkeley and are available upon request.

TABLE I. Microorganisms isolated from dying larvae and puparia of *R. pomonella* from Northborough, Mass., July, 1977. Initial sample size = 250 larvae and 500 puparia.

Stage	No. individuals	Microorganism	Previously known status as a pathogen
larvae	3	*Geotrichium* sp.	No
"	4	*Enterobacter* sp.	No
"	4	yeast	rarely
"	1	*Escherichia coli*	No
"	1	*Pseudomonas aeruginosa*	potential
"	1	*Bacillus cereus*	potential
"	1	*Fusarium* sp.	potential
puparia	2	*Streptococcus* sp.	potential
"	1	yeast	possibly
"	2	*Neoaplectana* sp.	Yes

Larvae containing the fungus *Geotrichium* sp. or the bacterium, *Enterobacter* sp. were motionless and generally had turned yellow brown, or grey in color. Larvae containing yeast infections were sometimes still alive but often contained black spots on their cuticles. The larva containing a *Fusarium* sp. was lethargic and yellow in color.

The puparia containing microorganisms were in general darker than healthy ones. Two puparia contained reproducing and infective stage juveniles, respectively, of *Neoaplectana* sp. (Fig. 1). These pupae also contained a strain of *Achromobacter nematophilus,* a bacterium that is symbiotically associated with neoaplectanid nematodes. The infective stage juveniles of *Neoaplectana* sp. were isolated and infected larvae of wax moth larvae *(Galeria mellonella)* in the laboratory. Infectivity tests with the other microorganisms were not performed.

Discussion

Several of the organisms isolated from diseased larvae and puparia of *R. pomonella* are known to cause insect diseases (Poinar and Thomas 1978).

Pseudomonas aeruginosa and *Streptococcus* sp. are considered potential pathogens capable of causing disease when an insect is under stress and it is possible they were acting as such in this study. On the other hand, *Enterobacter* sp. and *Geotrichium* sp. are saprophytic organisms commonly found in soil and have no history of causing insect disease. Both organisms probably invaded the

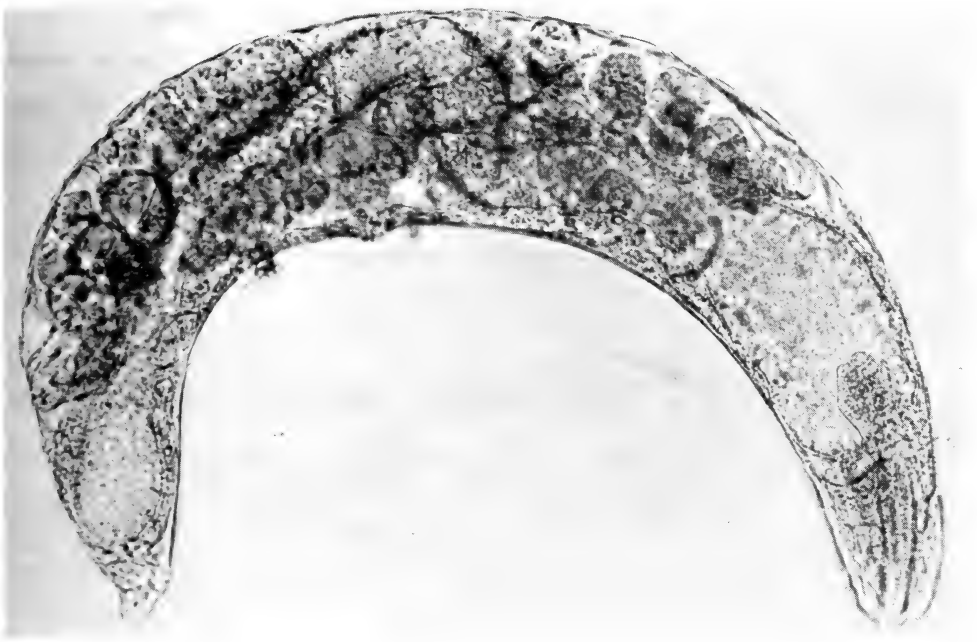

FIGURE 1. A "pigmy" female of *Neoaplectana* sp. isolated from a puparia of *R. Pomonella* (X 200).

larvae after they had become weakened from other causes. Another common soil inhabitant is *Bacillus cereus*. This bacterium is known to invade and kill insects, and thus could be a potential pathogen of apple maggot larvae. Yeasts are very common in rotting fruit and it is not surprising that they were isolated from dying larvae. A few yeasts are known to be pathogenic to insects, but it is not known whether the present isolates fall into this category.

Members of the genus *Fusarium* are also common soil inhabitants. A few are known insect pathogens, and the possibility of this isolate being one of those awaits further investigation.

Neoplacetanid nematodes are true insect pathogens, and are not able to survive saprophytically in soil. Infection was probably initiated in the puparial stage, since it is known that neoaplectanid nematodes can enter fly pupae (Poinar et al. 1977). This nematode is now being cultured in the laboratory on larvae of *Galleria mellonella* (L.) and on artificial dog food media. To our knowledge, this is the first report of a nematode pathogen of a trypetid fly. One of the infected puparia yielded several "pigmy" nematode females. These dwarf forms show up from time to time in neoaplectanid populations and their formation has been considered genetic in determination. However since no such females occurred when the nematodes were reared in *Galleria* larvae, it is probable that unfavorable environmental conditions are the cause of this abnormal condition.

The recent investigation shows that the larval and puparial stages of *R. pomonella* are exposed to disease-producing microorganisms. These microorganisms may be able to infest the apple maggot and may play a more important role in the natural control of this pest than previously realized. Clearly, further investigation is needed to test this hypothesis.

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FIELD OBSERVATIONS OF *ZETZELLIA MALI* (EWING) (ACARINA: STIGMAEIDAE) IN SOUTHERN ONTARIO APPLE ORCHARDS[1]

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Abstract

Zetzellia mali (Ewing) was observed in several apple orchards in southern Ontario during 1974 and 1975 to assess its population dynamics and role in regulating phytophagous mites. This predatory mite was found overwintering under twig scars and bark near its prey. Mortality during the winter was high, reaching 94% by April. Densities of the three or four annual generations of *Z. mali* were correlated with numbers of phytophagous mites on apple leaves. Peak predator populations occurred one to two weeks after prey populations reached maximum numbers. Although acaricides were detrimental to populations of *Z. mali,* the fungicides and insecticides commonly used in commercial orchards had no observable effects on this predator.

Introduction

Zetzellia mali (Ewing) is a predaceous mite that has considerable potential as a regulating agent of the European red mite, *Panonychus ulmi* (Koch) and the apple rust mite, *Aculus schlechtendali* (Nalepa), in integrated control programmes in apple orchards. This predator exhibits some degree of tolerance to pesticides (Croft 1975), often increases to high population densities (Hoyt 1969), attacks winter eggs of the European red mite (ERM) (Herne and Lund 1973), and can maintain itself on the apple rust mite during periods of low spider mite densities (Hoyt 1969). Thus, *Z. mali* may assist in reducing pest mite populations and the number of acaricide applications necessary for mite control in an orchard.

Z. mali, under the synonym *Mediolata mali* (Ewing), was first reported as a predator of ERM in Canada by Parent and LeRoux (1956) in southern Quebec. It has been reported to occur on the foliage of grape and apple in Sicily (Inserra 1970:, pear, plus and willow in Germany (Berker 1958), plum, peach and nectarine in California (Rice *et al.* 1976), and apple in Germany (Berker 1958), France Delattre 1971), New Jersey (Knisley and Swift 1972), Michigan (Croft 1975), Ohio (Holdsworth 1968), Washington (Hoyt 1969), Nova Scotia (Nesbitt 1946), and southern Ontario (Herne and Lund 1973). Although *Z. mali* is widely distributed it has received limited attention as a predator of phytophagous mites.

In this study, populations of *Z. mali* were observed throughout the growing seasons of 1974 and 1975 in several southern Ontario apple orchards to note correlations between this predator and its prey.

Materials and Methods

During the summer of 1974, five apple trees were sampled in each of seven apple orchards to determine the population fluctuations of *Z. mali* in relation to

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various pesticide applications and population fluctuations of phytophagous mites, most notably ERM and the apple rust mite.

The sample orchards were grouped into three categories: virtually abandoned, with one or no applications of fungicide; maintained orchards, with six or more fungicidal sprays; and commercial orchards, with more than ten fungicidal, four or more insecticidal, and up to three acaricidal applications.

Three orchards were monitored in the Guelph area. They were the Ontario Reformatory orchard which was classified as a maintained orchard; the Horticulture Experimental orchard, classified as a commercial orchard; and the Heming orchard which was classified as virtually abandoned. All three orchards received low volume spray applications.

Four commercial orchards were sampled in the Milton region. They were Bousfield and McCarthy (high volume sprays) and Brown and Chudleigh (low volume sprays).

Trees were sampled weekly during 1974 from May to October. Each sample consisted of twenty leaves per tree taken randomly from one to two m above the ground, near the periphery of the tree. Because *Z. mali* and most other mites were only present on the undersides of the leaves, only this area was observed. In addition, a random sample of 20 leaves per tree was taken each week from two marked trees in the Ontario Reformatory orchard to observe the population dynamics of the apple rust mite. Using a mite-brushing machine, these mites were removed from the leaves and the number of motile forms per leaf counted under a binocular microscope.

In the winter of 1974-75, monthly twig samples were taken from five marked trees in each of the three Guelph area orchards to observe the relative abundance and winter mortality of overwintering female *Z. mali*. Each sample consisted of five twigs, *ca.* 0.6 cm in diameter and 12.7 cm long. Twigs were selected at various heights throughout the trees according to the presence of potential overwintering sites, such as loose bark and twig scars.

During 1975 only the Ontario Reformatory and Horticulture Experimental orchards in the Guelph region were sampled. Forty leaves from each of the five trees used in 1974 were taken weekly to obtain greater accuracy in population assessment. A sub sample of ten leaves was taken from each weekly sample and the number of motile rust mites on one 2.2 cm diameter disc per leaf was recorded.

In the winter of 1975-76, twig samples were taken in November, February and April from each of the five marked trees in the Horticulture and Ontario Reformatory orchards. Each sample consisted of 280 cm of twigs, 0.6-1.3 cm in diameter which were taken from the periphery of the tree, *ca.* 1.5 m above the ground. All twig samples were taken to the laboratory where twig scars, scale insects, and loose bark were examined for *Z. mali*. Overwintering mites were considered 'dead' if they did not respond to prodding with a fine hair brush. Diapausing mites were found to respond at temperatures as low as 0°C.

Soil samples 0.1 m square and 8.0 cm deep, were taken on April 2, 1975 at a distance of one m from the trunk, to the east and to the west of the five trees of the Horticulture Experimental orchard. Each sample of soil and leaf litter was placed in a Berlese funnel.

Results and Discussion

Trends in Prey Populations

In 1974 and 1975, populations of *P. ulmi* reached maximum numbers between mid-July and late August while *Tetranychus urticae* Koch and *Tetranychus canadensis* (McGregor) reached maximum densities in September (Heming, Brown and Bousfield orchards). *A. schlechtendali* reached peak numbers in the last week of June and the first two weeks of July after which large numbers were observed overwintering on the woody parts of the trees (Figs. 1a-4a [figures representative of all trees sampled in both years]).

This observation corresponds to those of Parent (1967), Hoyt (1969) and Delattre (1974). *A. schlechtendali* has three generations in Nova Scotia (Herbert 1974), however, in this study the generations were not distinguished because of their overlap and because the motile stages were not differentiated.

Z. mali Trends in Populations

The number of adult *Z. mali* appears to either remain relatively constant throughout the growing season (Fig. 1b) or, more typically, to increase between mid-July and mid-September (Fig. 2b). The mortality of eggs and motile immature stages of *Z. mali* was often very high. Most of the samples taken in 1974 and 1975 showed a sharp decrease in numbers from egg to adult stages. The majority of *Z. mali* found on leaves in late September were males, the females apparently having left to find overwintering sites.

In France during 1970, Delattre (1974) found that eggs of *Z. mali* reached high numbers twice, once in June and more noticeably in July, while the number of adults peaked in September. This type of response was observed on only one sample tree during both 1974 and 1975. During the 1971 growing season in France, both the eggs and adults of *Z. mali* peaked in numbers in July, corresponding to the population fluctuations of *Z. mali* in Figure 3b.

Thomas *et al.* (1959) and Parent (1960) have observed that *Z. mali* increased toward the end of the growing season in New Jersey and Quebec respectively, and they became important in the regulation of tetranychid mites. Similar results were found in the Guelph area orchards (Fig. 2b).

Due to the overlap of successive generations of *Z. mali,* it is difficult to determine the number of generations per year, but our observations indicate that there are three to four generations in the orchards in southern Ontario (Figs. 2b, 4b). Berker (1958) and Bohm (1960) state that *Z. mali* has two complete generations in Germany and Austria; two or three generations have been recorded in France (Delattre 1971); three or four generations have been observed in southern Quebec (Parent 1967), and four generations per year have been recorded in Ohio (Ellingsen 1971).

In the current study no correlation was found between the population densities of *Z. mali* and the cultivar of the host apple tree.

Z. mali— Prey Interactions

A close relationship can be seen between the population dynamics of *Z. mali* and its prey. Egg deposition by the predator typically reached a maximum one to two weeks after the prey population had reached its peak, indicating a numerical response by the predator.

Z. mali and *P. ulmi* reached peak numbers on a sample tree in the Horticulture orchard near the end of July 1974 with the *Z. mali* population, which reached a peak of 12.5 motile forms per leaf, lagging one week behind its prey. After a decline in numbers during August, adult *Z. mali* became more numerous during September on some trees. This was possibly due to secondary peaks in the numbers of *P. ulmi* during late August.

In the Brown orchard, a large number of *T. urticae* and *T. canadensis* were present throughout September, 1974 and this seems to be reflected in the growth of *Z. mali* populations throughout August and September in this orchard. Egg deposition increased during the summer in response to *A. schlechtendali* while the adults of *Z. mali* reached peak numbers in early September at which time *T. urticae* and *T. canadensis* were at their greatest densities.

Spider mites were rarely observed on the trees sampled in the Ontario Reformatory orchard. During 1974 populations of *A. schlechtendali* were observed on two selected trees and reached numbers in excess of 1,000 motile forms per leaf early in July. Egg deposition by *Z. mali* reached a maximum in late July or early August. During 1975, *A. schlechtendali* populations reached their peaks during the last week of June and the first week of July in the Ontario Reformatory orchard; *Z. mali* egg production rose to a maximum a short time later (Figs. 1, 3). One tree (cv. Wealthy) had nearly 20 motile *Z. mali* per leaf at the peak population (Fig. 3b). Egg deposition by *Z. mali* decreased rapidly as the majority of *A. schlechtendali* left the leaves to overwinter. Thus it appears that the size of the population of *Z. mali* was dependent on the presence of *A. schlechtendali* in this orchard.

The correlation between the numbers of *A. schlechtendali* and egg deposition by *Z. mali* is also apparent in the Horticulture Experimental orchard (1975) (Fig. 2) although one tree (cv. Red Delicious), which had a build-up of *P. ulmi* throughout August, showed a peak in *Z. mali* egg deposition in late August apparently in response to *P. ulmi* (Fig. 4). Several peaks of egg deposition by *Z. mali* were observed on two trees in the Horticulture Experimental orchard throughout July and August. Although the *A. schlechtendali* populations were at relatively low levels at that time, enough were present on the leaves to support the motile *Z. mali*.

Effects of Pesticides

The population of *P. ulmi* in the Chudleigh orchard (1974) reached a maximum of over 40 per leaf in mid-July while the numbers of *Z. mali* peaked apparently in response to this host during late July. The application of the acaricide Omite on August 1 rapidly decreased the numbers of both species.

Considerable numbers of *Z. mali* were found in three commercial orchards that received low volume sprays (Horticulture, Brown, Chudleigh) as well as the maintained orchard (Ontario Reformatory) and the abandoned orchard (Heming). Members of the phytoseiid complex, as well as high densities of the phytophagous mite *A. schlechtendali,* were also present in these orchards. In the orchards undergoing low volume spray programmes, the regular application of fungicides (Cyprex, Captan) and insecticides (Guthion, lead arsenate) had no observable effects on the overall abundance of any of the mite populations.

The two commercial orchards which underwent high volume spraying contained neither *Z. mali* nor other predaceous mites but had high populations of ERM.

In the past, effects on *Z. mali* of a wide range of pesticides have been recorded (Parent 1960; Delattre 1971; Herne and Lund 1973). Some contradictions appear in the results of these studies but it is likely that this can be explained by varying tolerance to these chemicals between *Z. mali* populations. This seems to be borne out by the literature. *Z. mali* was found only in abandoned orchards in Germany and Austria by Berker (1958) and Bohm (1960). Hoyt (1969) rarely found this mite in Washington orchards where integrated control programmes were used but Montoyama *et al.* (1970) demonstrated organophosphorus tolerance in *Z. mali* populations in the southern United States as did Croft and Brown (1975) in Michigan. Knisley and Swift (1972) found this mite in all orchards they sampled in New Jersey. The present study indicates that the insecticides commonly used by commercial apple growers using reduced spray schedules and low volume application in southern Ontario do not have obvious detrimental effects on *Z. mali* populations. The two acaricides that were favoured for control of large populations of phytophagous mites were Omite and Plictran. Omite reduced the numbers of both *Z. mali* and *P. ulmi* in a low volume orchard, although both survived the treatment. Plictran virtually eliminated *P. ulmi* within a high volume orchard where no *Z. mali* were present.

It may be hypothesized that the large *P. ulmi* populations and the absence of predatory mites, i.e. *Z. mali* and phytoseiids and the alternate food source *A. schlechtendali,* in two commercial orchards was due to the regular application of high volume sprays. If this were the case, it would be difficult to detect since these orchards were sprayed more often and with a wider variety of chemicals than the commercial orchards receiving low volume sprays.

Overwintering

Twig samples were taken from three Guelph area orchards in 1974 and 1975 in an effort to determine the factors responsible for winter mortality, and relationships between the abundance of overwintering, adult females of *Z. mali* and the summer generations. Overwintering sites vary in number from tree to tree, and the mechanisms involved in the aggregation of *Z. mali* females in these sites are not known. Thus, further work is needed before statistically acceptable correlations can be found between either the abundance of the last summer generation or the succeeding spring generation and the number of mites finding suitable overwintering sites.

In 1975, *Z. mali* females were first found in overwintering sites in a sample taken September 3. Overwintering clusters of *Z. mali* varied in size from 1-141 individuals. The clusters were typically found under loose bark on apple twigs, near old twig scars and often in association with woolly apple aphids *Eriosoma lanigerum* (Hausmann) or near overwintering eggs of *P. ulmi*. *Z. mali* were seen to feed upon winter eggs of various aphid species, as has been reported by Berker (1958), as well as *P. ulmi* eggs and the overwintering, adult females of *A. schlechtendali*. Overwintering *Z. mali* were active when prodded with a fine hair brush at 0°C, and have been seen feeding at temperatures of *ca.* 5°C. In the winter of 1974-75, the mortality of the *Z. mali* populations in February was *ca.* 54%. In the winter of 1975-76, samples in November, February and April revealed mortalities of 8, 93, and 94% respectively. Ellingsen (1971) states that the overwintering mortality of *Z. mali* is often very high, and Chant (1959) has shown that winter mortality for several phytoseiids approached 54% in February and exceeded 90% at the end of the winter.

Z. mali has been found to overwinter in the soil at the base of apple trees (Parent 1967). However no overwintering *Z. mali* were found in the soil and leaf litter under trees in the Horticulture orchard although an assorted fauna emerged.

Conclusions

Z. mali cannot prevent the occurrence of high populations of phytophagous mites by itself. However, this predator exerts a regulating effect by reducing overwintering eggs of ERM in the fall and early spring, and it reduces the number of eggs and immature stages of phytophagous mites in the summer. With the presence of the apple rust mite early in the season, *Z. mali* may be able to keep low populations of ERM at tolerable levels late in the season.

Z. mali is a less effective predator than the Phytoseiidae because of its smaller size, lower mobility and relatively low intrinsic rate of increase (White and Laing 1977). These characteristics necessitate a high predator-prey ratio for control of pest mites. *Z. mali* also favours the apple rust mite as prey and this prey is often not economically important, compared to the major acarine pests in the family Tetranychidae (e.g. ERM, two-spotted mite).

The numbers and oviposition rate of *Z. mali* are directly correlated with the numbers of prey. However, it is often difficult to show correlations with specific prey since the predator may be feeding upon a complex of phytophagous mites (i.e. ERM, apple rust mite, two-spotted mite, four-spotted mite). In this study, such correlations were found since the only prey commonly available in several orchards was the apple rust mite.

Both *Z. mali* and phytoseiids can be present in an orchard and together they may control ERM but often the phytoseiids are eliminated by the use of pesticides to which *Z. mali* has some tolerance. In this case *Z. mali* may be the only acarine predator present.

Z. mali is an important part of the predatory acarine complex in apple orchards. Under ideal conditions this mite may provide a significant level of control of pest mites. However, where a number of insecticide applications are used in commercial orchards in southern Ontario, *Z. mali* should be classified as a poor regulating agent of phytophagous mite populations.

Acknowledgment

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SEE PAGE 30 FOR FOLLOWING FIGURES

FIGURE 1. Mite populations on an apple tree (cv. McIntosh) in the Ontario Reformatory orchard, 1975.

a. Motile *Aculus schlechtendali*/2.2 cm dia. disc/leaf.

b. All stages of *Zetzellia mali*/40 leaves.

FIGURE 2. Mite populations on an apple tree (cv. Red Astracan) in the Horticulture Experimental orchard, 1975.

a. Motile *Aculus schlechtendali*/2.2 cm dia. disc/leaf.

b. All stages of *Zetzellia mali*/40 leaves.

FIGURE 3. Mite populations on an apple tree (cv. Wealthy) in the Ontario Reformatory orchard, 1975.

a. Motile *Aculus schlechtendali*/2.2 cm dia. disc/leaf.

b. All stages of *Zetzellia mali*/40 leaves.

FIGURE 4. Mite populations on an apple tree (cv. Red Delicious) in the Horticulture Experimental orchard, 1975.

a. Motile *Aculus schlechtendali*/2.2 cm dia. disc/leaf.

b. All stages of *Zetzellia mali*/40 leaves and *Panonychus ulmi*/leaf.

FIGURE 1

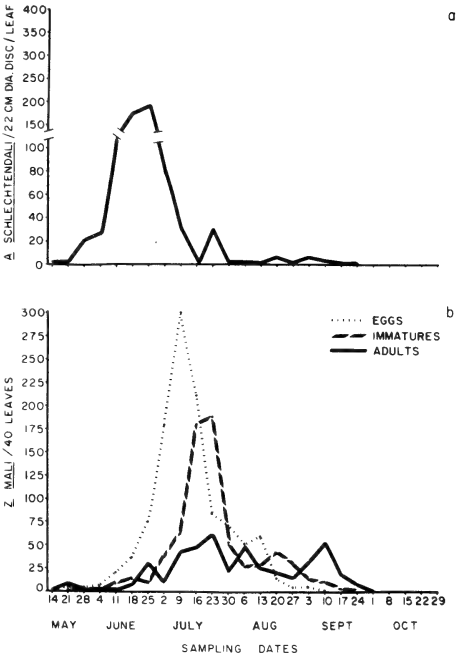


FIGURE 2

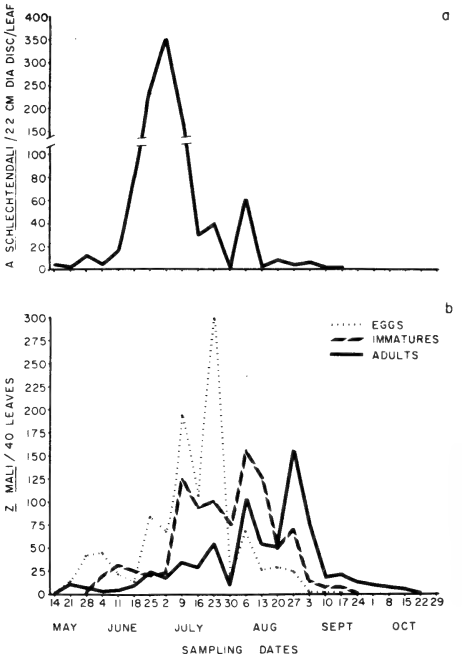


FIGURE 3

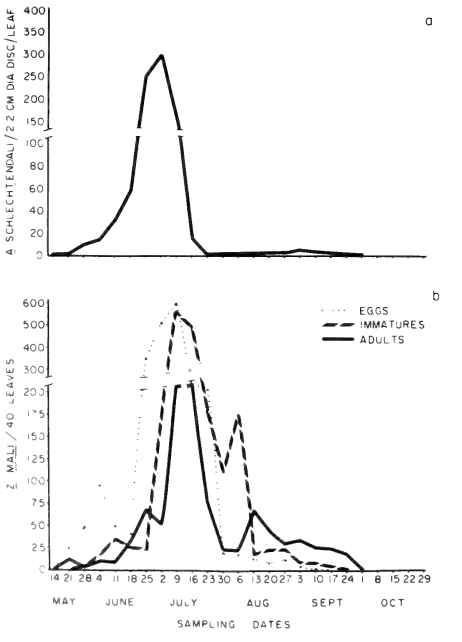
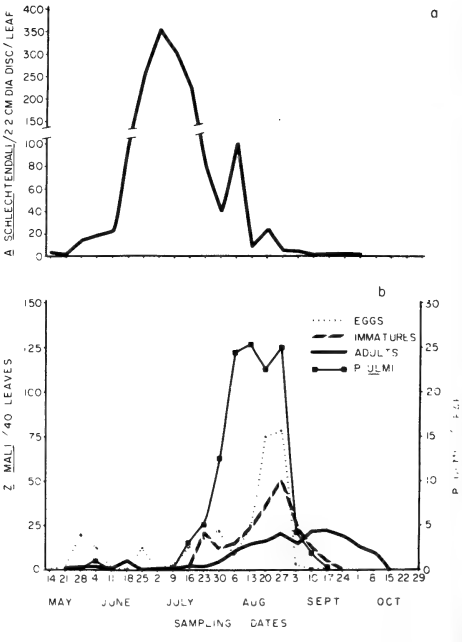


FIGURE 4



BRACHICOMA SPP. (SARCOPHAGIDAE) AND *MELITTOBIA CHALYBII* (EULOPHIDAE) AS PARASITES OF THE BROOD OF *BOMBUS* SPP. (APIDAE) IN SOUTHERN ONTARIO

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Abstract

Brachicoma spp., and *Melittobia chalybii* Ashm., were important parasites of larvae and pupae in nests of *Bombus* spp., in Ontario which had been transferred from natural surface sites or had established initially in hives mainly at ground level. The development of *Brachicoma* in bumble-bee nests indicated that there were two or three generations of *Brachicoma* each year. *Brachicoma setosa* Coq., is recorded as a parasite of *Bombus* for the first time, and *Brachicoma* is recorded as a new host for *M. chalybii*. Their status as parasites of *Bombus* in North America is reviewed briefly.

Introduction

The significance of parasites other than *Psithyrus* in bumble-bee nests has received little attention in North America (Plath 1934) or in Europe (Pouvreau 1973, Alford 1975). This study reports on two species parasitic on the larvae and pupae of bumble bees in Ontario. Current information on *Melittobia chalybii* Ashm., as a parasite of bumble bees was summarized by Edwards and Pengelly (1966). *Brachicoma devia* Coq., and *B. sarcophagina* (Townsend) have been recorded from Ontario (Stone *et al.*, 1965; Edwards-Anderka 1967). There is little information from North America on their biology or distribution (Frison 1926; Hallock 1940).

Methods and Materials

During the period 1971-73 studies were made on the development and parasitism of 44 nests belonging to 10 species of *Bombus* in the vicinity of Guelph, Ontario. Twenty-two nests were initiated in hives, the other 22 being transferred from natural sites to hives (Table I). The five naturally established nests of

TABLE I Species of *Bombus* and number of nests examined in the vicinity of Guelph, Ontario between 1971 and 1973.

Species	No. of nests from hives	No. of nests from natural sites	Species	No. of nests from hives	No. of nests from natural sites
affinis Cress.	0	1	*impatiens* Cress.	2	2
americanorum (F.)	0	2	*perplexus* Cress.	0	3
bimaculatus Cress.	0	2	*rufocinctus* Cress.	1	0
borealis Kirby	1	1	*terricola* Kirby	1	2
fervidus (F.)	5	9	*vagans* F. Sm.	12	0

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B. affinis, B. impatiens and *B. terricola* were underground, all others being at or above ground level.

Only one nest *(B. fervidus)* collected before August 20 had not reached maturity (produced new queens). Four nests were transferred after September 15 and in these the larvae of *Antherophagus* sp., (Mycetophagidae) and *Vitula edmundsi* (Packard) (Pyralidae) had produced substantial cocoon fragments at the base of the nest. Likewise, pupal cases of *Brachicoma* could have been destroyed. During May and until early July 1973, hives were inspected at least once a week to check nest establishment and development of *Bombus* and its parasites. In other years, and after this period, nests were checked less frequently, but usually every 14 days.

Results

The incidence of parasitism by *Brachicoma* spp., ranged from 0.2 per cent to 75 per cent of cocoons in the 11 nests affected (Table II). Twenty-nine per cent

TABLE II Nests of *Bombus* spp., parasitized by *Brachicoma* spp., and *Melittobia chalybii* in southern Ontario 1971-1973.

		Brachicoma (Sarcophagidae)	
infected (estimate)	Dates parasites found	*Bombus* spp., & site of nest initiation	No. of *Brachicoma* larvae (L) and pupae (P) and estimated level of parasitism
June 21-26	July 28	*vagans* (H)	2P 25% of brood 1
	Aug. 15	*vagans* (H)	1P*
June 24-29	July 14	*perplexus* (N)	10P[1,2]
	July 19	*perplexus* (N)	1L
July 4-8	Aug. 4	*fervidus* (H)	1P* 12.5% of brood 1
July 8-14	July 28	*vagans* (H)	11P Broods 2-4
	Aug. 21	*vagans* (H)	9P* 3P 34-49% of worker larvae
July 14-19	Aug. 8-20	*fervidus* (N)	14P, 7L 63-75% of worker larvae
July 30-	Aug. 18	*impatiens* (H)	23L[1,2] Broods 9-12;
Aug. 3	— 22	*impatiens* (H)	18-24% of male larvae
July 30-Aug. 2	Aug. 21	[3]*vagans* (H)	3L 3% of worker/male larvae
July	Aug. 23	[3]*fervidus* (N)	39P* 50P[2] (dead/parasitized) 40-80% of larvae
July-Aug.	Aug. 26	[3]*perplexus* (N)	48P* 39P[2] (dead/parasitized) 15-20% of larvae
Aug.	Aug. 29	*fervidus* (H)	4P* 1.5-2% of worker/male larvae
Aug.	Sept. 10	[3]*impatiens* (N)	0.2% of worker/male brood, probably male brood
		Melittobia chalybii (Eulophidae)	
July 26-31	Aug. 18	*fervidus* (H)	59-66% of worker larvae
July 26-31	Aug. 18	*fervidus* (H)	65-78% of worker larvae
July-Aug.	Aug.	[3]*fervidus* (N)	Worker larvae
July-Aug.	Aug.	[3]*vagans* (H)	1% of worker/male larvae
July	Aug.	[3]*perplexus* (N)	Few queens emerged most parasitized[2]
Aug. 20-30	—	[3]*impatiens* (N)	3 males parasitized, 0.6% worker/male larvae, 4% queen larvae
Aug.-Sept.	up to Sept. 20	*fervidus* (N)	Most of queen pupae parasitized

1. *Brachicoma setosa.*
2. This parasite not recorded previously from this host species.
3. Nest affected by both *Melittobia* and *Brachicoma.*
4. H = nest from a hive. N = nest from natural site.
P* = adult emerged from pupae.

of *B. fervidus* and 33 per cent of *B. vagans* nests (excluding a nest from which no workers emerged) were parasitized. Infestation was sufficiently early and severe in two nests of *B. vagans* and in two of *B. fervidus* to be a major factor in preventing these nests from reaching maturity. The four nests of *B. fervidus* affected by *Brachicoma* produced an average of 22.3 queens per nest from nests which averaged 124.5 larvae.

The incidence of parasitism within a nest was not always observed directly. *Brachicoma* larvae generally emerged from the cocoon and crawled to the bottom of the nest. The workers ejected the remains of the pupae within 2 days, and then trimmed the tops of the cocoons. Only 6 cocoons in the 11 nests examined showed round emergence holes at the side or bottom. The 100 *Brachicoma* larvae had left no other signs on the cocoons to indicate that *Bombus* larvae had been affected. Consequently, nests, especially those from natural sites, often had pupae at the base. In these instances, when many *Brachicoma* had emerged, the number of *Bombus* cocoons affected was estimated. Seventeen cocoons of *Bombus impatiens* produced an average of 1.35 parasites. In estimating the number of cocoons it was assumed that each produced 1.2-1.5 larvae of *Brachicoma*. *Brachicoma setosa* had parasitized 17 larvae of *B. impatiens* in late July and early August. The eggs of *Bombus* were laid from July 16-31 and the larvae spun cocoons from August 9-19, giving an average larval period of 12.5 days. The first larvae of *B. setosa* took 2.5 days to pupate and adults emerged after 7-12 days. The average period of development from egg to adult was 3 to 4 weeks for this species.

Melittobia chalybii affected 7 of the 44 nests of *Bombus* (Table II). This involved 29 per cent of the nests of *B. fervidus*. In two of the latter, *M. chalybii* developed so rapidly and so early that no new queens were produced, and in two others many queen larvae and pupae died. Four nests of *B. fervidus* with an average of 110-120 larvae, that were affected by *Melittobia,* produced only 4-6 queens per nest.

M. chalybii was a parasite of both *Bombus* and *Brachicoma* larvae in two nests. It affected 64 per cent and 36 per cent of the 137 *Brachicoma* pupae from nests of *B. fervidus* and *B. perplexus,* respectively. An average of 661 $\pm$ 26 (range 447-846) parasites developed from the 22 worker larvae of *B. fervidus* and 43.2 $\pm$ 5.6 (range 20-74) from the 12 larvae of *Brachicoma*. Pupae of *Bombus* produced from 1-210 parasites and those of *Brachicoma* from 1-16.

Discussions and Conclusions

Flies of *Brachicoma* spp., were reported to emerge from pupae in March and April and to produce several generations each year (Frison 1926; Hallock 1940; Pouvreau 1973). If adults of *B. setosa* emerged in March and April in southern Ontario, there would be few, if any, host larvae of *Bombus* available until the beginning of June (Macfarlane 1974). Observations on the life cycle from the present study indicated that there was a larval period of approximately 3 weeks and a pupal period of about 10 days, so that 2-3 generations could be produced each year in June, July, and August.

In previous studies, hives of bumble bees in Wisconsin (Fye and Medler 1954; Medler 1962) and Alberta (Hobbs *et al.,* 1962; Hobbs 1967) were not affected by either *Melittobia* or *Brachicoma*. However, in the present study these parasites were a major factor in restricting production of new queens in *B. fervidus* and *B. vagans*. Most previous studies on natural nests of bumble bees have recorded *Brachicoma* spp., from *Bombus* nests (Plath 1922, 1934; Webb 1961; Plow-

right 1966; Edwards-Anderka 1967). The species involved usually was identified as *B. sarcophagina,* and not *B. setosa* as in this study. *B. devia* is a frequent parasite of nests of bumble bees in Europe (Pouvreau 1973), but it has not been recorded from nests in N. America. Occasionally, specimens have been recorded in N. American surveys (Sanjean 1957). The significance of *Brachicoma* spp., as parasites in N. America will remain obscure until the genus is revised toxanomically and more surveys of *Bombus* nests are completed. Evidence now indicates that these parasites are present frequently in the nests located on or above the surface of the ground. Empty pupal cases can be easily overlooked, or could be destroyed by *Antherophagus* or *Vitula* which break down *Bombus* cocoons.

Parasitism by *Brachicoma* was observed in more nests and started earlier on average than did that by *M. chalybii,* but the latter had a more severe effect on the host's production of new queens for several reasons. Adult females of *M. chalybii* persist in the nests; the female : male ratio and number of parasites per host larva were much higher than in *Brachicoma,* whereas the generation interval was shorter than for *Brachicoma* (Hobbs and Krunic 1971). Many European and N. American studies of nests of bumble bees have failed to record the presence of *Melittobia* spp., (Pouvreau 1973, Alford 1975) or have found only a few in Japan (Sakagami and Katayama 1977) and New Zealand (Macfarlane unpublished). Nevertheless, in Russia, *M. acasta* Walker has been noted to have a severe effect on the nests (Grebennikov 1972). *M. acasta* appears to be closely related to *M. chalybii* (Van den Assem 1975).

Colonies of *Bombus* affected by parasites, especially *Melittobia* spp., which attack the larvae, will have fewer workers than will normal, non-parasitized colonies. These colonies will die out more rapidly than those that are not parasitized. Consequently, such nests are less likely to be detected during surveys. The actual incidence of *Melittobia* and *Brachicoma* in nests of *Bombus* could, therefore, be greater than what is recorded in the literature. These parasites affected 54 percent of 28 nests located at or above ground level. In five underground nests there was no evidence of parasitism by either *Melittobia* or *Brachicoma.*

In the nests of *B. fervidus,* each host larva produced four times as many *M. chalybii* as did the larva of *Megachile pacifica* (Panzer) that were observed by Hobbs and Krunic (1971). Problems with parasites could be encountered if surface-nesting species of *Bombus* and *M. pacifica* are used together for pollination since *M. chalybii* might multiply rapidly in host populations of both genera of bees.

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BIOLOGY OF *GLISCHROCHILUS QUADRISIGNATUS* (COLEOPTERA: NITIDULIDAE) IN SOUTHWESTERN ONTARIO

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Abstract

Glischrochilus quadrisignatus (Say) overwintered in the adult stage, with the largest numbers occurring in the top 2.5 cm of soil. Females fertilized in the fall laid viable eggs in the spring. Decomposing ears of corn were the principal, and often the only, oviposition sites. The earliest occurrence of the life stages in the spring was eggs on 27 April, larvae on 4 May, pupae in early June and adults in mid-June. The peak emergence of new generation adults occurred from mid-July to early August. Adults fed on many types of ripe and decomposing fruits and vegetables throughout the summer and fall. Corn fields often harbored large numbers. Attractancy studies showed that two-day-old sliced immature sweet corn captured the most beetles. Only one generation was observed in nature, but two were obtained when beetles were placed in outdoor cages and provided with an abundant supply of decomposing ears of corn and tomatoes.

Introduction

The nitidulid beetle, *Glischrochilus quadrisignatus* (Say), is a serious pest of several fruit and vegetable crops in southwestern Ontario (Foott and Hybsky 1976). It has also been a nuisance at roadside fruit and vegetable stands and in picnic areas. The data reported herein comprise the first comprehensive study of the insect's biology in Canada.

Overwintering

Investigations in the United States showed that the beetle overwinters as an adult beneath the bark of logs, in tree wounds, in the soil, in clumps of grass, beneath the residue of decomposing vegetables, fruit, or grain, in heavy leaf mold in forested areas, in gladiolus corms, etc. (Luckmann, 1963; McCoy and Brindley 1961; Osmun and Luckmann 1964; Windels *et al.* 1976). No data on numbers of beetles or winter mortality were published for any of the sites. We found that very few beetles overwintered under bark, under objects on the ground, or in leaf mold. Decomposing fruits and vegetables served as attractants but the accumulations weren't sufficiently large to persist and protect beetles throughout the winter. Preliminary observations suggested that most beetles burrowed into the soil.

Soil samples were taken for two years from six sites with different types of ground cover on farms near Dresden in Kent Co. Each sample consisted of a volume of soil 30.5 cm square by 5 cm deep, with the top and lower 2.5 cm portions being kept in separate plastic bags. The first samples were obtained in early December after beetle activity had ceased and the second were collected in March before spring activity commenced. By sampling from the same sites at each period we were able to obtain data on winter mortality. The samples were placed in a storage room with a maximum temperature of 4.5°C to prevent movement of the beetles before the soil was examined.

The results showed (Table I) that most beetles overwintered in the top 2.5 cm of soil. More were found in areas with grass sod and tall weeds than in those

TABLE I. Numbers of living and dead *G. quadrisignatus* found in soil samples from overwintering sites, near Dresden, Kent Co., 1971-73.

Site	Type of vegetation or ground cover	Month sampled	Numbers of living and dead forms[1] Top 2.5 cm of soil Living M[2]	F[2]	Dead	Lower 2.5 cm of soil Living M	F	Dead	Total of all forms
In wooded area	Leaves and leaf mold	Dec.	1.3	1.8	0.5	0.0	0.5	0.0	4.1
		Mar.	0.5	0.0	0.0	0.0	0.0	0.0	0.5
Edge of wooded area	Tall weeds, wild raspberry plants, grass and leaves	Dec.	3.5	4.5	0.5	1.0	0.5	0.0	10.0
		Mar.	5.5	2.0	0.5	0.5	1.0	1.0	10.5
Uncultivated area between cultivated field and wooded area	Sparse grass and short weeds	Dec.	1.0	0.0	0.0	0.0	0.0	0.0	1.0
		Mar.	1.5	2.0	0.5	0.0	0.0	0.0	4.0
Bank of drainage ditch near cultivated field[3]	Grass sod, tall weeds, abundant plant debris	Dec.	17.0	19.0	2.0	0.0	1.0	0.0	39.0
		Mar.	17.0	15.0	3.0	—	—	—	35.0
Sloping portion on north side of drainage ditch	Grass sod, short weeds, very little plant debris	Dec.	1.8	1.5	0.3	0.3	0.5	0.0	4.4
		Mar.	1.8	0.8	0.3	0.0	0.0	0.0	2.9
Sloping portion on south side of drainage ditch	Grass sod, short weeds, very little plant debris	Dec.	3.5	1.5	0.5	0.0	0.0	0.0	5.5
		Mar.	0.8	0.3	0.8	0.0	0.0	0.0	1.9

[1] Averages for two years
[2] M and F = male and female
[3] This site was only sampled in one year. Data for the two depths were combined in March because the ground was frozen.

with sod and short weeds. Except for one sample in one year, adults were seldom observed in forested areas or in soil with sparse vegetative growth. Random soil samples (not shown in Table I) indicated there were no overwintering beetles in soil which was cultivated in the fall. Approximately equal numbers of each sex hibernated. Winter mortality was low, and, since the mortalities observed in December and March were similar, it is probable that most beetles which die do so in the early part of their hibernation.

Spring and Summer Development

Overwintered adults — Adult activity was initially observed about mid-April when the first warm period occurred. On 15 April 1970 and 11 April 1971, when the maximum temperatures were 13.9°C and 24.4°C, respectively, hundreds of beetles were observed in low-level flight over fields which had been in corn the previous year. Small numbers of adults were found under exposed ears of corn and in traps baited with ripe bananas during and after these flights. Beetles often mated in the fall because many of the females removed from the soil during the winter and kept apart from males deposited viable eggs. Overwintered males produced viable sperm as indicated by their ability to fertilize laboratory-reared virgin females.

Eggs — Luckmann (1963) stated that there was no evidence that females oviposit on decomposing plant material, and that eggs were usually found scattered at random in the soil in the vicinity of such materials. However, in other papers by this author it was reported that eggs are laid on or in suitable food material (Luckmann and Hibbs 1959; Osmun and Luckmann 1964). McCoy and Brindley (1961) and Windels *et al.* (1976) also found that eggs were laid on or in the food medium. Previous work in southwestern Ontario showed that ears of field corn missed by harvesting machinery were the principal, and often the only, sources of decomposing vegetative matter available to the beetle for oviposition on most farms (Foott and Timmins 1971). Burial of ears under 7.5 and 15 cm of soil in either the fall or spring did not prevent beetles from locating them (Foott and Timmins 1971; Foott 1976b). We found eggs on the husks of ears, between the kernels, and in the soil, frequently in groups (Fig. 1). Two apparent requirements

FIGURES 1-3. Life stages of *G. quadrisignatus*.

Fig. 1. Eggs in soil.

for oviposition were that kernels be present on the cob and that at least a portion of the ear was sufficiently moist to soften the kernels and permit entry by the

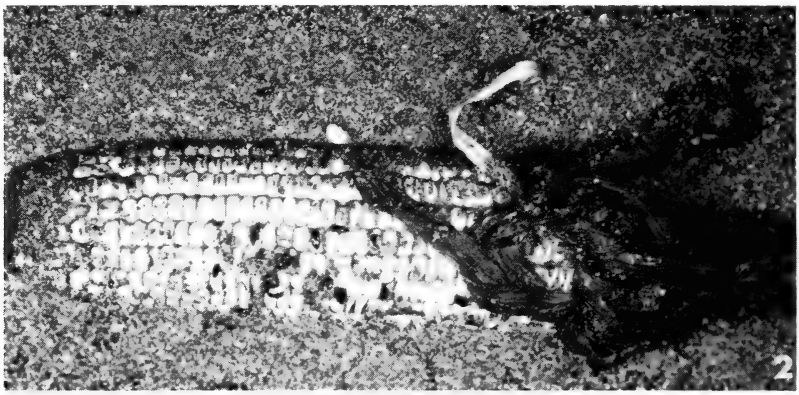

Fig. 2. Adults in soft corn kernels.

larvae and adults (Fig. 2). Eggs, larvae and adults were also found in rotting cabbages which were left in a field overwinter and in onions piled outside in the spring as a source of inoculum for disease studies. Other forms of decaying vegetative matter which have been reported as suitable sites for oviposition include spilled grain, soil saturated with the juices or ooze of decomposing plant material, decaying fruit, rotting corms of gladiolus and iris, and potato seed pieces (Luckmann 1963; McCoy and Brindley 1961).

The earliest date that eggs were found was on 27 April when small numbers were observed on ears of corn. The majority of the eggs were laid during May, but the ovipositional period could be lengthy if suitable vegetative materials were available. Eggs were found as late as 23 July on an ear buried 10 cm in the soil.

Larvae and pupae—The first larvae were observed on 4 May feeding in the kernels of ears of corn on the surface of a wet field. One ear already had 86 eggs and 42 larvae. By mid-May large ears buried in the soil contained hundreds of larvae, with 3 to 6 larvae per kernel. Most of the larval development occurred prior to mid-June, after which the endosperm of the kernels usually became depleted or was unsuitable as food. In a few instances larvae were still present in late July or early August.

No pupae were found in late May, but were common by 10 June. Most were found in earthen cells (Fig. 3) beside or below the buried ears, but in a few instances they were above the ear. Small numbers were found as late as early August.

New generation adults — New generation adults were first observed on 15 June. They could be distinguished from overwintered adults because they were tan-colored rather than black. It was evident from observations in the field and the laboratory that they remain inactive in the soil for a number of days before emerging. A previous study showed that the peak emergence of new generation adults from the soil occurred between mid-July and early August (Foott and Hybsky 1976). This agrees with findings in Illinois (Luckmann 1963), Iowa (McCoy and Brindley 1961) and Minnesota (Windels *et al.* 1976).

Fig. 3. Earthen cell opened to show pupa.

Summer Activities of Adults

Adult *G. quadrisignatus* have been reported from so many feeding sites that it is doubtful if any one could be considered the preferred source of food. Rotting peaches, pears, apples and melons had up to 72 beetles per fruit. Cracked and squashed tomatoes on the ground and in hampers were often severely infested, with populations occasionally exceeding 100 per fruit. In one instance a tomato had 304 beetles. A quart basket of raspberries had 158 beetles. Corn fields appear to harbor the most beetles because there were several parts of the plant which served as feeding sites. Ears which develop on tillers and which are usually smutted frequently contained 200-300 beetles and in some instances over 400. Smut balls on the stalks had 30-50. They were found in ears, at the base of tassels where they fed on pollen and honeydew, in stalk cavities made by the European corn borer *(Ostrinia nubilalis* (Hübner)), and under leaf sheaths where corn borer frass had lodged. Luckmann (1963) found 3,761 beetles in a single ear of corn that had been damaged by Japanese beetles.

Experiments were conducted with various materials to determine the range of odors to which beetles were attracted and to ascertain if any proved more attractive than ripe bananas, the most common ingredient used in traps. Each material was placed in a separate wide-mouthed 1-l. jar fitted with a saran screen cover in which a small hole was punctured. Some of the results were as follows:

Attractant	**No. beetles captured in 24 h** (Average for 2 replicates)
Fresh beer	186
Fresh tomato juice	0
Fresh beer + fresh tomato juice	125
Sliced bananas	308
Sliced bananas + fresh beer	450
Fresh, cracked tomatoes	69
Fresh, sliced immature ears of sweet corn	0
Stale beer	6
Stale tomato juice	0
Stale beer + stale tomato juice	21
1-day-old sliced immature sweet corn	98
2-day-old sliced immature sweet corn	629
Tap water	0

The large number of beetles in jars with immature ears of corn that had been sliced for two days indicates a high degree of attractancy. This helps to explain why large numbers of beetles infest young ears in the field subsequent to being damaged by other insects or birds. Slices of immature corn would make an excellent substitute for bananas in baited traps during that period of the year when the former are available. The odor of fresh beer rated high and explains why some people are bothered by the beetles when they sit outside with this beverage. It would not be a satisfactory substitute for bananas because it would have to be replenished daily, whereas bananas are effective for approximately one week (Foott and Hybsky 1976). The low attractancy of tomatoes in the foregoing summary is misleading because only fresh tomatoes were used. It was proven in other tests that tomatoes which were picked and cracked for several days prior to testing were much more attractive to beetles than those which were freshly picked and cracked. The ratio of beetles in tomatoes which were exposed 1, 2 or 3 days after cracking was 1:2:3 (Foott 1976a).

Studies in which the flight activities of beetles were monitored by the use of fluorescent powders as markers were reported earlier (Foott 1976a). Although the beetles appear to be weak fliers, a few of those which were marked and released were able to detect and infest two hampers of tomatoes 300 m from the release point in less than two hours.

Number of Generations

Investigators in the north central United States are uncertain as to the number of generations this insect has per year. Forbes (1892) reported that there were two generations per year in Illinois. However, as indicated by McCoy and Brindley (1961), literature dealing with the genus *Glischrochilus* prior to the early 1930's is difficult to interpret because distinctions between presently defined species were not recognized. McCoy and Brindley (1961) observed mating on July 25 and assumed that adults from these matings should have emerged in early September. They acknowledged that they did not follow the second generation closely and did not indicate that any of the immature stages were observed. McMullen and Shenefelt (1961) stated that two generations might be possible in Wisconsin on the basis of peaks of adult abundance found in banana bait traps. The peaks were based on low numbers and the investigation was only conducted for one year. Osmun and Luckmann (1964) also reported two generations, presumably for both Indiana and Illinois. Conversely, in another paper on the insect's biology, Luckmann (1963) stated that no second generation or evidence of it was ever observed in the field in Illinois. This conviction was confirmed by a personal communication in 1969.

We examined many sites during the summer and fall but did not detect any evidence of a second generation in nature. In some instances larvae were found in association with adult *G. quadrisignatus* but they always proved to be some other species. Overwintered beetles can oviposit for an extended period of time and, if a suitable food medium was present, eggs might be laid well into the summer. This could create the impression that a second generation occurred. In 1974, 14 adult females which had overwintered were brought into the laboratory and maintained in Petri dishes containing artificial food media (Luckmann 1963). An average of 132.9 eggs/female were deposited from 24 June to 25 July and substantial numbers were still being laid when the test was terminated. Similarly, nine females brought into the laboratory on 2 July oviposited an average of 131.8 eggs/female in the succeeding three weeks.

Previously published data on the capture of adults was tabulated according to three specific periods of activity, (1) reproduction in the spring and early summer, (2) emergence of new generation adults in mid-summer, and (3) beetle abundance in the late summer and fall (Foott and Hybsky 1976). When this information was revised on a monthly basis (Table II), similar to that of McMullen and Shenefelt (1961), there was no evidence of a second generation. There were large weekly variations within a month, but the only sustained peak occurred in July when newly developed beetles of the first generation emerged from the soil.

TABLE II. Number of *G. quadrisignatus* captured in banana bait traps from 1970 to 1972 inclusive.

Year	Trapping period[1]	No. traps[2]	Average no. beetles/trap
1970	May	40	3020.7
	June	"	3058.8
	July	"	9366.7
	Aug.	"	2824.8
	Sept.	"	2704.2
1971	May	48	5200.0
	June	"	5084.1
	July	"	10476.4
	Aug.	"	2297.5
	Sept.	"	1322.2
1972	May	46	3045.8
	June	"	3902.3
	July	"	42710.8
	Aug.	"	8118.9
	Sept.	"	1738.1

[1] Traps were emptied and replenished weekly.
[2] The trapping records from two farms were combined.

Luckmann (1963) did not observe any reproduction when adults of the new generation were placed in outdoor oviposition cages stocked with suitable foods, nor at outdoor oviposition sites supplied with rotting corn ears and both fresh and dried fruits and vegetables. We were successful in obtaining continued reproduction in outdoor cages.

In our investigation decomposing ears of corn were buried in soil in a metal pan and ripe tomatoes, which were replenished at frequent intervals, were placed on top of the soil. The soil was kept moist. Larvae which developed from eggs deposited by overwintering adults on ears of corn in the field were placed on the surface of the soil. A cage comprised of wood and saran screen was placed inside the pan and made to fit so snugly that no insects could enter or leave the pan. After sufficient time was allowed for the larvae to develop to adults, the soil was examined and the new generation adults placed in another pan with corn and tomatoes. Similarly, when sufficient time had passed to permit oviposition and egg hatch the ears of corn and tomatoes were examined for larvae and these were placed in a new pan until adults were present.

Test 1

June 4 — 218 larvae from field-collected ears of corn were placed in the pan.
July 13 — 17 female and 13 male beetles were found in the soil and transferred to a new pan.
July 29 — 37 larvae were found and transferred to a new pan.
Aug. 27 — 2 female and 5 male adults were in the soil.

Test 2

May 11 — Two field-collected ears of corn with an unknown number of small larvae were placed in a pan.

June 30 — A large number of adults and pupae were in the pan. Of these, 39 new generation adults of both sexes and 143 pupae were placed in a new pan.

Aug. 17 — 22 female and 30 male adults were found. There were also 79 pupae and 1238 larvae. Fifty of the larvae were placed in a new pan.

Oct. 5 — One female and 7 male adults were found. We forgot to moisten the soil during a long, dry period and this resulted in a high mortality.

The results showed that the beetles could produce two generations in an outside environment when moist soil and an abundant supply of suitable decomposing vegetative matter were available. This implies that there is no reproductive adult diapause and that a second generation might be possible if the required conditions existed in nature.

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EMONOMIC ENTOMOLOGY

TOXICITY OF SOME INSECTICIDES TO EGGS AND LARVAE OF THE APPLE MAGGOT[1] IN THE LABORATORY[2]

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Abstract

The toxicity of some insecticides to eggs and larvae of *Rhagoletis pomonella* (Walsh) was assessed in the laboratory. Fenthion and azinphosmethyl were more ovicidal than phosalone, phosmet, or dimethoate. Larval emergence was reduced in apples dipped, at regular intervals after egg laying, in suspensions of fenthion, azinphosmethyl, or dimethoate. Little or no larval feeding was found in fruit dipped in fenthion or azinphosmethyl 2 days after eggs were laid.

Introduction

Timing of spray applications based on a knowledge of seasonal abundance of pest species is an important part of most pest management programs. Based on trap catch data, sprays are applied to coincide with periods of activity of susceptible stages. Insecticide applications for apple maggot control, for example, have been timed using yellow sticky boards baited with protein hydrolysate: volatile ammonium salt mixtures (Neilson *et al.* 1976). These traps constitute a food attractant rather than a source of sex attractant or pheromone (Ross *et al.* 1977). Red sticky spheres also have been used to trap ovipositing flies (Prokopy, 1968). Sprays normally are applied within a week of first capture of females flies on yellow sticky boards or within two or three days of first capture on red spheres (R. Trottier, unpublished data). Two or more sprays, timed for control of adults are made at 2-3 week intervals to prevent egg deposition in fruit. However, if insecticide applications made for adults also affected eggs and small larvae in fruit, the spray interval might be extended and the chemical load thereby reduced. Reported here are effects on eggs and larvae in the laboratory of some insecticides used against apple maggot flies.

Materials and Methods

Apple maggot eggs were obtained from a colony reared on apples (Neilson 1965) by using an artificial egging system adapted from Prokopy (1966). Wax domes were formed by placing a 60-watt light bulb into a 1% emulsion of sodium lauryl sulphate and then into melted Ceresin wax. These domes were placed in a petri dish lined with moist filter paper and exposed to ovipositing flies. Eggs were collected daily by washing them from domes with distilled water. Before use, eggs were surface sterilized with 0.05% sodium hypochlorite for 20 min, rinsed in 70% ethanol and then in sterile distilled water.

The toxicity of insecticides to the eggs was determined by pipetting 1 ml of various concentrations, prepared in absolute ethanol onto a Whatman No. 1 filter paper in a plastic petri dish (100 x 25 mm). Two ml of sterile distilled water were

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added, and 15-20 eggs transferred, in 0.5 ml water, onto the filter paper. Tests at each concentration consisted of 5-7 dishes, each with 15-20 eggs. Check dishes contained 1 ml of absolute ethanol plus 2 ml of sterile distilled water. Each dish was covered, sealed with cellulose tape, and placed in a rearing cabinet at 30°C with a 16h photoperiod. The percentage egg hatch was determined under a binocular microscope after 7 days.

Toxicity of insecticides to maggots was determined by their addition to an artificial diet. The diet (Neilson 1969) consisted of agar (1.0 g), sucrose (4.0 g), Brewer's yeast (0.5 g), cholesterol (0.35 g), choline chloride (0.7 g), salt mixture No. 2 U.S.P. XIII (0.35 g), shredded tissue paper (2.0 g), and distilled water (100 ml). Formalin (36% formaldehyde) (0.5 ml) was added to control contamination. The prepared diet was autoclaved at 105°C and 0.35 kg/cm^2 for 30 min in glass blendor jars. Choline chloride, formalin, and 1 ml insecticide solution/100 ml of diet were added as the diet began to set. The diet was then blended for 1 min and poured into plastic petri dishes (100 x 25 mm) to a depth of approximately 20 mm. Two controls were used, one with the plain diet medium and a second with 1 ml of absolute ethanol per 100 ml of diet mix. In a sterile cabinet, groups of 15-20 eggs were transferred in small amounts of sterile distilled water onto a sterile 2.1 cm glass fibre filter paper (Reeve Angel®) placed on the surface of the diet in each petri dish. Dishes were covered, sealed with cellulose tape, and placed in a rearing cabinet at 30°C with a 16h photoperiod. The percentage egg hatch was determined after 7 days, and dishes were examined twice weekly thereafter for 6 weeks for larval development.

Effects of Insecticides on Larvae in Fruit

To determine effects of insecticides on egg and larval development in fruit, infested fruit were dipped in insecticide mixtures at various times after egg deposition. Two hundred Red Delicious apples were exposed to ovipositing flies for 24h and selected randomly for tests. On the day eggs were laid (0 days) and every second day thereafter for 18 days, 5 apples were dipped for 30 sec in 330 ppm (equivalent to 1 lb ai/300 Imperial gal) aqueous mixtures of insecticides (constantly agitated with a magnetic stirring bar). Check apples were dipped in water. After treatment, apples were held in separate holding containers for larval emergence. When emergence ceased, apples were cut and examined for feeding injury within.

Results and Discussion

One microgram of fenthion, azinphosmethyl or phosalone completely inhibited hatch of apple maggot eggs, whereas phosmet and dimethoate had little effect (Table I). Where egg hatch was inhibited, fully developed larvae were visible

TABLE I. Effects of insecticides on hatch of apple maggot eggs.

Treatment[a]	μg/10 cm petri dish	% Egg Hatch
Fenthion	1	0
Azinphosmethyl	1	0
Phosalone	1	0
Phosmet	1	82.3
Dimethoate	1	89.0
Check (1 ml ETOH)	—	84.1
Check (1 ml H_2O)	—	80.0

[a] Eggs placed on treated filter papers

TABLE II. Effects of insecticides on apple maggot eggs and larvae.

Treatment[a]	PPM in diet	% Egg Hatch	% Pupation
Fenthion	1.0	0	—
	0.1	15.7	0
Azinphosmethyl	1.0	0	—
	0.1	38.7	0
Phosalone	1.0	0	—
	0.1	76.9	0
Dimethoate	1.0	85.9	0
	0.1	85.9	0
Check (1% ETOH)	—	79.2	20.2
Check		92.3	21.6

[a] Incorporated into artificial diet.

within the eggs. On phosmet and dimethoate-treated plates, larvae were dead within a few mm of the eggs. Addition of 1 ml of absolute ethanol had no effect on egg hatch. When eggs were placed on the surface of diets containing 1 ppm of fenthion, azinphosmethyl or phosalone, hatch was completely inhibited (Table II). At 0.1 ppm, fenthion and azinphosmethyl reduced egg hatch but phosalone did not. Dimethoate at 1 ppm had no effect on egg hatch. No pupation and no visible larval development occurred with any insecticide at any of the test concentrations. Dead first instars were observed on the surface of diets where egg hatch had occurred. These data indicate that fenthion and azinphosmethyl are more toxic to eggs of the apple maggot than phosalone, dimethoate or phosmet. Phosalone was more ovicidal than either dimethoate or phosmet. In previous tests against adult flies, dimethoate was shown to be approximately 5 times more toxic than azinphosmethyl and approximately 10 times more toxic than phosalone (Bancroft *et al.* 1974). Fenthion was shown to be about as toxic as azinphosmethyl to adults. However, these studies indicate that the ovicidal properties of these insecticides show no relation to their toxicity to adults.

TABLE III. Effects of insecticides on emergence of apple maggot larvae from Red Delicious apples.

Time of Treatment (Days after egg laying)	Pupae/Apple[a]			
	Fenthion[b]	Azinphosmethyl	Dimethoate	Water
0	0	0	0	9.2
2	0.6	0	1.8	9.6
4	0.2	0.8	1.8	14.0
6	0	0.4	1.6	12.6
8	0	0	1.6	9.4
10	0	0.2	0.6	7.6
12	0	0.4	2.8	7.6
14	0.4	0	3.2	5.6
16	0.4	0.8	2.0	7.8
18	0.6	2.6	0.6	8.0

[a] 5 apples/treatment
[b] Dipped 30 sec in 330 ppm concentrations.

Fenthion, azinphosmethyl and dimethoate reduced larval emergence from apples over the entire 18-day experimental period (Table III). Most larvae which emerged from apples dipped 16-18 days after egg laying died upon emergence. When apples were examined for larval feeding, little or no feeding was found in fenthion or azinphosmethyl-dipped fruit in the 0 and 2 day samples. Dimethoate treated fruit had slightly more feeding than either fenthion or azinphosmethyl-

treated fruit. Evidence of feeding and the presence of dead, partially grown larvae increased from 4-18 days in all fruit. These data suggest that the more ovicidal insecticides, fenthion and azinphosmethyl, might be used to kill apple maggot eggs or first instar larvae in fruit in the field. In the laboratory, egg hatch occurred within 2-4 days at 22± 2°C. In the field, however, apple maggot eggs require 7-10 days to hatch (Dean and Chapman 1973). Since all fruit treated with insecticide, particularly from 0-10 days after egg laying had reduced larval feeding, some insecticide must penetrate the skin of the apple. Amounts less than 1 ppm were adequate to give 100% kill of 1st instar larvae (Table II).

One of the problems in using yellow baited sticky board traps to time apple maggot sprays is that a food attractant is unlikely to be as accurate as a sex pheromone baited trap in determining entry of flies into an orchard. Most females trapped on red spheres contain mature eggs (Prokopy 1968), which might suggest that some egg laying had already occurred. These factors are of particular concern in extrapolating trap catch data to recommendations on an area-wide basis. The use of insecticides such as fenthion or azinphosmethyl, which have considerable ovicidal effects and are also toxic to adult flies could reduce the need for pinpoint accuracy in timing spray applications, and allow extension of intervals between sprays through the season. In practice, this would probably be limited to conditions where stings in fruit do not affect marketability of fruit or where fruit is grown to be processed.

Acknowledgments

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OBSERVATIONS ON NEW INSECT PESTS OF GRAIN CORN IN ESSEX COUNTY, ONTARIO

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Abstract

The western corn rootworm, *Diabrotica virgifera* LeConte, the grape colaspis, *Colaspis brunnea* (Fabricius) and the whitemarked tussock moth, *Hemerocampa leucostigma* (J. E. Smith) are reported for the first time as pests of grain corn in Ontario.

In 1975, three insects which have never been reported as pests of corn in Ontario were observed in Essex County fields.

Western corn rootworm, *Diabrotica virgifera* LeConte

In August, 1975 this species was observed in the southern portion of the county. In every instance there was only one to several observed per field even when an intensive examination was made. In 1976, adults were observed over a wide area of the county and in greatly increased numbers. In some fields they were observed at a rate of approximately one per minute. In 1977, there was a further increase and up to 5 or 6 beetles per ear were observed.

This species invaded southwestern Michigan in 1971 (Anon. 1971) and by 1974 had spread to 97% of the corn-growing areas in the state (Anon. 1975). We examined numerous fields in Essex Co. for 10 years prior to 1975 during a study of other corn pests and never observed any insects we suspected as western corn rootworm. The four-year interval between its arrival in Michigan and its appearance in Ontario shows that there was a steady movement through the state rather than a long range wind-assisted invasion which occurs with some insects.

This is the first published report of the rootworm's occurrence in Canada, but not the first evidence of its arrival. Mr. B. C. Smith of the Harrow Research Station obtained specimens from Lambton Co. several days before beetles were identified in Essex Co.

The addition of this insect to the fauna of corn fields in southwestern Ontario compounds the damage caused by the northern corn rootworm, *Diabrotica longicornis* (Say), and could increase the need to treat fields for rootworms. The experience in the United States is that the western is a more serious pest than the northern corn rootworm.

Grape colaspis, *Colaspis brunnea* (Fabricius)

The types of leaf feeding damage caused by billbugs and the European corn borer, *Ostrinia nubilalis* (Hübner) are familiar to most growers and investigators of crop damage in Ontario. Adult billbugs eat small holes into the stems early in the season. These punctures, made while the developing leaves are curled in the heart of the plant, show up, after the leaves expand, as transverse rows of punctures (Fig. 1A). Damage by larvae of the corn borer consists of both a pinhole and an elongated type of injury on the leaves and there is usually a fine sawdust-like frass when the feeding is fresh (Fig. 1B). In late June, 1975, when corn plants were being examined, we observed feeding holes which were atypical of both these species. The holes were more jagged, they frequently occurred at the

edge of the leaves, and there was very little frass (Fig. 1C). Further examination showed they were caused by a beetle, later identified as the grape colaspis.

On 3 July, a portion of the field was examined for leaf injury to determine how many plants were attacked by the colaspis only, the corn borer only, and by both species. When plants had colaspis injury the number of leaves per plant with feeding injury was noted. Of 259 plants with feeding injury, 188 had only colaspis injury, 44 had only borer injury and 27 were attacked by both species. The colaspis damaged an average of 3.7 leaves/plant when alone, but only 1.5 leaves when cohabiting with the borer. The average number of leaves/plant at the time

FIGURE 1. Feeding injuries on corn leaves by A, adult billbugs; B, larvae of *O. nubilalis;* C, adults of *C. brunnea.*

of examination was 11. These two sets of data indicate that interspecific competition might have been a factor in both the numbers of plants infested by each species and the level of damage done by the colaspis. Additional injury would have been caused by the beetles had we not destroyed them over a period of several days to prevent further interference with our corn borer project.

Most of the portion of the field where the colaspis damage occurred was seeded with alfalfa in the spring of 1973, and the remainder was seeded with alfalfa in April, 1974. Both fields were in wheat before the alfalfa was planted. Bigger (1928) noted that in red clover the largest numbers of larvae were found around the roots of second year plants, with very few in a first year crop. The same relationship probably applied to alfalfa.

The only reference to colaspis damage in field crops in Ontario was by MacNay (1954), who reported that soybeans were damaged in Kent Co. He reported it as *C. flavida,* a synonym for *C. brunnea.* However, since the colaspis has damaged corn in the United States when the crop was grown on land previously sown to legumes (Anon. 1939, 1953), it is possible that infestations have occurred in Ontario but the leaf injury was not differentiated from that of other insects. The illustrations included here might assist investigators who note feeding holes which are not corn borer or billbug damage.

Bigger (1931) reported that the grape colaspis overwinters as a larva in Illinois and that the first adults were observed on June 19. Since we observed the first adults during the latter part of June, the life history in southwestern Ontario is probably similar.

Whitemarked tussock moth, *Hemerocampa leucostigma* (J. E. Smith)

The armyworm, *Pseudaletia unipuncta* (Haworth), occasionally causes severe damage to leaves of corn plants in the early summer by chewing out large sections of the leaves (Fig. 2A). Grasshoppers will also cause extensive damage. In early September, 1975 we observed numerous plants with severe leaf damage in a corn field that had not been infested with either of these insects (Fig. 2B). Closer

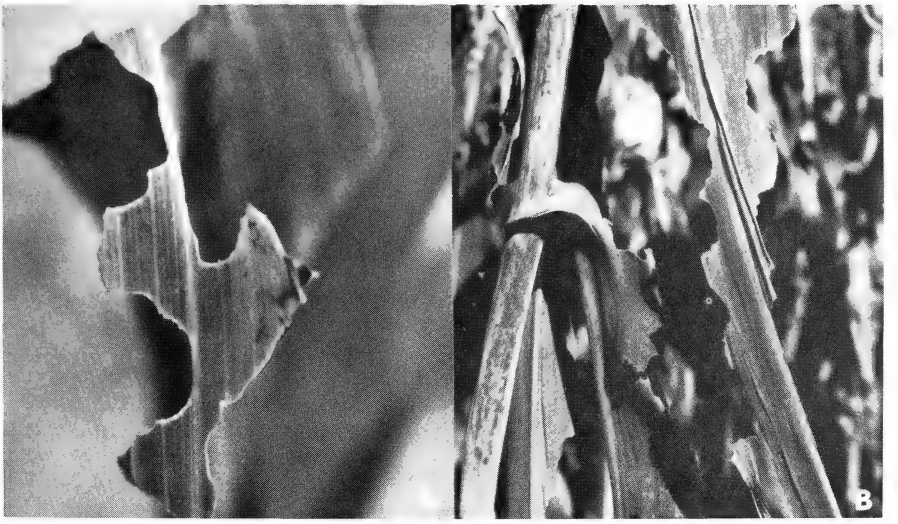

FIGURE 2. Feeding injuries on corn leaves by A, larvae of *P. unipuncta;* B, larvae of *H. leucostigma.*

examination revealed that larvae of the whitemarked tussock moth were responsible and that they had extensively damaged most of the plants in a 13 m by 22 m area.

The source and stage of development of the insects which initiated the infestation was not determined. The females are wingless and it is unlikely that

they were involved. The most logical explanation is that larvae were blown to the field. If so, they must have travelled a considerable distance because none of the trees in the vicinity of the field were infested.

Although this appears to be the first report of damage by this moth to corn in Ontario, there are reports of injury to corn in New Brunswick and Prince Edward Island (Kelleher 1975). The severest injury occurred in the inner parts of the field and probably would have escaped notice until harvest if the field had not been used for experimental work. It could be difficult for growers or agricultural extension specialists to determine with certainty at that time what insect was responsible. Our illustration of damage, plus the knowledge that injury occurs late in the summer, might assist other investigators.

Acknowledgment

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A FIELD EVALUATION OF ELECTROCUTORS FOR MOSQUITO CONTROL IN SOUTHERN ONTARIO

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Abstract

The mean number of mosquitoes biting in backyards with an electrocutor was 30.68, whereas the mean number in nearby control yards was 24.6 when tested against spring *Aedes* sp. The mean number of mosquitoes biting in yards with an electrocutor was 22.72, whereas the mean number in adjacent yards was 30.6 when tested against *Aedes vexans* (Meigen) and *Coquilletidia perturbans* (Walker). These means were not statistically different. Female mosquitoes killed in electrocutors represented 17-24% of total numbers in electrocutors and biting collections. They represented 0.42-4.1% of the total insects killed by electrocutors. Under the experimental design and conditions of this study, electrocutors did not prove effective in reducing mosquito biting counts.

Introduction

Electrocutors or electric grid-type light traps were first developed in the early 1900's (Heinton, 1974). With increased public awareness of pesticide residues and environmental contamination, there has been an increased use of light trap electrocutors for fly control around domestic animals, processing plants, and for backyard nuisance fly control. Canada Department of Agriculture (1976, Memorandum R1-4-44) requested that all manufacturers of such devices demonstrate that "the number of bites or landings are significantly reduced within the effective range of the device in comparison to a control area without a device". This study was designed to evaluate light trap electrocutors for control of mosquitoes under "back yard conditions".

Materials and Methods

Two study sites with high mosquito activity in the vicinity of Guelph, Ontario were used. Before electrocutors were tested at either site, two to seven nights of biting activity assessment were conducted. These tests were done to determine population levels of mosquitoes and biting periodicity. One site tested from May 12 - June 23, 1977, was in a recently completed subdivision. Two homes located on a crescent-type street were used. These yards were separated by four houses and because of the crescent shape of the street, the light from one yard could not be seen from the other. The yards of all homes abutted on a deciduous woods ca. 10 acres in size which served as an ideal breeding site for spring *Aedes* species.

In each yard a standard grid-type electrocutor, with an 18-inch black light, was hung. In the initial tests, from May 12 - May 29, the lights were 1.4 m above the ground but were lowered to .5 m thereafter. Under each trap a small plastic pool (ca. $0.5m^2$) was placed to collect insects killed by the trap. Two female students did biting counts for the entire summer. The two students were of similar weight and height and during the course of trials dressed identically in brown coveralls.

The light was run continuously throughout each evening's test in the one backyard. Biting counts, of 15-minute duration, were made throughout the evenings. Biting counts were followed by 15 minutes in which the students left the study areas. Mosquitoes captured were identified and totalled for each 15-minute interval. Studies were conducted in what were considered peak hours for home usage, 19:30-23:00 hours, such that in each evening six to seven biting counts were made. On each night the same student did biting counts in the same yard. Tests were carried out on a rotating basis (Table I).

TABLE I. Operational method of electrocutor evaluation, Guelph, Ontario, 1977.

	Yard 1		Yard 2	
Evening 1	No light	(Student A)	Light	(Student B)
" 2	Light	(Student A)	No light	(Student B)
" 3	No light	(Student B)	Light	(Student A)
" 4	Light	(Student B)	No light	(Student A)

When mosquito activity declined in late June the test site was moved to Aberfoyle, Ontario. Two adjacent country homes, each on ca. two acres of land were used. Lights were situated in relation to the houses such that they could not be seen from the other home. The surrounding area consisted of fields and woods with a large number of drainage ditches and cattail ponds. *Aedes vexans* (Meigen) and *Coquillettidia perturbans* (Walker) predominated in these areas.

During the initial trials the subjects sat in the lawn grass but on June 1 and thereafter a simulated patio situation was created by placing 20 m^2 of plastic sheeting on the ground and having the subject sit on a folding chair in the centre of the sheeting. Distances from the light varied from 3-15 m throughout the trial period. There appeared to be no correlation between biting activity and distance from the trap. When observers stood close to electrocutors (<1 m), there was an increased number of mosquitoes killed.

For three nights, between Aug. 5-9, solid CO_2 (dry ice wrapped in newspaper) was hung directly over the electrocutors in an attempt to increase attractancy.

Results and Discussion

The results of electrocutor studies for the Guelph site are presented in Figure 1. Only those mosquitoes which were actually captured are represented in the biting counts; females landing but not captured are not recorded. There was no significant difference in the mean number of mosquitoes captured ($P < 0.05$) in the yards with or without light traps using the t-test. When number of females caught in yards with the light are combined with the light kill there was no significant difference ($P < 0.05$) between the control yard and the yard with the electrocutor. It would appear however, based on 19 nights of collection, that there was an increased number of female mosquitoes in the yard with the light particularly when both light kill and actual captures are combined (37.2 vs 24.6). Female mosquitoes killed in the trap represented 4.1% of the insects killed and 17.3% of the total number of females both killed and captured. Insect orders collected in the trap are listed in Table II.

The predominate mosquito species found at the Guelph site based on identification of captured females were: *Aedes stimulans* (Walker), *Aedes fitchii* (Felt and Young), *Aedes euedes* Howard, Dyar and Knab, and *Aedes canadensis* (Theobald). No attempts were made to identify those specimens killed in the electro-

TABLE II. Major insect orders collected from electrocutors at Guelph and Aberfoyle, Ontario, 1977.

Site	Dates	Insects		Total Identified
Guelph	May 24 - June 26	Diptera	77.3%	4,662
		Coleoptera	10.2%	
		Lepidoptera	1.2%	
		Homoptera	.9%	
Aberfoyle	July 4 - July 7	Diptera	56.4%	19,182
		Homoptera	13.4%	
		Coleoptera	8.5%	
		Lepidoptera	.6%	
	Aug. 5 - Aug. 9	Diptera	57.3%	4,307
		Homoptera	25.5%	
		Coleoptera	5.6%	
		Lepidoptera	.3%	

cutors. During the course of this study there was a periodicity in biting of the spring *Aedes* (Fig. 1). Mosquito activity reached a maximum between 21:15 and 21:30 hours (Eastern Daylight Savings Time). During the time period of this study sunset occurred between 20:50 - 21:08 hours (EDT). This periodicity however was not consistent from night to night but could be seen on many nights. The periodicity remained constant in both the yard with electrocutor or without.

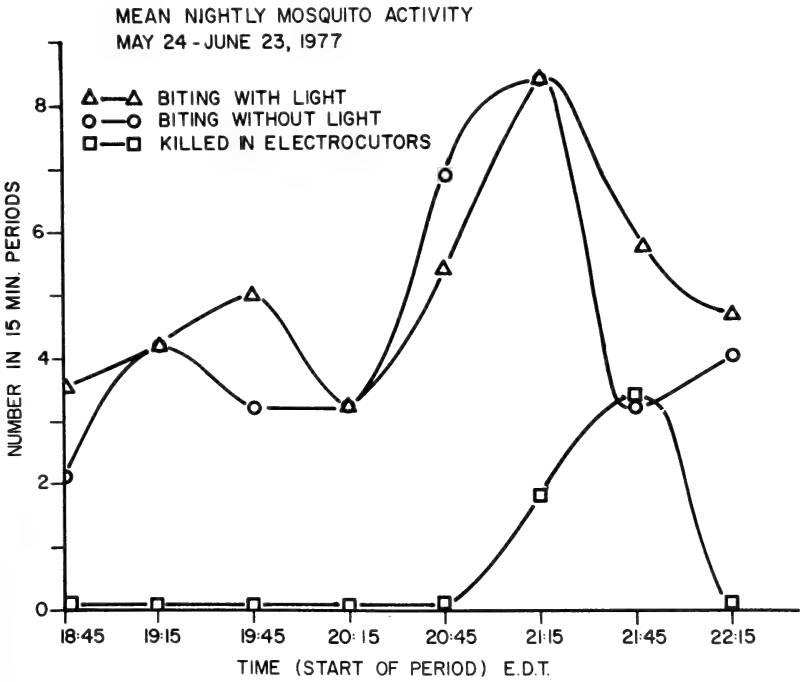

FIGURE 1. Mean nightly mosquito counts in yards with and without electrocutor, Guelph, Ontario, 1977.

Analysis was conducted to determine if significant differences in mosquito numbers occurred between yards or between students conducting the tests. The

mean number of mosquitoes captured in one yard was 39.3 and 31.9 in the other. The mean number of mosquitoes captured by student 'A' was 34.6 and by student 'B' 31.6. Both sets of means were not significantly different. The greatest variability observed was based on differences from night to night. Temperature, wind and humidity are major factors in determination of mosquito activity.

The results of the electrocutor studies for the Aberfoyle site are presented in Figure 2. Only those mosquitoes which were actually captured are represented in the biting counts. There was no significant difference in the mean number of mosquitoes captured with or without light traps using the t-test ($P < 0.05$). The predominant species captured biting at this site were *Ae. vexans* and *C. perturbans*. Mosquitoes killed in the electrocutors represented an average 0.42% of all insects destroyed. The predominate insect groups found are listed in Table II. A definite periodicity in biting was noted at the Aberfoyle site which was consistent throughout the study (Fig. 2). Activity reached a maximum from 21:45 to 22:00. Sunset occurred between 20:51 to 21:07 during the time span of this study.

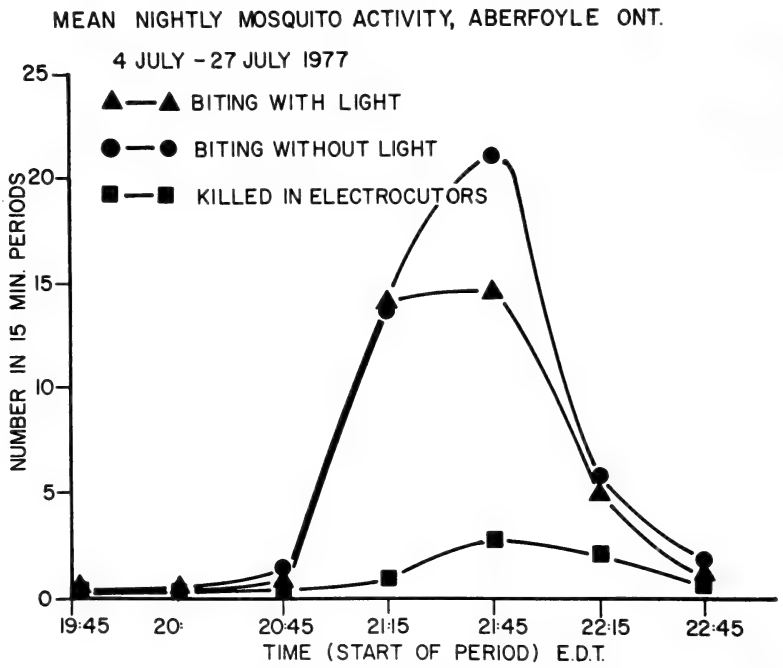

FIGURE 2. Mean nightly mosquito counts in yards with and without electrocutor, Aberfoyle, Ontario, 1977.

A dramatic increase in light trap efficiency occurred when CO_2 was added to the top of the electrocutor (Fig. 3). The percentages of mosquitoes killed in traps vs those biting jumped from 24% to 88.8%. The mean number of mosquitoes biting in the yard with electrocutor was 9.3 vs 2.6 in the yard without electrocutor. It would appear that the heavy CO_2 concentration attracted mosquitoes into the yards with the light. Most mosquitoes were being killed by the trap but there appeared to be an increased number of mosquitoes biting in the yard with the light. No statistical analysis was made on these data because only three nights' testing were made.

Analysis was conducted to determine if significant differences in mosquito numbers occurred between yards. The mean number of mosquitoes captured and missed in one yard was 40.4 vs 37.3 in the other yard. These means were not significantly different.

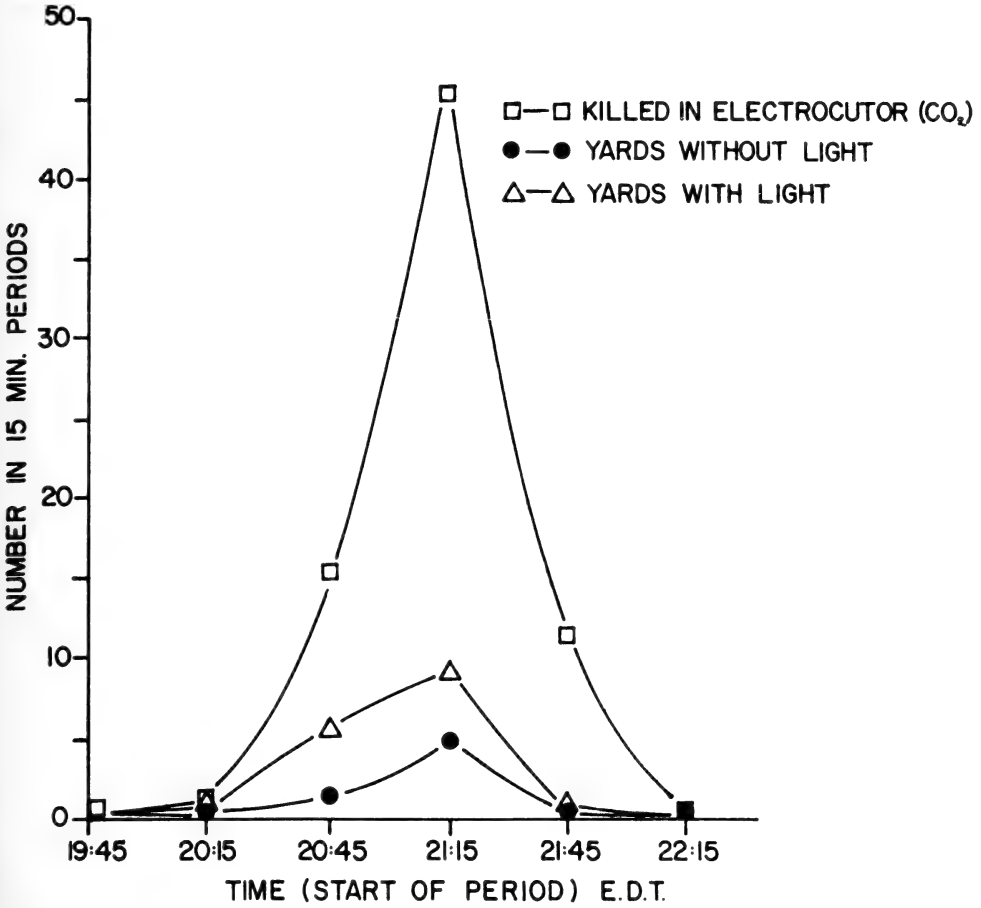

FIGURE 3. Mean nightly mosquito counts in yards with and without electrocutor baited with CO_2, Aberfoyle, Ontario, 1977.

Conclusions

Electrocutors destroy a large number of insects of great diversity. Mosquito females constitute only a small component of these electrocutor kills. Under the experimental conditions and design of this study electrocutors did not provide significant benefit in reducing mosquito biting counts.

Acknowledgments

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FIELD EVALUATION OF ELECTRONIC MOSQUITO-REPELLERS IN ONTARIO

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Abstract

Two types of electronic repellers, Buzz-Off and ME, were field tested against *Aedes stimulans* (Walker); *Ae. euedes* Howard, Dyar and Knab; *Ae. canadensis* (Theobald) and small numbers of *Ae. fitchii* (Felt and Young); *Ae. excrucians* Walker and *Ae. abserratus* Felt and Young. On average, 17 mosquitoes landed on the forearm when using the Buzz-Off repeller and 15 landed without it. Nine landed using the ME repeller and 8 landed without it. These repellers afford no protection from the mosquitoes encountered in this study.

Introduction

This study was undertaken to determine if electronic mosquito repellers afford appreciable protection to the user. These devices produce sound waves which, according to the manufacturer's label, greatly repel most females within a range of 1-2.4 m. Several workers have tested these devices either in the laboratory or in the field against the following mosquitoes: *Aedes sollicitans* (Walker), *Ae. taeniorhynchus* (Wiedemann), *Ae. sierrensis* Ludlow, *Ae. aegypti* (Linnaeus), *Ae. communis* (DeGeer), other unstated *Aedes* species, *Anopheles freeborni* Aitken, *Culex pipiens* Linnaeus, *C. salinarius* Coquillett, *Coquillettidia* and *Culiseta* sp. (Gorham, 1974; Kutz, 1974; Rasnitsyn *et al.*, 1974; Garcia *et al.*, 1976; Schreck *et al.*, 1977; Singleton, 1977). No significant repellent action has been shown in any of these studies. In June 1976, two types of locally-available mosquito repellers were tested against several additional mosquito species common to the Guelph, Ontario area.

Materials and Methods

The two types of repellers tested were: 1) Buzz-Off Electronic Mosquito Repeller distributed by Crisis Control Corp. Ltd., P.O. Box 479 Markham, Ontario and 2) ME Electronic Mosquito Repeller, manufacturer or distributor not given. The point of purchase was 'The Port Hole', Westmount Plaza, Waterloo, Ontario.

Two tests with each repeller were done in a wooded area in Guelph, Ontario between 14 15 and 16 45 hr. on 18 and 21 June, 1976. During the observation periods of the tests, personnel were seated at assigned stations at least 30 m apart. Throughout the tests all personnel wore tan overalls, headnets and used no chemical repellents.

Landing collections were used to evaluate the effectiveness of the repellers. A standard procedure was followed during each observation period. All personnel left from a central site and went to their assigned station where they took a cross-legged sitting position. At the end of a two-minute period each person bared the left arm to just above the elbow. All mosquitoes landing on the arm and hand during the succeeding four-minute period were collected by a tube aspirator. At the end of the four-minute period the mosquitoes were placed in appropriately

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labelled containers and the numbers of mosquitoes missed in aspiration attempts recorded. All personnel then returned to the central site, made arrangements for the next collection and simultaneously returned to their assigned stations where the procedure was repeated. The repellers were turned on when the personnel left the central site and were kept on during the entire observation period. The repellers were hung around the neck with a strap so they were within six inches of the left forearm. The collection periods were timed by one person who announced when to begin and stop each collection.

The procedure used for testing the repellers with four subjects is shown in Table I. When two people did a test, the procedure for 'subjects two and three' were followed. Landing collections without repellers were made before and after the series of collections with repellers to determine if any changes in mosquito activity had occurred during the test.

TABLE I. The procedure used to evaluate electronic mosquito repellers.

Landing Collection (4 minute period)	Subject 1/	2/	3/	4/
a.	No repeller	No repeller	No repeller	No repeller
b.	Repeller	Repeller	No repeller	No repeller
c.	No repeller	No repeller	Repeller	Repeller
d.	Repeller	Repeller	No repeller	No repeller
e.	No repeller	No repeller	Repeller	Repeller
f.	No repeller	No repeller	No repeller	No repeller

Results and Discussion

In these tests, *Aedes stimulans, Ae. euedes* and *Ae. canadensis* were the most common species caught. Small numbers of *Ae. fitchii, Ae. excrucians* and *Ae. abserratus* were also present. In the Guelph area, these species are the major pest mosquitoes during May and June. The numbers of mosquitoes landing before and after the tests were not significantly different. During the tests the mean number of mosquitoes landing on all subjects with either repeller was not significantly different from the mean number landing without repellers (Table II), Furthermore, the mean number of mosquitoes landing on each person with a repeller was usually comparable to, or more than, the number landing on that person without a repeller even though considerable variation occurred between individuals.

TABLE II. Mean number of female mosquitoes landing on forearm with and without an electronic mosquito repeller.

Sub-ject	Buzz-Off Repeller # Landing With Rep.	# Observ.	# Landing Without Rep.	# Observ.	ME Repeller # Landing With Rep.	# Observ.	# Landing Without Rep.	# Observ.
BVH	16.75	4	19.75	4	11.25	4	10.5	4
RJS	11.0	2	8.5	2	4.5	2	6	2
WJK	8.5	2	13.5	2	5.0	2	4.5	2
NSW	24	2	14.5	2	9.5	2	8.5	2
BWM	24	2	13.5	2	12.0	2	10.5	2
	$\bar{x}$ 16.8	ξ 12	$\bar{x}$ 14.9	ξ 12	$\bar{x}$ 8.9	ξ 12	$\bar{x}$ 8.4	ξ 12

Neither the Buzz-Off nor the ME repeller afforded protection from the mosquitoes encountered by the five people involved in this study. These results corroborate those of several workers in other areas dealing with different species and in many cases using different types of repellers.

Acknowledgments

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THE GREAT KISSING BUG "EPIDEMIC"

At the 36th annual meeting of the Society (1899) and as subsequently reported in the 30th Annual Report of the Society, the "kissing bug" received much attention. Dr. C. J. S. Bethune, a Past President of the Society, presented a brief paper on it; the Society president, Henry H. Lyman referred to it at some length in his presidential address: and Rev. T. W. Fyles, incoming president, in his Notes on the Season of 1899, devoted two paragraphs to the insect.

Why all this emphasis on the kissing bug? Apparently, it all started in Washington, D.C. or was it Baltimore? On a Wednesday morning some reporters, while having a beer, were complaining about the lack of news and the almost unbearable muggy heat. One of them knew an entomologist in the Division of Entomology and an appeal went out to him for help. He joined them. After another round or two or three, an idea came to the entomologist. It seems that that very morning the mail had contained, along with other insects for identification, a specimen that he called "a kissing bug". This was all that was needed. A synthetic epidemic, involving many of the southern and central states, and eventually all of U.S. and much of Canada, began at once and spread with the rapidity of a juicy bit of gossip. Newspapers all over reproduced the news item and the public never questioned its authenticity. Wild stories spread about the bug; deaths were attributed to it; and many people were much alarmed.

On the first of September (1899), the following paragraph appeared in one of the Toronto papers and was quickly copied by most newspapers throughout the Province and elsewhere:

> "Kissing Bug's Bite Fatal — Uxbridge, Aug. 31 — Roy Stevenson, the four-year old son of Mr. George Stevenson, carpenter of Udora, was bitten on the calf of the leg by a kissing bug on Thursday last. Dr. McDermott was called but despite his best efforts, blood-poisoning set in and the child died last night."

Here was a definite case, with locality, names and date. Dr. Bethune requested that the specimen, if still available, be sent to him for identification. The doctor who attended the case forwarded the insect stating that "the case is clear against the insect, whatever it is, as its bite was the direct cause of the boy's death." He further stated, "we have not pronounced it the Kissing Bug and we do not know what it is. It bit the boy behind and below the left knee and the leg became very painful and swollen. He died from profound blood-poisoning on the fifth day. He was in good health previously."

Although the bug was badly crushed, Dr. Bethune with the assistance of Alston Moffat, Librarian and Curator of the Society, and reference to the Society's collections, the specimen was identified as "*Sinea diadema* Fab., which is the same as *Sinea multispinosa* Am. and Serv. and *Reduvius raptatorius* Say. It is a true bug of the order Hemiptera and family Reduviidae." The reduviids are usually classed as beneficial organisms as most of the known species prey on other insects. For man the "bite" is very painful and lingering. Alston Moffat, a collector of many years, states "it was the severest sting I ever experienced; the pain from a bite on one finger extended up my arm, which became swollen to the elbow, and continued to be painful all night, while the wound on the finger did not disappear for several weeks."

Somewhat similar cases have been reported. A sting by a wasp on the lip of a stout man in England; he died the same night from blood-poisoning and perhaps from other complications. At Johns Hopkins University hospital, a boy was brought in suffering from the effects of a mosquito bite; every effort was made for his relief but without success and he died within a day or so. Other cases could be cited but "all show that a patient's condition must often have much to do with the effects of bites and stings of insects."

Much discussion followed Dr. Bethune's presentation. It was finally agreed that either the boy's skin at the puncture-site was contaminated with bacteria or viruses or the mouth parts of the bug's piercing and sucking beak were contaminated with the decomposed juices of previous insect victims. In either event, blood-poisoning developed.

Meanwhile, in other parts of Canada and the United States, suspect specimens of many insects — the larger, the better — were being brought into newspaper offices and displayed there for the public to see. No one seemed to know what a kissing bug looked like — favourites were cicadas (dog-day harvest flies), male dobson flies (with huge mandibles), horntails, and even one of the hawk moths (the Cerisy's Sphinx)and others. In Rev. Fyles' report, mention is made of his coming upon a group of excited people in Quebec City. "I looked over the shoulders of the crowd and saw a man exhibiting a very fine specimen of the moth (mentioned above) as the veritable bug." "And this", said he, uncoiling its proboscis with a toothpick, "is the instrument that it kisses with." "A shudder passed through his auditors as they thought of the deadly effects of a thrust from this long osculatory weapon into the soft cheek of a sleeping beauty."

In time, the excitement died down — a Washington reporter admitted his involvement in the plan and "the cat was out of the bag." Strangely enough, the Baltimore newspapers completely ignored the incident — makes one wonder if they weren't quite happy to let Washington take all of the blame.

This reminds one of our recent "epidemic" of swine flu. Was another reporter trying to stir up a little excitement?

Editor

THE EFFECTIVENESS AND PERSISTENCE OF SOME INSECTICIDES USED FOR CONTROL OF THE VARIEGATED CUTWORM ATTACKING TOMATOES IN SOUTHWESTERN ONTARIO

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Abstract

In laboratory tests, 3 pyrethroid insecticides, permethrin, Shell WL 41706 [(±)-alpha-cyano-3-phenoxybenzyl 2,2,3,3-tetramethylcyclopropane carboxylate], and Shell WL 43775 [(±)-alpha-cyano-3-phenoxybenzyl (±)-2-(4-chlorophenyl)-3-methylbutyrate] were more toxic by direct contact to 3rd-instar variegated cutworm, *Peridroma saucia* (Hübner) than methomyl and chlorpyrifos. Carbofuran, endosulfan, carbaryl, and azinphosmethyl were ca. 1/10 as toxic. Third-instar larvae were 2.9X and 5th-instar larvae 3.7X more tolerant to permethrin than 1st-instar larvae. In other laboratory tests the 3 pyrethroid insecticides were effective against 3rd- to 4th-instar larvae at rates as low as 62.5 g AI/ha when applied to the surface of moist sand. Methomyl, chlorpyrifos, and carbaryl were less effective. All soil insecticide treatments were less effective against 6th- to 7th-instar larvae. In microplot field tests, permethrin, WL 41706 and WL 43775 applied at 140 g AI/ha caused 98, 73, and 63% mortality, respectively, of 3rd- to 4th-instar larvae infesting tomatoes. Chlorpyrifos, carbaryl, methomyl, and carbofuran were not effective even though applied at higher rates of application. Thirty days after treatment with 140 g AI/ha of permethrin, WL 41706, and WL 43775, residues detected on tomatoes were 0.12, 0.03, and <0.01 ppm respectively.

* * * * * * *

Introduction

The variegated cutworm, *Peridroma saucia* (Hübner) damages agricultural crops in many areas of the world. Rings *et al.* (1976) published a comprehensive review of the world literature. In southwestern Ontario, the adults appear to be migratory and are present throughout the growing season (McClanahan and Elliott 1976). The larvae periodically damage vegetable and field crops in the early part of the growing season but usually are a greater problem in mid-summer, especially in fields of processing tomatoes. Some organochlorine insecticides were effective against the variegated cutworm (Harris *et al.* 1961) but they can no longer be used in Ontario. Several organophosphorus and carbamate insecticides are toxic to this species (Harris and Svec 1968a). Of these, only carbaryl and methomyl are recommended (Anon. 1978). Neither insecticide provides satisfactory control. The objective of this study was to evaluate the effectiveness and persistence of some other insecticides for variegated cutworm control.

Materials and Methods

Laboratory Studies

Two hundred late-instar larvae were collected from a field of tomatoes near Simcoe, Ontario. The larvae were placed, 30/container, in plastic dishpans 30 cm long X 15 cm wide X 9 cm deep, containing 4 cm sterilized sand. One-half of the

1) Contribution No. 716.

sand was moistened with distilled water for pupation, while the other half was left dry for feeding larvae. Chinese cabbage leaves, dipped in 0.001% benomyl to suppress microsporidial infection, were provided as food. Pupae were screened out of the sand and placed in plastic containers (20/container) half-filled with moist sand covered with a layer of paper towelling. Fluted paper towelling was added above the pupae for protection of newly emerged moths. Glass panelled cages 41 cm high X 20 cm square were used for emergence (2 containers of pupae/cage). Fluted paper towel was fastened to the corner of each cage to provide cover and support for the moths, and water and 10% honey solution were provided. After emergence and mating the moths were placed, for oviposition, in 4.5 liter jars. Moist filter paper was placed in the bottom of each jar and food was provided as above. Fluted paper towelling served as a substrate for oviposition. Eggs were removed daily and incubated in 15 cm petri dishes lined with moist filter paper. Larvae were reared in 4.5 liter jars containing a 4 cm layer of sterilized sand to absorb moisture and debris. Bundles of fresh clover were used as food for 1st- to 3rd-instar larvae and Chinese cabbage leaves for later larval stages. All stages were reared at 26°±1°C, 65±5% RH, and 16 h photoperiod.

Insecticides tested were: azinphosmethyl, carbaryl, carbofuran, chlorpyrifos, endosulfan, methomyl, permethrin, Shell WL 41706 [(±)-alpha-cyano-3-phenoxybenzyl 2,2,3,3-tetramethylcyclopropanecarboxylate], and Shell WL 43775 [(±)-alpha-cyano-3-phenoxybenzyl (±)-2-(4-chlorophenyl-3-methylbutyrate].

In initial screening tests to determine direct contact toxicity, technical grade insecticides were dissolved in 19:1 acetone:olive oil (v/v). Solvent controls and insecticide solutions (0.001, 0.01, 0.1, and 1.0%) were applied using a Potter spray tower (Harris *et al.* 1962). Duplicates of 10, 3rd-instar larvae were tested at each concentration. Treated insects were placed in containers half-filled with moist sand and food was provided. The containers were covered with glass lids and held at 27°±1°C and 65±5% RH under continuous light for 48 h and then mortality counts were made. Corrections for natural mortality (never >10%) were made using Abbott's formula (Abbott 1925) and results obtained at the same dosage were averaged. In subsequent tests, done in a similar fashion, with permethrin to determine the effect of stage of larval development on susceptibility to contact applications of insecticides, dosage-mortality curves were determined for 1st-, 3rd-, and 5th-instar larvae. Five to 8 insecticide concentrations causing ca. 15-90% mortality were used. Duplicate groups of 10 larvae were tested at each concentration. Each assay was run 3 times. Mortality values obtained at each concentration were pooled and analyzed using probit analysis (Finney 1952).

The effectiveness of soil surface applications of formulated insecticides was tested in metal trays 43 cm square X 10 cm deep containing a 5 cm layer of moist (5% water) Plainfield sand. Two replicates of 10 larvae, either 3rd- to 4th- or 6th- to 7th-instar, were placed on the soil around leaves of Chinese cabbage and covered with plastic cages (Harris *et al.* 1972). The cutworms were allowed to take cover and after one h the cages were removed and insecticides sprayed on the surface of the soil using 450 liters of water/ha. The cages were replaced over the areas containing the cutworms. Tests were done at 27°±1°C, 65±5% RH, and 16 h photoperiod. Untreated controls were included with all tests. Mortality counts were made after 48 h and corrected for natural mortality as above. Results of duplicate assays at each dosage were averaged.

Field Studies

Tests were conducted in microplots (2.2 m long X 0.9 m wide) containing a sandy clay loam, in a manner similar to that used on the darksided cutworm,

Euxoa messoria (Harris) (Harris *et al.* 1971). Tomatoes, variety 'Early Red Chief', were transplanted May 28, 1 row/plot, 5 plants/row. On July 19, as the first tomatoes were beginning to ripen, two plants in each plot were infested with 20 3rd- to 4th-instar laboratory-reared variegated cutworms. Insecticides were applied in the late afternoon the same day, after the cutworms had become established around the plants. Insecticides were applied in 450 liters of water/ha using an Oxford Precision Sprayer. All treatments and untreated controls were in duplicate. Cutworm mortality was assessed 24, 48, 72 and 96 h after treatment, and results obtained in duplicate treatments were averaged. Soil moisture was ca. 50% of field moisture capacity and maximum temperature was 30°C during the experimental period.

Residue Studies

Ripe tomatoes were harvested on August 18 from plots treated with 140 g AI/ha of permethrin, WL 41706, and WL 43775, and from the control plots. Crop samples from duplicate treatments were combined and a representative portion selected for extraction. The pyrethroid insecticides were extracted using a standard procedure (Chapman and Harris, in press) involving maceration with acetone, filtration, and extraction of the resulting acetone-water mixture with hexane. The extracts were sufficiently clean to permit analysis without column cleanup and were analyzed by gas-liquid chromatography (Chapman and Simmons 1977).

Results and Discussion

Of the 2 insecticides currently recommended for variegated cutworm control in Ontario (Anon. 1978) methomyl was ca. 10X more toxic to 3rd-instar larvae by direct contact than carbaryl (Table I). Chlorpyrifos was similar in toxicity to methomyl, while the 3 pyrethroids, namely permethrin, WL 41706, and WL 43775 were more toxic. Carbofuran, endosulfan, and azinphosmethyl are recommended in Ontario for control of other important insect pests of tomatoes, e.g. the Colorado potato beetle, *Leptinotarsa decemlineata* (Say) and the potato flea beetle, *Epitrix cucumeris* (Harris) (Anon. 1978). It was therefore of interest to know if these insecticides would be effective also against the variegated cutworm. All 3 insecticides were similar in toxicity to carbaryl, i.e. ca 1/10 as toxic as chlorpyrifos, methomyl, and the pyrethroids.

TABLE I. Direct contact toxicity, in laboratory tests, of 9 insecticides to 3rd-instar variegated cutworm.

Insecticide	Avg. corr. % mortality at % insecticide solution indicated			
	0.001	0.01	0.1	1.0
Permethrin	5	100	100	100
WL 41706	15	95	100	100
WL 43775	0	90	100	100
Chlorpyrifos	0	72	100	100
Methomyl	0	70	100	100
Carbofuran	0	15	95	100
Endosulfan	0	0	90	100
Carbaryl	0	0	85	100
Azinphosmethyl	0	0	80	100

Lepidopterous larvae are generally more tolerant to insecticides as development progresses, and require larger dosages of insecticides to achieve the same degree of mortality (Kerr and Brazzel 1960, Harris and Svec 1968b; 1969, Harris

and Gore 1971, Harris *et al.* 1975). Often, infestations of variegated cutworm in tomatoes are not detected until larvae are in later stages of development. Thus, it was important to determine if variegated cutworm susceptibility to insecticides followed the same pattern as in other Lepidoptera, and also to determine if this applied to pyrethroids as it did to other groups of insecticides. First-instar variegated cutworms were very susceptible to permethrin (Table II). However, later stages became progressively more tolerant with 3rd- and 5th-instar larvae being 2.9X and 3.7X more tolerant, respectively.

TABLE II. Susceptibility, in laboratory tests, of variegated cutworms to permethrin relative to stage of larval development.

Larval instar	Equation of regression line	LD_{50} (% solution)	95% CL Lower	95% CL Upper	Relative tolerance (x/1st-instar)
1	$Y = 23.9 + 5.75\ x$	0.00052	0.00050,	0.00055	X 1.0
3	$Y = 22.9 + 6.34\ x$	.0015	.0014,	.0016	X 2.9
5	$Y = 17.2 + 4.47\ x$	.0019	.0018,	.0021	X 3.7

The 3 pyrethroids were effective when formulated insecticides were tested in the laboratory by applying them to the surface of moist sand and a food source (Chinese cabbage) simulating foliage, causing 100% mortality of 3rd- to 4th-instar larvae at 62.5 g AI/ha in 48 h (Table III). Methomyl caused 100% mortality at 125 g AI/ha while chlorpyrifos was less effective. As in the contact toxicity tests (Table I) carbaryl was markedly less effective than the other insecticides (Table III). The importance of stage of larval development on susceptibility to insecticides was apparent; all the insecticides were less effective against 6th- to 7th-instar larvae as compared to 3rd- to 4th-instar larvae (Table III).

TABLE III. Toxicity, in laboratory tests, of 6 formulated insecticides applied to the surface of moist (5% water) Plainfield sand[1] to 3rd-to 4th- and 6th- to 7th-instar variegated cutworms.

Insecticide	48 h. avg. corr. % mortality at indicated g AI/ha								
	15.8	31.3	62.5	125	250	500	1000	1500	2000
	3rd- to 4th-instar larvae								
Permethrin[2]	0	95	100	100	100	100			
WL 43775[2]	0	90	100	100	100	100			
WL 41706[2]	0	75	100	100	100	100			
Methomyl[3]	0	0	60	100	100	100			
Chlorpyrifos[2]	0	0	30	90	100	100			
Carbaryl[4]	0	0	0	0	0	100			
	6th- to 7th-instar larvae								
Permethrin[2]			95	100	100	100	100	100	100
WL 43775[2]			90	100	100	100	100	100	100
WL 41706[2]			40	100	100	100	100	100	100
Chlorpyrifos[2]			0	0	0	0	80	95	100
Methomyl[3]			0	0	0	10	30	85	100
Carbaryl[4]			0	0	0	0	10	90	85

[1] Chinese cabbage leaves placed on surface of soil prior to treatment to simulate plant foliage and serve as a source of food.
[2] Emulsifiable concentrate; [3] Soluble concentrate; [4] Wettable powder.

In the microplot field tests, the foliage of the tomato plants was dense and some fruit were close to, or resting on, the ground. When the plants were infested with 3rd- to 4th-instar cutworms, they tended to become established adjacent to or beneath fruit close to, or on the ground. Most cutworm feeding occurred on the fruit rather than the foliage making it difficult to apply the insecticide in a manner insuring penetration of the spray to an area where the cutworms would come in contact with it. Once established the cutworms did not move about much. For these reasons, mortality occurred slowly necessitating mortality counts after 96 h. Permethrin was the most effective insecticide causing 98% mortality at 140 g AI/ha (Table IV). WL 41706 and WL 43775 caused 73 and 63% mortality, respectively, at the same application rate. None of the other insecticides, including those recommended for control of other species of insects attacking tomatoes, was effective at the application rates tested.

TABLE IV. Effectiveness, in microplot field tests, of 7 insecticides against 3rd- to 4th-instar variegated cutworm attacking tomatoes.

Insecticide	g AI/ha	96 h avg. % mortality
Permethrin[1]	140	98
	70	53
WL 41706[1]	140	73
	70	50
WL 43775[1]	140	63
	70	25
Chlorpyrifos[1]	280	33
Carbaryl[2]	2240	28
Methomyl[3]	280	10
Carbofuran[4]	560	5
Control	—	0

[1] Emulsifiable concentrate; [2] Wettable powder; [3] Soluble concentrate; [4] Flowable.

Residues of permethrin, WL 41706, and WL 43775 detected on the fruit 30 days after treatment with 140 g AI/ha were 0.12, 0.03, and < 0.01 ppm, respectively. The greater effectiveness of permethrin, as compared to the other pyrethroid insecticides may have been due, in part, to its longer persistence on the tomatoes.

In other studies on control of the darksided cutworm, the white cutworm, *Euxoa scandens* (Riley), and the black cutworm, *Agrotis ipsilon* (Hufnagel) some pyrethroid insecticides were effective at application rates as low as 70 g AI/ha (Harris *et al,* 1978). Results of the laboratory tests reported here indicate that the variegated cutworm is as susceptible to these pyrethroid insecticides as the other 3 species. The lower effectiveness of the pyrethroid insecticides in the microplot field tests against the variegated cutworm attacking tomatoes is due undoubtedly to two factors: the lack of mobility of the larva once it becomes established near or under the fruit or under the heavy canopy; and the difficulty in obtaining adequate penetration with the insecticide spray. The pyrethroid insecticides show promise for control of variegated cutworm attacking tomatoes. However, to achieve adequate control: 1) the insecticides should be applied when larvae are small; 2) application rates of 140-210 g AI/ha would likely be necessary; and 3) applications should be made in a manner resulting in the most effective coverage of the foliage possible.

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TOXICITY OF SOME INSECTICIDES TO EGGS OF THE ORIENTAL FRUIT MOTH[1] AND CODLING MOTH[2,3]

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Abstract

In the laboratory, permethrin and azinphosmethyl were more toxic than phosmet to eggs of the Oriental fruit moth, (OFM) *Grapholitha molesta* (Busck). Newly laid codling moth (CM) *Lasperesia pomonella* (L.), eggs were more susceptible to permethrin than OFM eggs. Permethrin was more toxic to newly laid CM eggs than to blackhead eggs. For OFM, differences between egg stages were not significant ($P > .05$). Blackhead eggs of OFM were more susceptible than newly laid to azinphosmethyl. For phosmet, differences were not significant. In the field, permethrin reduced hatch of CM eggs for 17-21 days. All treatments reduced OFM egg hatch for at least 14 days.

Introduction

In the pest management programs developed for Oriental fruit moth (OFM) *Grapholitha molesta* (Busck) control on peaches and codling moth (CM) *Lasperesia pomonella* (L.) control on apples, sex pheromone traps are normally utilized to time sprays for periods of insect abundance. Currently, spray applications are timed to coincide with the hatching of first instar larvae, a 3-7 day period. However, if the insecticides were also effective against the egg stage, timing of the spray to achieve maximum control would be less critical. This paper reports the toxicity of azinphosmethyl, phosmet and permethrin to eggs of the OFM and CM in the laboratory and in the field.

Methods

Eggs for laboratory tests were obtained from colonies of OFM and CM maintained on whole green apples at 24°C, 70% RH and a 16 h photoperiod. Moths deposited eggs on waxed paper oviposition cages (George and Howard 1965), which were cut into strips each with ca. 50-100 eggs. Tests were conducted on newly laid eggs 0-24 h old and on blackhead eggs just prior to egg hatch. In the laboratory, OFM and CM eggs reached the blackhead stage in 3 and 5 days after deposition respectively. Newly laid eggs were treated within 24 h whereas blackhead stage eggs were often held up to 7 days in a refrigerator to accumulate sufficient numbers for testing.

Waxed paper strips with eggs were dipped for 30 sec in agitated aqueous suspensions of the various insecticides. Suspensions were prepared fresh daily in distilled water using commercial wettable powder formulations. Five concentrations with 10 replications at each concentration were used in all tests. Azinphosmethyl and phosmet were tested against CM eggs only at 500 ppm. After treatment, the

1. Lepidoptera : Tortricidae
2. Lepidoptera - Olethreutidae
3. Rec'd for publication 78 05 23.

waxed paper strips were suspended on wire screens over water saturated cotton pads and held in a room at 20°C, 65% RH, and 16 h photoperiod until egg hatch was complete. Egg hatch was determined under a binocular microscope. The mortality data were transformed to probits and analysed. LC_{50} data were compared using a T-test adapted from Finney (1971).

In the field, ovicidal effects of the insecticides were assessed by allowing caged OFM to oviposit on peach foliage prior to and after application of the spray. Treatments were applied to single tree plots, cv. Loring, replicated 4 times using a Spray Miser gun and jeep-mounted sprayer at 2000 kPa. Sprays were applied to runoff (ca. 9 liters/tree). Application rates for the various pesticides were those used in pest management programs and those suggested for OFM control in spray calendar recommendations.

To determine the effects of insecticides on OFM eggs present on foliage, 10 1-day old moths were placed in 15 cm long x 15 cm diam screen sleeve cages, two cages per tree, three days prior to spray. Water was supplied from a cotton pad or wick. Moths were allowed to oviposit on foliage for 3 days, after which cages were removed, and 100 eggs/tree (ca. 50/cage) marked for assessment. Trees were then sprayed as described. Seven days later and at prescribed intervals thereafter additional OFM moths were caged for 3 days on the same trees. Percent mortality of these marked eggs was determined, 7 days after moths were removed, in a laboratory using a binocular microscope. At 14, 21 and 28-day intervals after spraying, percent mortalities on the upper vs lower leaf surfaces were also compared.

The ovicidal properties of permethrin against CM eggs were assessed on McIntosh trees sprayed with 189 g a.i./ha applied by a Swanson concentrate sprayer at 1032.5 liters/ha. Moths (4-6 pairs) were placed in sleeve cages similar to those used for OFM tests, and allowed to oviposit on sprayed foliage 5-8 days. Percent mortalities of eggs were determined, in the field, 7-10 days later.

Results and Discussion

Permethrin and azinphosmethyl were more toxic than phosmet to both newly laid and blackhead eggs of OFM (Table I). Newly laid CM eggs were more susceptible to permethrin than newly laid OFM eggs. Permethrin was more toxic to newly laid CM eggs than to blackhead eggs. For OFM, differences were not significant ($P > .05$). Blackhead eggs of OFM were more susceptible than newly laid eggs to azinphosmethyl. The differences in mortalities between newly laid and blackhead eggs treated with phosmet were not significant ($P > .05$). All eggs, regardless of the stage treated had highly developed embryos at time of death. A few eggs treated with permethrin contained dead larvae which had cut a hole in the eggshell but failed to emerge. Blackhead or late stage eggs have often been shown to be more susceptible than earlier stages to organophosphorous insecticides (Smith and Salkeld, 1966). This has usually been correlated with increased amounts of acetylcholine in late stage eggs. Pyrethroids have also been shown to be more toxic to late stage eggs than to newly laid eggs. Salkeld and Potter, (1953) showed, for allethrin, that mortality of eggs of 2 lepidopterous species was higher in later stages than in the early stages. They also observed that at low concentrations of allethrin many larvae attempted to emerge by eating holes in the eggshells, whereas at higher concentrations shells were unperforated but contained fully developed larvae. At high concentrations of allethrin they observed that some eggs contained partially developed embryos or that there was no visible development.

TABLE I. Toxicity of insecticides to eggs of the Oriental fruit moth and codling moth in the laboratory.

Insecticide	Egg Stage	Equation of Regression Line	LC_{50} (% Solution)[a]	95% CL Lower	95% CL Upper
Oriental fruit moth					
permethrin	Newly Laid	$y = 2.20 + 2.21x$	.0018	.0012	.0025
	Blackhead	$y = 2.25 + 1.91x$	.0032	.0021	.0048
azinphosmethyl	Newly Laid	$y = 3.41 + 0.91x$	.0057	.0001	.0145
	Blackhead	$y = 4.25 + 0.65x$	.0014	.0003	.0028
phosmet	Newly Laid	$y = 2.91 + 0.79x$	.0446	.0288	.0804
	Blackhead	$y = 2.34 + 1.01x$	.0311	.0234	.0412
Codling moth					
permethrin	Newly Laid	$y = 3.88 + 1.29x$	.0007	.0005	.0009
	Blackhead	$y = 3.34 + 1.18x$	.0025	.0019	.0034

[a] Expressed as % a.i. in suspension, using commercial WP formulations.

TABLE II. Toxicity of permethrin residues to codling moth eggs in the field.

Date of Application	Days After Spraying when moths caged	Percent Egg Mortality Permethrin[a]	Unsprayed
17.6.1976	5	68.7[b]	16.1[c]
	11	56.8	
	17	29.2	
21.7.1976	13	50.7	
	19	16.1	
15.6.1977	7	19.5	33.3
	14	50.0	9.1
	21	31.3	6.3
	28	0	

[a] Applied at .24 kg/ha a.i. in 1032 l/ha
[b] 25 - 213 eggs/test
[c] Average from 11 tests

TABLE III. Effects of insecticide residues on hatch of Oriental fruit moth eggs in the field.

Treatment	kg a.i./ha	Percent Mortality Days After Spraying — When Moths Caged[a] 0	7	14	21	28
permethrin	.12	61.1 ab	23.3 e	21.2 j	63.9 n	32.2 pg
azinphosmethyl	.56	52.6 bc	55.2 f	42.7 kl	35.9 m	21.3 op
azinphosmethyl	.98	67.6 b	75.0 gh	32.9 jkl	30.4 m	35.8 pg
phosmet	1.12	41.0 bc	65.8 fg	30.1 jk	29.9 m	34.9 pg
phosmet	2.10	53.0 bc	76.5 h	46.8 l	30.1 m	43.4 g
Unsprayed	—	6.1 a	3.1 d	1.7 i	22.4 m	7.0 o

[a] Numbers followed by same letter not significantly different, Duncan's Multiple Range Test at P = .05 level. Comparisons are for each day.

TABLE IV. Relative toxicity of insecticide residues on upper and lower peach leaf surfaces to Oriental fruit moth eggs.

Days After Spraying	permethrin .12 kg/ha	phosmet 1.12 kg/ha	phosmet 2.10 kg/ha	azinphosmethyl .56 kg/ha	azinphosmethyl .98 kg/ha	unsprayed
			Mortality (%)[a]			
14 Days						
Upper Surface	18.2 a	17.5 d	32.0 i	30.0 n	21.2 r	2.63 v
Lower Surface	25.4 a	51.5 e	66.9 j	55.1 n	47.4 s	1.52 v
21 Days						
Upper Surface	65.6 b	29.6 f	25.8 k	34.4 o	29.4 t	24.1 w
Lower Surface	62.5 b	33.2 f	37.3 k	37.4 o	31.6 t	20.0 w
28 Days						
Upper Surface	39.5 c	18.6 g	25.3 l	10.9 p	38.7 u	9.5 x
Lower Surface	23.3 c	47.9 h	62.3 m	32.1 q	42.5 u	5.5 x

[a] Numbers followed by same letter not significantly different, T test (P = .05)

Few such eggs were observed in our experiments. However, Salkeld and Potter also showed that newly laid eggs of the cotton stainer *Dysdercus fasciatus* Sign. (Hemiptera: Pyrrhocoridae) were more susceptible than older and more highly developed eggs. They suggested that the reduced toxicity of allethrin to older eggs was related to the mode of larval eclosion.

Application of azinphosmethyl and phosmet against codling moth eggs in the laboratory at 500 ppm resulted in the following mortalities:

Treatment	% Mortality	
	Newly Laid	Blackhead
Azinphosmethyl	89.3	82.4
Phosmet	68.5	66.9
Permethrin	100[a]	100[a]
Check	22.2	20.3

[a] Calculated from probit data in Table I.

Mortality of blackhead stage codling moth eggs was similar to that of newly laid for both organophosphorous insecticides. Hagley, (1975) made a similar observation but obtained higher mortalities of eggs at similar rates in some of his tests. Neither azinphosmethyl nor phosmet was as toxic as permethrin to codling moth eggs. Results obtained in the laboratory suggested that permethrin and to a lesser extent azinphosmethyl and phosmet should cause substantial egg mortality in the field.

In the field, permethrin reduced hatch of CM eggs for 17-21 days (Table II). All treatments significantly reduced OFM egg hatch for at least 14 days after sprays had been applied (Table III). All eggs were not killed when they were directly sprayed with any of the insecticides (0 day). Less than 5% of the marked eggs were lost. Moths caged on treated foliage were not killed in large numbers by the residual deposits. Effects on total egg production were not measured, but 100 eggs/tree were normally readily obtained.

In the 21-day sample, only permethrin caused significant mortality of eggs (Table III). Mortality of eggs on unsprayed foliage was unusually high (22.4%). Temperatures during the developmental period of these eggs were 27-31°C, and 21-24°C during the rest of the experiment. High temperatures may explain the mortality on unsprayed foliage, but do not explain the lower mortality on foliage treated with organophosphorous insecticides, nor the higher mortality on foliage sprayed with permethrin. Harris and Kinoshita (1977) have shown that the synthetic pyrethroids are more toxic at lower temperatures than at higher. Salkeld and Potter, (1953) also reported that allethrin was more toxic to insect eggs at lower temperatures than at higher (14° vs 24°C).

Egg mortalities on lower leaf surfaces were significantly higher than on upper surfaces in 6 of 15 cases (Table IV). Whether pesticide residues were higher on the lower shaded leaf surface than on the upper, more exposed surface was not determined.

Permethrin, azinphosmethyl and phosmet are considerably ovicidal to eggs of OFM and CM. These toxic effects probably supplement those exerted on first instar larvae. However, it is unlikely that the ovicidal properties of these materials

will provide adequate control of either OFM or CM in the field, and no change in timing of spray applications is warranted.

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TAXONOMY

A REVISION OF THE GENUS *ELAMPUS* SPINOLA *(NOTOZUS* AUCTT.) (HYMENOPTERA: CHRYSIDIDAE) IN AMERICA NORTH OF MEXICO[1]

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Abstract

The genus *Elampus* Spinola (Hymenoptera: Chrysididae) in America north of Mexico is revised. Seven species and one subspecies are included. These are *E. hyalinus* (Aaron), *E. rotundus* Huber sp. nov., *E. nitidus nitidus* (Aaron), *E. nitidus californicus* Huber subsp. nov., *E. viridicyaneus* Norton, *E. marginatus* (Patton), *E. aaroni* Bodenstein, and *E. versicolor* Norton. *E. versicolor* is considered as a species of uncertain status. *E. connexus* (Viereck) and *E. mexicanus Mocsáry* are synonomized under *E. viridicyaneus* and *E. nitidus nitidus* respectively. All available types were examined. A neotype is designated for *E. marginatus*. The holotypes of *E. viridicyaneus* and *E. versicolor* were examined but, subsequently, were lost in the mail. A few possible, additional species were segregated but are not described or named herein.

A discussion of diagnostic characters for North American species and a short historical review is presented. Discriminant analysis of eighteen measurements and ratios for the first six of the above mentioned taxa was undertaken and gave quantitative characters useful for species distinction. Information on the biology of *Elampus* is summarized on a world basis. Intraspecific variation is discussed in detail under each species.

Introduction

Historical Review

The genus *Elampus* consists of about 40 species (Bischoff, 1913) distributed throughout the Western Hemisphere and the Palaearctic and Ethiopian regions. It has been studied relatively little and most studies on *Elampus* form part of more inclusive studies dealing with the whole family for various geographical areas. The only paper dealing exclusively with *Elampus* (as *Notozus)* was by Móczár (1964). Most of the literature on the family and, consequently, the genus deals with the European fauna. Major, relatively recent, works for Europe are by Trautmann (1927) and Linsenmaier (1951). Smaller geographical areas were treated by Trautmann (1930) (North and Central Europe); Berland and Bernard (1938) (France); Atanassov (1940) (Bulgaria); Benno (1950) (Holland); Balthasar (1954) (Czechoslovakia); Haupt (1956) (Central Europe); Noskiewicz and Pulawski (1958) (Poland) and Móczár (1964, 1967) (Hungary). Relatively few papers containing information on *Elampus* were published for areas other than Europe. Important ones are: Tosawa (1931) (Japan); Edney (1940) (Southern Africa); Balthasar (1951) (Palestine and surrounding areas); Tsuneki (1954) (Manchuria); Linsenmaier (1959, 1968) (Palaearctic region) and Semenov-Tian-

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Shanskij (1967) (USSR). Zimmermann (1961) described a new species of *Notozus* from Madagascar. Ducke (1913) catalogued the Brazilian Chrysididae. A world revision and two catalogues of the family were provided by Mocsáry (1889), Dalla Torre (1892), and Bischoff (1913), respectively.

The literature on *Elampus* for North America consists essentially of a number of descriptions of new species of *Elampus (Notozus)* and a revision of the family Chrysididae by Aaron (1885). Apart from a catalogue of the North American species of Chrysididae by Bodenstein (1951) and a very few papers which include some reference to species of *Elampus* (e.g. Krombein, 1963; Kurczewski, 1970) virtually nothing has been published on North American *Elampus* since Aaron's revision. This is the first revision of *Elampus* for North America since 1885.

Nomenclature and Generic Relationships

Two names, *Elampus* and *Notozus,* have been used for the genus. The name *Elampus* has priority but the name *Notozus* has been used more extensively. In general, old world authors have used the name *Notozus* whereas North Americans have used the name *Elampus*. The name *Elampus* has also been used for the related genus *Omalus* Panzer (e.g. Taschenberg, 1866; Aaron, 1885; Buysson, 1891; Bischoff, 1913; Berland and Bernard, 1938; Semenov-Tian-Shanskij, 1967). A discussion of the use of the two names and a plea for the suppression of *Elampus* and the addition of *Notozus* to the Official List of Generic Names was given by Huber (1975). In this paper the name *Elampus* is used pending a decision by the International Commission on Zoological Nomenclature.

The genus *Elampus* is most closely related to the genus *Omalus*. Bohart and Campos (1960) listed several characters common to both genera. The occurrence of species having character combinations or characteristics apparently intermediate between the two genera led Linsenmaier (1959, 1968) to treat *Elampus (Notozus)* as a subgenus of *Omalus*. Peters (1966) discussed the separation of the two genera and noted that no single character was sufficient to separate all species but that a combination of characters was necessary. He considered that *Elampus (Notozus)* and *Omalus* should be kept as separate genera. Radoszkowski (1889) and Lorencowa (1962, 1966) considered the male genitalia and the hidden abdominal segments of females, respectively, of *Elampus* and *Omalus* to be sufficiently distinct to keep them as separate genera. In the present paper *Elampus* is considered distinct from *Omalus* on the basis of differences in genitalia, the presence of *Elampus* and the absence in *Omalus* of distinct secondary sexual characters, and differences in biology based on the scanty biological evidence available.

Biology

Very little is known about the host-parasite relationships of *Elampus*. From the few available records it appears that species of *Elampus* parasitize soil-nesting sphecids. Spooner (1948) gave a fairly complete account of parasitism of *Mimesa* by *Elampus,* summarizing records by Morice (1903), Bischoff (1913), Trautmann (1927), and Berland and Bernard (1938). Bohart (1976) brought the nomenclature of the species of *Mimesa* up to date and, quoting Móczár (1967), lists the following species of *Elampus* as parasites of *Mimesa: Elampus panzeri* (F.) on *M. equestris* (as *Psen bicolor* Shuckard); *E. constrictus* (Foerster) on *M. bicolor* and *M. lutaria* (as *Psen shuckardi* Westmael). In addition, Spooner listed *Elampus spina* (Lepeletier) as a parasite of *M. lutaria* in Sweden.

In North America the only published host record is of *Elampus viridicyaneus* parasitizing *Psammecius costalis* (Cresson) (Krombein, 1958, 1963). Negative,

circumstantial evidence indicates that species of *Elampus* in North America parasitize soil-nesting rather than twig-nesting wasps. For example, of several trap-nesting studies undertaken (Medlar, 1964; Krombein, 1967) no *Elampus* were reared authough species of *Omalus* and other Chrysididae were reared relatively often from their twig-nesting hosts. Many of the pinned specimens of *Elampus* examined in the present study had sand grains firmly stuck in the coarser punctures of the body or on the apical truncation suggesting that the wasps had been burrowing in sandy soil.

The habits of *Elampus* are poorly known. Collection records indicate that adults are often caught on flowers. Buysson (1891) mentioned that species of *Elampus (Notozus)* were attracted to the sweet secretions on leaves and Balthasar (1954) noted that they were attracted to honeydew and could be caught most readily in dry areas. Kurczewski (1970) collected *E. maginatus* and *E. viridicyaneus* on gravel and sand at the edges of woodlands.

Nothing is known about the life cycle or immature stages of *Elampus*. Krom*bein* (1963) suggested that *E. viridicyaneus* was multivoltine in Maryland.

Materials and Methods

Approximately 2,300 pinned specimens of North American *Elampus* were examined. Material for this study was borrowed from a number of institutions. Institutions in which type material is deposited are followed by their abbreviations. The assistance of the curators responsible for the loan of the specimens from their respective institutions is gratefully acknowledged. Academy of Natural Sciences, Philadelphia (ANSP) (W. W. Moss); American Museum of Natural History, New York (AMNH) (M. Favreau); Biosystematics Research Institute, Ottawa (BRI) (C. Yoshimoto); California Academy of Sciences, San Francisco (CAS) (T. J. Zavortink); California Insect Survey, University of California, Berkeley (CIS) (H. V. Daly); Connecticut Agriculture Experimental Station, New Haven (K. A. Welch); Cornell University, Cornell (CORN) (L. L. Pechuman); Field Museum of Natural History, Chicago (J. B. Kethley); Florida Department of Agriculture, Division of Plant Industry, Gainesville (E. E. Grissel); K. V. Krombein Personal Collection, Washington, D.C.; W. Linsenmaier Personal Collection, Ebikon, Switzerland (LINS); Lyman Entomological Museum, Macdonald College, Ste. Anne de Bellevue (V. R. Vickery); Michigan State University, East Lansing (MSU) (R. L. Fischer); Museum of Comparative Zoology, Harvard University, Cambridge (J. F. Lawrence); Museum D'Histoire Naturelle, Geneva, Switzerland (MNHG) (C. Besuchet); North Carolina State University, Raleigh (D. A Young); Northern Arizona University, Flagstaff (C. D. Johnston); Royal Ontario Museum, Toronto (G. B. Wiggins); Strickland Museum, University of Alberta, Edmonton (G. E. Ball); United States National Museum, Washington, D.C. (USNM) (K. V. Krombein); University of British Columbia, Vancouver (G. G. E. Scudder); University of California, Davis (UCD) (R. M. Bohart); University of California, Riverside (UCR) (S. Frommer); University of Kansas (Snow Collection), Lawrence (G. W. Byers); Washington State University, Pullman (W. J. Turner). Type material was seen unless otherwise indicated.

Measurements were made on a representative sample (usually 10 males and 10 females of six taxa using a standard 400 square ocular reticule. A given structure was measured under the highest magnification possible with the structure completely visible within the area of the reticule. The measurements made, with the abbreviations used in the Figures 10-13 and Tables I, II, and III are as follows: length and width of head (LH and WH respectively); width of face (WF);

TABLE I. Measurements (in mm) and ratios for the type specimens of North American *Elampus* species (Hymenoptera, Chrysididae).

Species	*Elampus nitidus nitidus* (holotype)	*E. mexicanus* (lectotype)	*E. nitidus californicus* (holotype)	*E. viridicyaneus* (holotype)	*E. connexus* (holotype)	*E. versicolor* (holotype)	*E. marginatus* (neotype)	*E. hyalinus* (paratype)	*E. aaroni* (=*productus*) (paratype)	*E. rotundus* (holotype)
Sex	♂	♂	♂	♂	♂	♂	♀	♀	♂	♂
Type no.	4910	83	4910	4920	914	4921	N.A.	4912	4913	N.A.
TL (Var. 1)	5.8	5.1	4.5	7.1	7.0	6.2	4.8	5.6	5.3	4.4
WH / LH = (Var. 3)	1.35/0.62 = 2.19	1.32/0.53 = 2.50	1.28/0.59 = 2.15	1.85/0.70 = 2.63	1.94/0.70 = 2.75	1.65/0.64 = 2.59	1.21/0.46 = 2.63	1.50/0.66 = 2.27	1.43/0.57 = 2.50	1.19/0.48 = 2.45
WP / LP = (Var. 2)	1.23/0.66 = 1.87	1.17/0.62 = 1.27	1.10/0.57 = 1.92	1.72/0.79 = 2.15	1.85/0.86 = 2.15	1.54/0.70 = 2.19	1.14/0.66 = 1.73	1.45/0.75 = 1.97	1.28/0.66 = 1.93	1.06/0.59 = 1.78
W_I / L_I = (Var. 4)	1.58/0.52 = 3.06	1.09/0.59 = 2.06	1.41/0.48 = 2.91	2.33/0.70 = 3.31	2.51/0.79 = 3.17	1.88/0.70 = 2.67	—	1.67/0.55 = 3.04	1.56/0.62 = 2.54	1.32/0.40 = 3.33
W_{II} / L_{II} = (Var. 5)	1.63/1.14 = 1.42	1.67/1.17 = 1.43	1.52/1.06 = 1.44	2.38/1.58 = 1.50	2.60/1.81 = 1.43	1.94/1.41 = 1.38	1.43/1.08 = 1.32	1.80/1.23 = 1.32	1.60/1.14 = 1.39	1.41/0.97 = 1.45
L_{III} / W_{III} = (Var. 6)	1.36/0.80 = 1.71	1.41/1.14 = 1.23	1.30/0.79 = 1.64	2.05/1.06 = 1.95	2.02/1.23 = 1.64	1.50/0.97 = 1.55	1.32/1.14 = 1.16	1.63/1.23 = 1.32	1.23/0.85 = 1.45	1.23/0.76 = 1.62
W_t / H_t = (Var. 7)	0.30/0.22 = 1.36	0.35/0.26 = 1.33	0.24/0.18 = 1.38	0.53/0.32 = 1.51	0.53/0.32 = 1.51	0.51/0.35 = 1.44	0.31/0.21 = 1.48	0.33/0.29 = 1.26	0.46/0.29 = 1.58	0.26/0.28 = 0.92
H_t / H_I = (Var. 8)	0.22/0.04 = 6.06	0.26/0.04 = 6.00	0.18/0.04 = 4.00	0.35/0.15 = 2.41	0.32/0.08 = 4.18	0.35/0.11 = 3.22	0.21/0.07 = 3.00	0.29/0.09 = 3.00	0.29/0.07 = 4.44	0.26/0.01 = 24
W_t / W_{III} = (Var. 10)	0.30/1.36 = 0.22	0.35/1.41 = 0.25	0.24/1.30 = 0.19	0.51/2.05 = 0.26	0.53/2.02 = 0.26	0.51/1.50 = 0.34	0.31/1.32 = 0.23	0.33/1.63 = 0.20	0.46/1.23 = 0.38	0.26/1.23 = 0.21

Species	*Elampus nitidus nitidus* (holotype)	*E. mexicanus* (lectotype)	*E. nitidus californicus* (holotype)	*E. viridicyaneus* (holotype)	*E. connexus* (holotype)	*E. versicolor* (holotype)	*E. marginatus* (neotype)	*E. hyalinus* (paratype)	*E. aaroni (=productus)* (paratype)	*E. rotundus* (holotype)
Sex	♂	♂	♂	♂	♂	♂	♀	♀	♂	♂
L_F (Var. 11)	3.8	3.6	3.3	4.9	5.2	—	3.4	—	4.2	3.2
ST (Var. 16)	1.50	1.50	1.32	—	2.11	—	1.41	—	1.72	1.26
L_{RS} (Var. 12)	0.26	0.26	0.22	0.40	0.40	0.36	0.24	0.22	0.26	0.13
L_S (Var. 13)	0.31	0.31	0.24	0.35	0.40	0.35	0.26	0.26	0.32	0.26
$\frac{F_I}{F_{II}}$ (Var. 9)	$\frac{0.26}{0.18}=1.50$	$\frac{0.26}{0.18}=1.50$	$\frac{0.22}{0.15}=1.43$	$\frac{0.37}{0.26}=1.43$	$\frac{0.40}{0.24}=1.64$	$\frac{0.35}{0.24}=1.46$	$\frac{0.31}{0.11}=2.82$	$\frac{0.22}{0.11}=2.00$	$\frac{0.31}{0.18}=1.75$	$\frac{0.22}{0.14}=1.43$
SD (Var. 17)	0.44	0.48	0.44	0.62	0.65	0.62	0.44	0.53	0.50	0.39
WF (Var. 14)	0.86	0.84	0.79	1.08	1.19	1.03	0.84	0.92	0.92	0.77
LF (Var. 15)	0.91	0.92	0.88	1.14	1.19	1.19	—	1.03	1.07	0.81
LID (Var. 18)	0.26	0.24	0.26	0.31	0.35	0.39	0.24	0.33	0.29	0.26
OOD (Var. 19)	0.31	0.31	0.26	0.42	0.40	0.51	0.31	0.26	0.35	0.23

Abbreviations: TL = total length; $\frac{WH}{LH}$ = width/length of head; $\frac{WP}{LP}$ = width/length of pronotum; $\frac{W_I}{L_I}, \frac{W_{II}}{L_{II}}, \frac{W_{III}}{L_{III}}$ = width/length of first, second and third tergite, respectively; $\frac{W_t}{H_t}$ = width/height of apical truncation; $\frac{H_t}{H_t}$ = height of truncation/height of incision; $\frac{W_t}{W_{II}}$ = width of truncation/width of third tergite; L_F = length of forewing; ST = length of forewing from stigma to wing tip; L_{RS} = length of radial sector; L_S = length of stigma; $\frac{F_I}{F_{II}}$ = length of first flagellomere/second flagellomere; SD = length of scape; WF = width of face; LF = length of face; LID = least interocellar distance; OOD = ocellocular distance; N.A. = not available.

TABLE II. Means and standard deviations for ratios and measurements (in mm) of males and females of eight taxa of North American *Elampus* (Hymenoptera, Chrysididae).

Species		*E. nitidus nitidus*[1]		*E. nitidus californicus*[1]		*E. viridi-cyaneus*[1]		*E. marginatus*[1] (green-black form)		*E. hyalinus*[1]		*E. rotundus*[1]		*E. aaroni*[3]	*E. versicolor*[2,3]
Sex		♂	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀	♀	♀
n		15	20	10	10	10	10	10	10	10	25	6	9	3	1
TL	m	5.0	5.1	4.6	4.7	7.2	7.7	5.8	5.7	4.6	4.7	4.6	5.0	5.7	5.8
	S.D.	0.6	0.5	0.3	0.5	0.3	0.4	0.7	0.4	0.6	0.5	0.3	0.7	0.5	—
WH / LH	m	2.37	2.51	2.21	2.32	2.71	2.73	2.44	2.66	2.38	2.42	2.44	2.43	2.78	1.45/0.55=2.61
	S.D.	0.15	0.24	0.11	0.09	0.26	0.12	0.09	0.14	0.13	0.12	0.05	0.12	0.10	
WP / LP	m	1.87	1.71	1.87	1.75	2.08	1.88	1.86	1.66	1.91	1.86	1.93	1.80	1.69	1.28/0.70=1.81
	S.D.	0.08	0.09	0.07	0.11	0.12	0.10	0.09	0.04	0.09	0.07	0.21	0.11	0.03	
W_{II} / L_{II}	m	1.45	1.41	1.40	1.38	1.52	1.44	1.46	1.38	1.52	1.51	1.45	1.50	1.35	1.67/1.28=1.31
	S.D.	0.07	0.05	0.05	0.08	0.06	0.05	0.07	0.02	0.07	0.07	0.02	0.06	0.02	
W_{III} / L_{III}	m	1.61	1.46	1.57	1.48	2.00	1.71	1.58	1.42	1.30	1.31	1.66	1.44	1.32	1.32/0.77=1.71
	S.D.	0.20	0.30	0.18	0.24	0.39	0.20	0.16	0.19	0.10	0.13	0.09	0.19	0.05	
W_t / H_t	m	1.48	1.35	1.51	1.41	1.80	1.82	1.43	1.33	1.26	1.15	1.00	0.98	1.47	0.44/0.31=1.43
	S.D.	0.23	0.24	0.16	0.28	0.17	0.30	0.11	0.10	0.18	0.10	0.07	0.09	0.05	
H_t / H_1	m	4.13	3.21	3.74	3.51	2.69	1.72	3.88	3.28	6.74	4.87	23.3	18.2	3.53	0.31/0.09=3.50
	S.D.	1.46	1.26	0.67	0.70	0.62	0.26	0.94	1.20	2.91	1.28	8.0	16.0	0.41	
W_t / W_{III}	m	0.25	0.22	0.22	0.21	0.24	0.26	0.26	0.23	0.25	0.23	0.24	0.21	0.34	0.44/1.32=0.33
	S.D.	0.03	0.04	0.03	0.03	0.04	0.05	0.04	0.03	0.03	0.02	0.02	0.03	0.03	
L_F	m	3.7	3.6	3.1	3.2	5.5	5.8	4.1	4.1	3.3	3.5	3.2	3.7	4.4	4.7
	S.D.	0.5	0.3	0.3	0.2	0.3	0.4	0.5	0.4	0.3	0.3	0.3	0.4	0.2	
L_{RS}	m	0.25	0.25	0.21	0.22	0.42	0.47	0.31	0.30	0.21	0.22	0.16	0.18	0.31	0.35
	S.D.	0.05	0.03	0.03	0.03	0.06	0.04	0.06	0.04	0.03	0.03	0.02	0.02	0.04	
L_S	m	0.28	0.26	0.25	0.25	0.42	0.44	0.35	0.29	0.26	0.27	0.27	0.27	0.33	0.40
	S.D.	0.04	0.03	0.02	0.02	0.06	0.06	0.06	0.02	0.02	0.02	0.02	0.03	0.03	

Species		*E. nitidus*[1] *nitidus*[1]		*E. nitidus californicus*		*E. viridi-cyaneus*[1]		*E. marginatus*[1] (green-black form)		*E. hyalinus*[1]		*E. rotundus*[1]		*E. aaroni*[3]	*E. versicolor*[2,3]
Sex		♂	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀	♀	♀
$\frac{F_I}{F_{II}}$	m	1.53	1.82	1.47	1.68	1.57	1.66	1.52	1.80	1.58	1.82	1.47	1.73	1.81	$\frac{0.35}{0.19}=1.88$
	S.D.	0.11	0.27	0.12	0.12	0.14	0.36	0.14	0.15	0.18	0.34	0.04	0.19	0.04	
SD	m	0.49	0.52	0.43	0.48	0.66	0.82	0.53	0.57	0.38	0.40	0.39	0.45	0.58	0.57
	S.D.	0.05	0.05	0.03	0.03	0.06	0.03	0.07	0.06	0.04	0.05	0.05	0.05	0.02	
WF	m	0.85	0.86	0.80	0.84	1.15	1.25	0.93	0.97	0.73	0.82	0.79	0.87	0.96	1.03
	S.D.	0.09	0.07	0.05	0.07	0.06	0.05	0.12	0.05	0.06	0.07	0.06	0.11	0.09	
LF	m	0.94	0.98	0.86	0.93	1.20	1.37	1.02	1.04	0.84	0.90	0.81	0.91	1.12	1.08
	S.D.	0.08	0.06	0.06	0.06	0.05	0.05	0.09	0.11	0.07	0.07	0.06	0.11	0.11	
LID	m	0.28	0.26	0.25	0.26	0.31	0.33	0.27	0.27	0.27	0.28	0.28	0.30	0.30	0.25
	S.D.	0.03	0.02	0.02	0.02	0.03	0.02	0.03	0.03	0.03	0.03	0.02	0.04	0.03	
OOD	m	0.31	0.31	0.28	0.29	0.42	0.46	0.34	0.34	0.22	0.24	0.24	0.26	0.38	0.40
	S.D.	0.03	0.03	0.02	0.02	0.02	0.02	0.04	0.04	0.03	0.02	0.02	0.03	0.02	
MOD	m	0.097	0.095	0.088	0.092	0.138	0.142	0.098	0.097	0.098	0.096	0.095	0.095	0.098	0.114
	S.D.	0.011	0.009	0.007	0.007	0.010	0.011	0.007	0.005	0.005	0.007	0.007	0.016	—	

[1] Measurements for these taxa used for discriminant analysis.
[2] Measurements and ratios only are given (n = 1).
[3] Not included in discriminant analysis.

Abbreviations: n = number of specimens measured; TL = total length; $\frac{WH}{LH}$ = width/length of head; $\frac{WP}{LP}$ = width/length of pronotum; $\frac{W_I}{L_I}, \frac{W_{II}}{L_{II}}, \frac{W_{III}}{L_{III}}$ = width/length of first, second and third tergite, respectively; $\frac{W_t}{H_t}$ = width/height of apical truncation; $\frac{H_t}{H_i}$ = height of truncation/height of incision; $\frac{W_t}{W_{III}}$ = width of truncation/width of third tergite; L_F = length of forewing; ST = length of forewing from stigma to apex; L_{RS} = length of radial sector; L_S = length of stigma; $\frac{F_I}{F_{II}}$ = length of first flagellomere/length of second flagellomere; SD = length of scape; WF = width of face; LF = length of face; LID = least interocellar distance; OOD = ocellocular distance; MOD = midocellus diameter; m = mean; S.D. = standard deviation.

TABLE III. Results of Scheffé's multiple range test on six taxa of North American *Elampus* (Hymenoptera, Chrysididae)[a].

Variable	Scheffé at 0.01 level of significance[b,c,d]					
Total length (TL) (Variable 1)	1	2	5	4	3	6
Width / Length of tergite II (W_{II}/L_{II}) (Variable 5)	1	3	4	6	5	2
Width / Length of tergite III (W_{III}/L_{III}) (Variable 6)	2	3	1	5	4	6
Width of apical truncation / Height (W_t/H_t) (Variable 7)	5	2	3	4	1	6
Height of truncation / Height of incision (H_t/H_i) (Variable 8)	6	3	1	4	2	5
Length of forewing (L_F) (Variable 11)	5	1	2	4	3	6
Length of radial sector (L_{RS}) (Variable 12)	5	1	2	4	3	6
Width of face (WF) (Variable 14)	2	1	5	4	3	6
Length from stigma tip to wing tip (ST) (Variable 16)	1	5	2	4	3	6
Least interocellar distance (LID) (Variable 18)	1	4	2	3	5	6
Ocellocular distance (OOD) (Variable 19)	1	4	2	3	5	6

[a] Summarized from a computer printout (available at University of Guelph, Department of Environmental Biology).
[b] Means ranked in ascending order.
[c] 1 = *Elampus nitidus californicus*, 2 = *E. hyalinus*, 3 = *E. marginatus*, 4 = *E. nitidus nitidus*, 5 = *E. rotundus*, 6 = *E. viridicyaneus*.
[d] Lines connecting taxa indicate no significant difference among taxa means.

midocellus width (MOD); least interocellar distance (LID): ocellocular distance (OOD); length of scape (SD); length of first and second flagellomeres (F_I, F_{II}); length and width of pronotum (LP and WP respectively); lengths and widths of tergites I, II, III, (L_I, L_{II}, L_{III}, W_I, W_{II}, W_{III}, respectively); width of apical truncation (W_A); height of incision (H_i); length of forewing (L_F); length of stigma (L_S); length of radial sector (L_{RS}). A number of measurements were used in the form of ratios. Body length was measured in three parts as follows: maximum length of head (with face vertical); length of thorax from anterior margin of pronotum to apex of postscutellar blade measured in side view or from above when both extremes were in focus; length of abdomen from propodeum to apex of snout-

like projection measured in side view. The three measurements combined were used for total length (TL).

Using the Statistical Package for the Social Sciences (SPSSH) — version 6.01 at the University of Guelph, the following statistical analyses were performed on 16 variables (Table I):

1. discriminant analysis, treating six taxa without regard to sex and the two sexes without regard to taxon;
2. two-way ANOVA on each variable, testing for the main effects of sex and taxon and interaction between sex and taxon;
3. one-way ANOVA treating the six taxa as six groups without regard to sex.

The one-way ANOVAs were used to perform Scheffé's multiple range test for variables which were highly significant for species only (as determined by the two-way ANOVAs) since the SPSSH package had no multiple range test option for significant factors in the two-way ANOVA. Because no program at the University of Guelph could perform discriminant analysis using individuals with missing observations, variable 4 ($\frac{W_I}{L_I}$) was removed since it had the most missing observations. Any further individuals with missing variables were ignored in the analysis.

Puncture size and density were described as follows: large punctures — diameter equal to or larger than the width of midocellus; medium punctures — about 0.5 times the width of midocellus; small punctures — about 0.25 times the width of midocellus; minute punctures — very small punctures, diameter not greater than depth; contiguous punctation — punctures touching each other; dense punctation — punctures less than one puncture-width apart but not touching; moderate punctation — punctures one to two puncture-widths apart; sparse punctation — punctures greater than two puncture-widths apart.

Male genitalia and the hidden tergites and sternites of the ovipositor tube of females were dissected from relaxed specimens, cleared in hot, dilute, sodium-hydroxide solution, washed in distilled water, and mounted in Hoyer's medium for microscopic examination. The lengths of a digitus, cuspis, and paramere were measured at 100X magnification using an ocular micrometer. The lengths of the digitus and cuspis were measured from their junction, and the paramere length from its junction with the gonobase (Fig. 14). The measurements were expressed as ratios of digitus to cuspis (d/c) and cuspis to paramere (c/p) lengths, respectively. Measurements are given in Table IV. Terminology of parts of the hidden tergites and sternites of females follows that of Lorencowa (1962).

Scanning electron micrographs were taken using specimens coated with 300A gold/palladium at 5 or 10 kv in an ETEC Autoscan scanning electron microscope.

Taxonomic Characters

The amount of variation within species of *Elampus* was considerable. Diagnostic, species characters were few and often variable. A few species, e.g., *E. hyalinus* and *E. rotundus* sp. nov., were easily recognizable and one or two diagnostic characters were sufficient to distinguish all specimens accurately. Others, e.g., *E. marginatus* and *E. aaroni* were relatively difficult to distinguish and the extremes of one species appeared to intergrade with the extremes of another species so that it was impossible to determine confidently every specimen to species, although if a

number of characters were considered most specimens could be identified with certainty.

Body colour was the most conspicuous character in the genus. Within a given species, however, it was extremely variable and some species, e.g., *E. marginatus* were polychromic, having several different colour forms. Once the colour variations were known they were an important aid to identification in some species. Telford (1964) and Horning (1969) discussed the possible reasons for colour variation. Frey (1936), Berland and Bernard (1938), and Balthasar (1954) discussed in detail colour and its formation in Chrysididae. Wing colour was important in distinguishing one species *viz., E. hyalinus.*

Punctation was similar in all species. Within a species, the density of punctation on a particular sclerite sometimes varied considerably, especially on the thorax and abdomen. In some species, e.g., *E. marginatus* and *E. nitidus nitidus* specimens from the southern part of the range had denser punctation than did specimens from the northern part of the range. Buysson (1908) seemed to suggest this for *Notozus productus* Dahlbom in Egypt and Horning (1969) noted this for *Chrysura sonorensis* (Cameron) in North America.

On the head, the major qualitative character, useful for distinguishing species, was the nature of the scapal basin which varied from smooth or somewhat rugose to finely, evenly, and distinctly striate depending on the species. No useful taxonomic characters were found on the thorax. The pattern of ridges on the propodeum was complex but there did not appear to be any significant differences among species. The number of teeth in the tarsal claws was very important in distinguishing certain species although within a species there was some variation.

Most specific characters were found on the abdomen. The colour and shape of the abdomen and, in particular, the shape of the third tergite and apical truncation were very important in spite of a certain amount of intraspecific variation. No consistent differences were found in the shape of the hidden abdominal segments of females but more study of this character is needed. Lorencowa (1966) found useful taxonomic characters in the hidden segments of *Hedychrum.* In the male genitalia, differences were found in the relative lengths of the digiti, cuspides, and parameres of some species (Table IV).

TABLE IV. Ratios of lengths of digitus/cuspis and cuspis/paramere of male genitalia of North American *Elampus* species (Hymenoptera, Chrysididae).

Species	n	$\frac{d}{c}$		$\frac{c}{p}$	
		m	S.D.	m	S.D.
Elampus nitidus nitidus	4	0.58	0.05	0.61	0.04
Elampus nitidus californicus	1	0.57	—	0.62	—
Elampus hyalinus	4	0.61	0.06	0.50	0.03
Elampus viridicyaneus	15	0.62	0.03	0.64	0.03
Elampus marginatus	23	0.62	0.04	0.62	0.04
Elampus versicolor (?) (ex Bard, California)	1	0.52	—	0.64	—
Elampus aaroni (paratype)	1	0.59	—	0.66	—
Elampus rotundus	2	0.58	0.02	0.52	0.02
Elampus mexicanus (paratype)	1	0.64	—	0.61	—

Abbreviations: n = number of genitalia measured; m = mean; S.D. = standard deviation; $\frac{d}{c}$ = digitus length/cuspis length; $\frac{c}{p}$ = cuspis length/paramere length.

TABLE V. Summary of highly correlated variables for North American *Elampus* (Hymenoptera, Chrysididae) (from statistical analyses of 18 variables and six taxa)[a].

Character	Above 80% correlation	Above 70% correlation
Total length (variable 1)	Length of forewing (variable 11) Length of face (variable 15) Length from stigma to wing tip (variable 16)	Length of scape (variable 17) Least interocellar distance (variable 18) Ocellocular distance (variable 19)
Length of forewing (variable 11)	Length from stigma tip to wing tip (variable 16)	Length of face (variable 15)
Length of face (variable 15)	Length from stigma tip to wing tip (variable 16) Length of scape (variable 17) Ocellocular distance (variable 19)	Least interocellar distance (variable 18)
Length from stigma tip to wing tip (variable 16)		Length of scape (variable 17) Least interocellar distance (variable 18) Ocellocular distance (variable 19)

[a] Summarized from a computer printout available at the University of Guelph, Department of Environmental Biology.

The discriminant analysis, treating six taxa (of the eight considered in this paper) without regard to sex, showed that certain variables were highly correlated (Table V). Five discriminant functions were derived with four functions being highly significant ($P \leq 0.001$). Based on all five discriminant functions and 18 variables, Table VII was produced which shows the percentage of the predicted groups (i.e., those groups based on quantitative data only) placed correctly into the actual groups (i.e., those groups based on qualitative data). The most important variables for the first four discrimnant functions based on the standardized discriminant function coefficients, appeared to be variables 8 ($\frac{H_t}{H_i}$), 11 (L_F), 12 (L_{RS}), 15 (LF), 16 (ST), 17 (SD), and 19 (OOD). Using four functions based on these eight variables an 81.9% correct, predicted group-membership was obtained. The discriminant analysis, treating the two sexes as groups without regard to taxon, gave a 91.2% correct, group-membership based on one discriminant function.

The results of the two-way ANOVAs can be summarized as follows:

1. interaction between sexes and taxa was significant for variables 17 (SD) ($P \leq 0.001$), 15 (LF) ($P < 0.05$), and 13 (L_S) ($P < 0.05$).

2. differences between sex means were significant for variables 2 ($\frac{WP}{LP}$) ($P < 0.01$) and 9 ($\frac{L_I}{L_{II}}$) ($P < 0.05$).

TABLE VI. Numbers of specimens of the North American species *Elampus marginatus* and *E. viridicyaneus* (Hymenoptera, Chrysididae) collected during each month (from data labels on pinned specimens).

Species	January	February	March	April	May	June	July	August	September	October	No date	Total
Elampus marginatus (black colour form)	0	0	0	0	0	11	20	4	0	0	4	39
E. marginatus (green-black colour form)	0	0	0	0	15	54	254	37	2	5	18	385
E. marginatus (green colour form)	0	0	0	7	14	48	66	16	2	2	15	170
E. marginatus (other colour forms)	0	0	1	11	37	97	256	55	19	12	20	508
E. marginatus (all colour forms combined)	0	0	1	18	66	210	596	112	23	19	57	1,102
E. viridicyaneus	1	0	0	6	60	293	87	8	1	0	28	484

TABLE VII. Discriminant analysis for six North American taxa of *Elampus* (Hymenoptera, Chrysididae): predicted results giving percentage of correct placement of predicted groups into actual groups based on five discriminant functions and 18 variables[a].

Actual group	No. of cases	Predicted group membership Group 1	Group 2	Group 3	Group 4	Group 5	Group 6
Group 1	19	16.	0.	0.	3.	0.	0.
(E. nitidus californicus)		84.2%	0.0%	0.0%	15.8%	0.0%	0.0%
Group 2	30	0.	30.	0.	0.	0.	0.
(E. hyalinus)		0.0%	100.0%	0.0%	0.0%	0.0%	0.0%
Group 3	18	0.	0.	15.	3.	0.	0.
(E. marginatus)		0.0%	0.0%	83.3%	16.7%	0.0%	0.0%
Group 4	28	5.	0.	4.	19.	0.	0.
(E. nitidus nitidus)		17.9%	0.0%	14.3%	67.9%	0.0%	0.0%
Group 5	10	0.	1.	0.	0.	9.	0.
(E. rotundus)		0.0%	10.0%	0.0%	0.0%	90.0%	0.0%
Group 6	20	0.	0.	0.	0.	0.	20.
(E. viridicyaneus)		0.0%	0.0%	0.0%	0.0%	0.0%	100.0%

Percentage of "grouped" cases correctly classified: 87.20%.

[a] Taken from computer printout. Available at the University of Guelph, Department of Environmental Biology.

3. the mean of at least one taxon was significantly different ($P \leq 0.001$) from the others for variables 1 (TL), 2 ($\frac{WP}{LP}$), 3 ($\frac{WH}{LH}$), 5 ($\frac{W_{II}}{L_{II}}$), 6 ($\frac{W_{III}}{L_{III}}$), 7 ($\frac{W_t}{H_i}$), 8 ($\frac{H_t}{H_i}$), 11 (L_F), 12 (L_{RS}), 13 (L_S), 14 (WF), 15 (LF), 16 (ST), 17 (SD), 18 (LID), and 19 (OOD). Variables which were highly significant for taxa ($P \leq 0.001$) but showed no significant interaction or sex difference were subjected to Scheffé's multiple range test at the 0.01% level of significance. The results are summarized in Table III.

In general, for North America, the species of *Elampus* were found to be very similar with few, and often disappointingly variable, diagnostic characters. Therefore, in the present study relatively broad species limits were recognized and considerable attention was given to describing intraspecific variation. Rather than giving formal latin names to distinct colour forms or possible new species the philosophy of a relative "lumper" was adopted.

Systematics

Genus *Elampus* Spinola

Elampus Spinola, 1806, Ins. Liguriae 1: 10; Spinola, 1808, Ins. Liguriae 2: 75, Spinola, 1851, Gay Hist. Fisic. Chile 5(6): 412; Dahlbom, 1854, Hym. Europae 2: 38; Norton, 1879, Trans. Am. ent. Soc. 7: 233 (ex parte); Provancher, 1881, Nat. Canad. 12: 302 (ex parte); Frey-Gessner, 1887, Fn. Insect. Helvet.: 30 (ex parte); Morice, 1896, Entomol. mon. Mag. 32: 118; Alayo, 1974, Acad. Cien. Cuba, Ser. Biol. No. 52: 4, 12.

Ellampus Agassiz, 1846, Nomen. Zool. Index Universalis: 136 (emendation); Mocsáry, 1889, Monogr. Chrysididarum: 64, 65 (as subgenus *Notozus);* Friese, 1926, Franch. Verlangshand.: 184, 185 (ex parte); Bodenstein, 1939, Trans. Am. ent. Soc.: 126.

Elampos Dahlbom, 1854, Hymenoptera Europae II:xv (typographical error).

Notozus Förster, 1853, Verh. Naturh. Ver. preuss. Rheinl. 10: 331; Taschenberg, 1866, Die Hymenopteren Deutschlands VIII: 148, 149 (nec *Elampus* Taschenberg, 1866: (148); Tournier, 1879, Annls. Soc. ent. Belg. 22: 89; Aaron, 1885, Trans. Am. ent. Soc. 12: 212, 217 (nec *Elampus* Aaron, 1885: 215); Buysson, 1891, Species des Hyménoptères d'Europe et d'Algérie VI: 95 (nec *Ellampus* Buysson, 1891: 116); Bischoff, 1913, in Wytsman: Genera Insectorum 151: 4, 5 (nec *Ellampus* Bischoff, 1913: 7); Trautmann, 1927, Die Goldwespen Europas: 23; Trautmann, 1930, in Schmiedekneckt: Die Hymenopteren Nord- und Mitteleuropas: 488, 489; Berland and Bernard, 1938, Fn. France 34: 25, 26 (nec *Elampus* Berland and Bernard, 1938: 31); Edney, 1940, Occ. Pap. natn. Mus. sth. Rhod. 9: 33, 35; Atanassov, 1940, Izv. bulg. ent. Druzh. 11: 205; Balthasar, 1946, Acta ent. Mus. Natl. Pragae. XXIV, 324: 225; Benno, 1950, Publties natuur. Genoot. Limburg III: 18; Balthasar, 1951, Acta ent. Mus. Natl. Pragae XXVII, Suppl. 2: 38; Balthasar, 1954, Fn. ČSR 3: 72; Haupt, 1956, Abh. Ber. Mus. Tierk. Volkerk. Dresden 23: 48; Noskiewicz and Pulawski, 1958, Polski Związek Ent. 24: 16; Móczár, 1964, Annls. hist-nat. Mus. natn. hung. 56: 439; Móczár, 1967, Fn. Hungariae 86: 19; Semenov-Tian-Shanskij, 1967, Trudȳ zool. Inst., Leningr. 43: 120 (nec Semenov-Tian-Shanskij, 1967, 119).

Notorus Antiga and Bofill, 1903, Catálech insectes Catalunya: 3 (typographical error).

Omalus Linsenmaier, 1959, Mitt. schweiz. ent. Ges. 41: 22 (as subgenus *Notozus).*

Type-species: *Chrysis panzeri* Fabricius 1804, designated by Latreille (1810).

Adults. Small to medium, relatively robust wasps varying in length from three to eight millimeters. Colour variable, metallic green, blue, violet, black or coppery. Body more or less completely covered with punctures, each usually bearing a fine hair from its centre.

Head. Scapal basin wide, shallow, striate, rugose or smooth (Figs. 56, 57), indistinctly separated from rest of face; separated from inner margins of compound eyes by one or two rows of round punctures which become smaller below. Front distinctly punctuate with round, medium, contiguous to moderately spaced punctures. Clypeus slightly bulging medially; smooth with a few minute, shallow, indistinct punctures; its apical margin incised below each antennal socket. Ocellar triangle with small to minute, irregularly spaced punctures, with a shallow, indistinct, groove sometimes joining hind margins of lateral ocelli. Vertex with slightly larger, more irregularly spaced punctures than in ocellar triangle and a small, smooth area posterolateral to each lateral ocellus (Fig. 60). Genae relatively broad above, narrow below, irregularly punctate to rugose-punctate; smooth along compound eyes. Hairs of genal fringe fine, long, relatively sparse in males; coarse, short, dense in females (Figs. 52, 53). Malar space very narrow, less than one ocellar diameter in width. Scape indistinctly and finely punctate above, smooth below. Pedicel brown, paler apically. Flagellum brown or black, covered with short, dense, white setae, first flagellomere longer than second, and second slightly longer than third; remaining flagellomeres subequal (Fig. 65). Mandibles with two inner teeth (Fig. 54), metallic green or blue basally, light brown medially, dark to reddish brown at apices of inner teeth and apex; fringed with a few long, white setae.

Thorax. Pronotum longer and narrower than head (Fig. 60), tapering anteriorly; small, densely spaced punctures medially along anterior margin, elsewhere medium, densely to moderately spaced punctures, often loosely clumped medially and contiguous laterally; sides concave and rugose-punctate. Mesonotum more or less evenly covered with small to medium, densely spaced punctures anteriorly, between and just outside notaulices (Fig. 55), becoming larger posteriorly, largest between notaulices near hind margin. Notaulices fine, complete, ending in elongate pits at anterior and posterior margins. Scutellum with large, distinct, round to angular, contiguous punctures, slightly smaller laterally, ending in a deep, striate pit next to insertion of hind wings (Fig. 72); a small, impunctate triangle medially on anterior margin, hind margin sometimes impunctate as well. Postscutellum produced into a distinct, backward-projecting blade with parallel or slightly tapering sides, rounded or truncated apically. Postscutellar punctures large, deep, distinct, angular, and contiguous becoming smaller, shallower, and more rounded laterally. Underside of blade with medium, angular, contiguous punctures. Propodeum produced laterally into a more or less sharply pointed spine. Punctation variable; medially a narrow triangle of small to medium, angular, contiguous punctures bordered laterally by two or three very large, angular foveolae; large, angular to round, contiguous punctures lateral to foveolae, becoming smaller anteriorly and towards apex of spine (Fig. 61). Underside of spine deeply excavated, smooth to indistinctly striate (Fig. 72). Mesopleura as in Figure 72.

Wings. Venation as in Figure 11. Basal cell of forewing asetose or nearly so. Remainder of wing covered with short setae. Radial sector relatively short, variable in length. Veins brown, wing membrane clear within basal cells, brownish beyond cells, rarely either completely brown or completely clear.

Legs. Green, blue, or violet, usually metallic. Apex of tibiae and tarsi yellow to brown. Fore femore broadened basally, as wide as deep. Mid and hind femora compressed, usually distinctly punctured above, smooth below. Tibiae, especially apically, more evenly and distinctly punctured than femora. Tarsal claws with one to four inner teeth (Figs. 66-69).

Abdomen. First and second tergites covered in minute, round, distinct, usually moderately spaced punctures medially, becoming small, oval, usually densely spaced laterally and around basal pit of first tergite. Third tergite normally more densely and coarsely punctured than first or second tergites, with small to medium punctures, larger and less distinct laterally and apically. Lateral margins bisinuate, with a shallow groove above apical sinus. Apical, snout-like projection more or less prominent, relatively long, narrow and readily visible to short, broad and not readily visible; truncated apically, the truncation filled with a coloured membrane, varying in colour from yellow to black and incised more or less deeply below. Shape of truncation variable (Figs. 26-35). Sternites green, blue or violet medially, brown laterally, covered with minute, densely spaced punctures (Figs. 15-18, 70).

Pilosity. Head, except scapal basin, with fine, whitish hairs longest on front, shortest along inner, lower margin of compound eyes. Thorax evenly covered with erect, whitish pubescence, appressed on anterior, ventral face of mesopleura, almost absent on posterior face. Legs with long, fine, white, dense hairs on coxae, shorter and sparser on femora, rather setose on tibiae and tarsi. Abdomen with appressed to subdecumbent hair along, and just above, anterior margin of first tergite, lateral margins of first and second tergites, and hind margin of second tergite. Third tergite evenly covered with longer hair except medially along anterior margin (Fig. 71).

Male Genitalia. Similar to those of *Omalus* (Fig. 51) (Bohart and Campos, 1960), but cuspides are long and narrow, not partly enclosing aedeagus, and digiti are relatively narrower (Figs. 14, 43-50).

Immature stages are unknown.

Sexual Dimorphism. In the subfamily Hedychrinae, only *Elampus* has distinct, secondary sexual characters sexual characters which are found in all species except for some in South America.

The differences between males and females are:

1. Genal fringe short, dense, setose in females (Fig. 52); long, sparse, fine in males (Fig. 53).
2. Inner margins of compound eyes slightly convergent below in females (Figs. 8, 56); straight or slightly divergent in males (Figs. 9, 57).
3. Genae relatively broad above in females; relatively narrow in males. This character is somewhat variable and difficult to use.
4. Hind margin of third sternite concave in females; convex in males (Figs. 17, 18).
5. Underside of base of fore femora usually angular and projecting in females, and fringed with short, dense setae; usually rounded in males with relatively long, fine hairs (Figs. 40-41).

Other characters for separating the sexes were given by Buysson (1891) but most of the differences proposed were found to be variable and not applicable to *Elampus* although they could be important for distinguishing males and females of *Omalus*. The computer analysis of quantitative characters gave an almost perfect

separation of the sexes but no attempt was made to determine which of the 16 variables were the most important in the separation of the sexes.

Diagnostic Characters for the Genus

The combination of the backwards projecting, blade-like postscutellum, the truncated, membrane-filled, snout-like projection of the third abdominal tergite and the more or less evenly punctured mesonotum is diagnostic for North American species. The male genitalia can also be used to separate *Elampus* from *Omalus*. In *Elampus* the cuspides are long and slender whereas in *Omalus* they are short and broad.

Key to North American Species of *Elampus*

1. Apical truncation of tergite III round or oval, almost completely filled with membrane (Fig. 27); one vertical, inner tooth in each tarsal claw (Fig. 36); radial sector of forewing about one-half length of stigma ..... *rotundus* sp. nov.
   Apical truncation not as above, usually crescent shaped, only partially filled with membrane which is distinctly incised below (Figs. 26, 28-35); two to four inner teeth in each tarsal claw (Figs. 37-39) (if only one tooth it is set at an angle); radial sector of forewing as long as, or only slightly shorter than, stigma 2
2. Wings hyaline, not at all infuscated beyond venation; each tarsal claw with one or two angled inner teeth ..... *hyalinus* (Aaron)
   Wings more or less infuscated beyond venation; each tarsal claw with three or four inner teeth (rarely only two in some very small specimens) 3
3. Usually large, relatively robust, wasps (5.3-8.2 mm, $\bar{X}$ = 7.0 mm); apical, snout-like projection of tergite III, seen from above, short, not projecting very distinctly beyond the continuous line of the margin of tergite III; membrane in apical truncation usually black, concave, with an incision greater than one half the height of the truncation (Fig. 28); three or four inner teeth in each tarsal claw ..... *viridicyaneus* Norton
   Usually smaller, relatively more slender, wasps (4.1-7.1 mm, $\bar{X}$ = 5.7 mm); apical snout-like projection of tergite III, seen from above, usually long, projecting distinctly beyond the continuous line of the margin of tergite III; membrane in apical truncation usually brown, flat, with an incision less than one half the height of the truncation; usually three inner teeth in each tarsal claw (rarely only two inner teeth in some very small specimens) 4
4. Colour of thorax, especially propodeum, contrasting sharply with colour of abdomen, colour of tergites bright green with a more or less extensive colour varying to coppery-red, rarely only bright green without copper or coppery-red without green 5
   Colour of thorax, especially propodeum, not contrasting sharply with colour of abdomen; colour of tergites variable — green, blue-green, violet or black, occasionally brown or brass coloured 6
5. Average size 4.0-6.0 mm ($\bar{X}$ = 5.1 mm, n = 35); punctures on front distinct, medium in size, mostly contiguous; scapal basin distinctly striate, very little smooth space between punctures of front and striations of scapal basin. Mexico to Canada (Fig. 3) ..... *nitidus nitidus* (Aaron)
   Average size 3.8-5.4 mm ($\bar{X}$ = 4.7 mm, n = 20); punctures on front indistinct, small, densely to moderately spaced; scapal basin almost smooth to finely and indistinctly striate; considerable smooth space between punctures of front and striations of scapal basin. Coastal California (Fig. 3).... *nitidus californicus* subsp. nov.

6. Ratio of width of apical truncation to maximum width of tergite III less than 0.31 (usually about 0.25); punctures on tergite II separate and distinct *marginatus* (Patton)
   Ratio of width of apical truncation to maximum width of tergite III greater than 0.31 (usually about 0.33); punctures on tergite II apparently coalescing and indistinct, giving the tergite a roughened appearance under low magnification 7
7. Colour mainly green ..... *aaroni* Bodenstein
   Colour mainly violet ..... *versicolor* Norton

Elampus hyalinus (Aaron)
Figs. 26, 39, 42, 48, 68
Distribution map Fig. 1

Notozus hyalinus Aaron 1885: 217, 218; original description.
Notozus hyalinus; Cresson 1887: 253; North American list.
Ellampus hyalinus; Mocsáry 1889: 76, 77; key and original description quoted.
Elampus hyalinus; Dalla Torre 1892: 13; world catalogue.
Notozus hyalinus; Bischoff 1913: 6; world list.
Notozus hyalinus; Cresson 1928: 29; type material.
Notozus hyalinus; Brimley 1938: 435; North Carolina list.
Notozus hyalinus; Bodenstein 1951: 719; North American catalogue.

Description. Males. Length 3.9-5.8 mm ($\overline{X}$ = 4.5 mm, n = 10). Other measurements in Table II. Colour green to blue-green often with a violet tinge or reflections on the following: scape, scapal basin, hind margin of vertex and genae, pronotum, mesonotum, laterally on postscutellum, propodeum, and abdomen. Rims of punctures of scutellum and apex of blade of postscutellum dark brown or black. Flagellum brown usually with a reddish tinge. Membrane of wings clear, without brown colouring, with purple or green iridescence in certain lights. Posterior margin of second tergite and membrane in apical truncation usually brown to reddish-brown. On those parts of the specimen having a metallic colour the underlying brown cuticle is often apparent, especially on the scape and legs.

Scapal basin usually rugose, especially laterally, occasionally smooth or indistinctly striate. Punctures on abdomen sparsest on first tergite, densest on third, often with a smooth area with scattered punctures on anterior face of first tergite above basal pit. Lateral margins of third tergite bisinuate, the basal sinuation usually shallower. Apical snout-like projection distinct, narrow, readily visible from above or from the side, sharply truncated apically. Incision in apical membrane relatively shallow (Fig. 26). Tarsal claws with one or two inner teeth set at an angle (Figs. 39, 68). Underside of base of fore femora rounded. Male genitalia as in Figure 48. Measurements in Table IV.

Females. Length 3.3-5.8 mm ($\overline{X}$ = 4.7 mm, n = 25). Other measurements in Table II. Colour of face darker than in males, usually with more extensive violet tinge. Underside of fore femora prominent, angular (Fig. 42).

Variation. The amount and distribution of violet colour on the body varies considerably. The colour of the apical membrane varies from yellow (one specimen seen) to black. The density of punctation on the abdomen also varies slightly. One Mexican specimen had a faint brown tinge in the wing membrane. The depth of the apical incision varies from very shallow to almost half the height of the truncation (Fig. 26).

Diagnosis. The combination of clear wings and one or two angled, inner teeth in each tarsal claw is diagnostic. The more or less rugose scapal basin and relatively

shallow incision in the apical membrane are additional features not usually found in other North American species.

Elampus albipennis Mocsáry, from Eastern Europe and the USSR, also has clear wings and two inner teeth in the tarsal claws.

Type Material. Aaron (1885) described *E. hyalinus* on the basis of three specimens from Montana and Nevada. The female paratype seen was labelled as follows: "Paratype 4912, Nev.". The specimen is quite dirty and the wings partly torn and stuck together making it difficult to see their colour. However, it is a typical *hyalinus*. Its measurements are given in Table I. The lectotype and other paratype were not seen. All three specimens bear the number 4912 and are deposited in the Academy of Natural Sciences, Philadelphia.

Material Examined. 22 males, 53 females. Collection dates extend from 2 April (Blythe — 18 mi. W., Riverside Co., California) to 24 September (Raleigh, North Carolina).

CANADA: ONTARIO: Chatterton.

UNITED STATES: ARIZONA: Apache (3-5 mi. S.W.); Benson (5 mi. S.); Cameron (22 mi. N.); Douglas; Oak Creek Canyon; Portal (5 mi. W., S.W. Research Station, Chiricahua Mountains, 5400'); Toltec (9 mi. S.); Wilcox (and 2.5 mi. S). CALIFORNIA: Blythe (18 mi. W.). COLORADO: State record only; Crook; Lyons; Mont Alto, West Chicago Creek (Clear Creek Co.); Wray. CONNECTICUT: E. Hartford. FLORIDA: Bratt. ILLINOIS: Kankakee. KANSAS: Burdett; Downs; Lawrence; Liberal; Manhattan; Menlo; Clark Co. (County record only); Clay Co. (County record only). MICHIGAN: Grand Junction. MONTANA: State record only. NEVADA: State record only (paratype). NEW MEXICO: Alamogordo; Cloudcroft; Elk (8 mi. N.); Mesilla Park (3 mi. E.); Moriarty; Rodeo (13 mi. N.); Ruidoso; Socorro (6.7 mi. W.); White Sands National Monument (Chaves Co.); Torrance Co. (County record only). NORTH CAROLINA: Raleigh. OKLAHOMA: Grandfield. SOUTH DAKOTA: Maurine. TEXAS: David Mountains (Jeff Davis Co.); Dell City (7 mi. N.E.); Imperial; Romero. UTAH: Greenriver; Lehi.

MEXICO: Concho (Chihuahua); Lake Zocoalco (Jalisco).

Floral Records. *Baccharis glutinosa, Chenopodium watsoni, Melilotus alba.*

Biology. Nothing is known about the life history and immature stages of *E. hyalinus*. No hosts have been recorded.

Elampus rotundus, sp. nov.
Figs. 27, 36, 49, 57, 69, 75
Distribution map Fig. 1

Description. Holotype male. Length 4.4 mm. Head green with violet tinge on clypeus, laterally on face, in ocellar triangle, along posterior margin and in punctures of vertex. Scape brown with a violet tinge. Flagellum dark brown, apical flagellomeres lightest. Pronotum green with bluish tinge and traces of violet laterally. Mesothorax and mesopleura green. Scutellum blackish with green-blue in punctures. Postscutellum dark brown on blade, metallic green basally and laterally. Propodeum green. Legs brown with blue and green. Apex of tibiae and tarsi yellow. Forewings slightly tinged with brown beyond venation, clear basally. Abdomen blue-green with violet tinge medially, green laterally. Lateral margins of third tergite dark brown. Membrane of apical truncation with dark brown rim, yellowish-brown medially and lighter above.

Scapal basin finely rugose, smooth above. Front with distinct, round, small to medium, moderately spaced punctures (Fig. 57). Hairs of genal fringe sparse, fine,

whitish. Pronotum with medium to small, irregularly spaced punctures on dorsum. Edges of mesopleura rounded, not sharp and distinct. First and second tergites with minute, round, distinct punctures medially, larger and more densely spaced laterally; moderately to sparsely spaced on first tergite, densely to moderately spaced on second tergite with a round, impunctate area above basal pit. Third tergite with minute, contiguous punctures medially becoming small to medium laterally and apically. Apical snout-like projection readily visible from above or the side. Apical truncation circular, completely filled with membrane which is only slightly incised below (Fig. 27). Lateral margin of third tergite bisinuate, basal sinuation very shallow, almost straight. Base of fore femora evenly rounded below. Tarsal claws with a single, small, vertical, inner tooth (Figs. 36, 69). Radial sector very short, about half as long as stigma. Male genitalia as in Figure 49. Measurements and ratios as follows: width/length of head, 2.5; width/length of pronotum, 1.8; width/length of tergites I, II, 111, 3.3, 1.5, 1.6, respectively; width/height of truncation, 0.92; ratio of flagellomere I/flagellomere II, 1.43; forewing length, 3.2 mm; stigma length, 0.33 mm; radial sector length, 0.18 mm; distance between compound eyes, 0.77 mm; distance from median ocellus to clypeal margin, 0.81 mm; length of scape, 0.39 mm; distance between lateral ocelli, 0.26 mm; distance from compound eye to lateral ocellus, 0.23 mm; diameter of median ocellus, 0.09 mm.

Allotype (female). Length 5.6 mm. Similar to male except for secondary sexual differences and larger size.

Variation. Males: 4.3-5.1 mm ($\overline{X} = 4.6$ mm, $n = 6$). Females: 3.8-5.9 mm ($\overline{X} = 5.0$ mm, $n = 9$). Other measurements in Table II. There is some variation in colour and punctation. The shades of green and the extent of violet tinge on the different sclerites varies among specimens. The colour of the postscutellum, contrasting strongly with the colour of the mesothorax varies from brown to black with more or less green, blue or violet tinge in some of the punctures. The apical membrane varies from yellow to brown with a darker brown, or occasionally black rim.

The scapal basin is usually finely rugose, especially laterally and around the antennal sockets, but may be smooth. Body punctation varies slightly in density. The apical truncation is usually circular but may be oval (Figs. 27, 75). Male genitalia have relatively short digiti and cuspides (Fig. 49), similar to certain South American species such as *E. gayi* Spinola (Fig. 50). Ratios are: digitus/cuspis length, 0.58; cuspis/paramere length, 0.52 ($n = 2$).

Diagnosis. The combination of the circular apical truncation almost completely filled with membrane, the single, vertical inner tooth in each tarsal claw, and the very short radial sector is diagnostic. The name *rotundus* refers to the circular apical truncation.

E. rotundus is more closely related to South American species of *Elampus* than to other North American species.

Type Material. Holotype (male). Labelled as follows: "Bard, Imperial Co. Cal., 14-VI-1965/Ex cotton/Akins & Roy Coll./CSDA" (blue label). The holotype is deposited in the University of California, Davis.

Allotype (female). Labelled as follows: "Brownsville, Texas, June 25, 1908/ sweeping, S. Tex. Garden/ex. coll. M. A. Cazier". The allotype is deposited in the American Museum of Natural History, New York. Labels indicating the sex and type designation were added to each specimen.

Of the remaining 17 specimens, four are in poor condition or poorly labelled (each labelled: Tex. 1576/from coll. USNM) and are not considered as paratypes.

Paratypes. UNITED STATES: CALIFORNIA: Bard, Imperial Co., VIII-18-1965, H. Ray (UCD) 1 ♀. MISSOURI: Columbia (ex malaise trap), VII-17-1967, F. D. Parker (UCD) 1 ♀. OKLAHOMA: Grandfield, VII-5-1937, Standish-Kaiser (MSU) 1 ♀; Waurika, VII-4-1937, Standish-Kaiser (UCD) 1 ♀. TEXAS: Bay City, V-4-1953, R. H. Beamer (SNOW) 1 ♀; Brownsville, 1929, no name (USNM) 1 ♀; Brazos Co. (County record only), VII-24-1957, A. H. Alex (UCD) 1 ♂; Plano, VII-?-1907, E. S. Tucker (USNM) 1 ♂; Plano, VIII-14-1905, C. R. Jones (USNM) 1 ♂.

MEXICO: El Limon (Tamaulipas), VI-17-1953, no name (CIS) 1 ♀; San Pedro (2 mi. N.E.) (Baja California), IX-19-1967, J. Chemsak, A. & M. Michelbacher (CIS) 1 ♀; Navajo (Sonora), IX-27-1966, G. E. & A. S. Bohart (UCD) 1 ♀; Villa Union (Sinaloa), XI-1-1950, A. Alcorn (SNOW) 1 ♀.

Floral Records. *Gossypium hirsutum, Cucumis sativus.*

Biology. Unknown. No hosts have been recorded.

Elampus nitidus nitidus (Aaron) stat. nov.
Figs. 30-32, 46, 54
Distribution map Fig. 3

Notozus nitidus Aaron 1885: 218, original description.
Notozus nitidus; Cresson 1887: 253, North American list.
Notozus nitidus; Cameron 1888: 458, Central American list.
Notozus nitidus; Provancher 1889: 222, Canadian list.
Ellampus nitidus; Mocsáry 1889: 72, 76: key, original description quoted.
Ellampus nitidus; Dalla Torre 1892: 14, world catalogue.
Notozus nitidus; Bischoff 1913: 6, world list.
Notozus nitidus; Cresson 1928: 30, type material.
Elampus nitidus; Bodenstein 1951: 719, North American catalogue.
Elampus nitidus; Gibson and Carillo 1959: 200, Mexican list.
Ellampus mexicanus Mocsáry 1889: 72, syn. nov.
Ellampus mexicanus; Dalla Torre 1892: 13, world catalogue.
Notozus mexicanus; Bischoff 1913: 6, world list.

Description. Males. Length 4.0-6.0 mm ($\bar{X}$ = 5.0 mm, n = 15). Other measurements in Table II. Colour of head and thorax green, blue-green or violet. Abdomen copper coloured, rarely light green without copper colour. Head light or dark green often with more or less violet in ocellar triangle, along hind margin of vertex and on clypeus. Scapal basin usually lighter green than vertex, often with gold reflections. Pronotum, mesonotum and mesopleura green to blue-green, often with more or less violet tinge or reflections along margins of each sclerite, rarely completely violet on mesopleura. Scutellum green in punctures. Postscutellar blade black apically, rarely brown; green or violet basally, laterally and under blade. Propodeum green, blue-green or violet. Wings hyaline basally, brown stained beyond venation. Abdomen light green, gold and copper, the copper colour usually extending over the central area of each tergite with gold-green or green laterally; rarely either all green or deep coppery-red. Often a dark purple-copper longitudinal median streak on second tergite and a purple tinge near apex of third tergite. Snout-like projection dark brown or black above apex. Apical membrane black, brown or, rarely, yellow. Sternites green or blue-green, sometimes violet.

Scapal basin striate, the striations usually distinct, fine, close together and curved but varying to rather indistinct, wavy, further apart and straight. Punctures

of front distinct, medium-sized and contiguous, rarely densely spaced. Punctures on first tergite minute to small, moderately spaced medially on posterior half of tergite, dense to contiguous around basal pit, often with an impunctate spot or longitudinal line medially. Punctures on second tergite minute, distinct, moderately spaced medially to small, rather indistinct and densely spaced in some Mexican specimens, and oval, small to medium, densely spaced to contiguous laterally. Often a narrow impunctate border along anterior margin. Punctures of third tergite small, densely spaced to contiguous and distinct basally to medium sized and less distinct apically and laterally. Apical truncation with incision less than half the height of the truncation (Figs. 30-32). Tarsal claws with three inner teeth (as in Fig. 37). Male genitalia as in Figure 46. Measurements in Table II.

Females. Length 4.2-5.6 mm ($\overline{X}$ = 5.1, n = 20). Other measurements in Table II. Scapal basin usually with more or less violet, otherwise similar to males.

Variation. The most noticeable variation is in colour. The thorax varies from green with very little violet to almost completely blue or violet. The amount and intensity of copper on the abdomen varies from almost completely copper to coppery-red with very little green laterally to completely green with no copper. The latter forms are rare and tend to be smaller than average. Mexican specimens tend to have a deeper, more extensive, copper colour than do the more northern ones. In addition, some have the punctures of the abdomen closer together and slightly larger, especially on the third tergite, than those in northern specimens. The depth of the apical incision varies and is often relatively shallower in Mexican specimens (Figs. 31, 32). Despite this variation the Mexican specimens cannot be separated objectively from specimens from Canada or the United States into two groups worthy of specific or subspecific status as the differences are not very constant and their limits, both morphological and geographical, are difficult to define.

Diagnosis. The copper or bright green abdomen contrasting strongly with the dark green, blue or violet thorax (especially the propodeum) is diagnostic. Specimens lacking copper may be confused with the green form of *E. marginatus* but in the latter the green colour of the thorax and abdomen is the same shade and does not contrast sharply.

The European species, *E. panzeri* (Fabricius), *E. spina* (Lepeletier), *E. constrictus* (Förster), and *E. sanzii* (Gorgoza) apparently are similar in colour to *E. nitidus*.

Type Material. Aaron (1885) described *E. nitidus* from two males, one from California and one from Montana. He did not designate a holotype. However, the Montana specimen bears a red holotype label and the California specimen bears a blue paratype label. Presumably, these labels were added later, possibly by Cresson (see Cresson 1928: 1-3). Both specimens were examined and the specimen from California was selected as holotype of *E. nitidus californicus* subsp. nov. (see below). The Montana specimen is considered as the holotype of *E. nitidus nitidus*. Measurements of both specimens are given in Table I. The holotype of *E. nitidus nitidus* is missing three tarsal segments of the left mesothoracic leg and two flagellomeres of the right antenna. It is deposited in the Academy of Natural Sciences, Philadelphia.

Elampus mexicanus was described from seven specimens, including both sexes (Mocsáry, 1889). He did not designate a holotype. Five males were seen, one of which is labelled "typus" on a red label. This specimen is considered as a lectotype. The specimens are very dirty and one specimen lacks a head. They are deposited

in the Muséum D'Histoire Naturelle, Geneva. The whereabouts of the other two specimens is unknown.

The specimens of *mexicanus* seen have violet-coloured sternites, a relatively dark (blue-green with considerable violet) coloured thorax, dense or contiguous punctation on the third abdominal tergite, and a relatively shallow incision in the apical membrane (Fig. 32). The colour of the abdomen varies from green with no copper to a deep coppery-red all over. A male labelled *"Notozus mexicanus,* Mocsáry collection" was seen in the British Museum (Natural History) and is virtually identical to the lectotype in the type series. These characteristics agree with those of several other Mexican specimens examined. Possibly these specimens all should be considered as *E. mexicanus*. However, the differences between the Mexican specimens and specimens from further north are relatively small, inconsistent and not easily delimited. Possibly, colour differences could be related to climatic differences (Telford, 1964, Horning, 1969). As there is no clearcut geographical separation of the two groups, *E. mexicanus* is considered to be a synonym of *E. nitidus*.

The male genitalia of one specimen of the type series of *mexicanus* was removed and measured (Table IV). Other measurements for the lectotype are given in Table I. The holotype of *nitidus nitidus* is labelled as follows: "Montana" (white label)/"Type no. 4910" (red label)/"*nitidus* Aaron" (white label with red line near top margin).

Material Examined. 42 males, 62 females. Collection dates extend from 29 May (Furnace Creek, Death Valley, California) to October (Venta de Zopilote, Mexico).

CANADA: ALBERTA: Lethbridge; Pincher. MANITOBA: Aweme; Carberry; Teulon; Virden. SASKATCHEWAN: Big River; Elbow; Little Quill; Moose Jaw; Saskatoon.

UNITED STATES: ARIZONA: Apache (9 mi. N.); Cameron; Eloy (11 mi. W.); San Pedro River, Benson; Toltec (8 mi. S.); Yuma (15 mi. N.). CALIFORNIA: Experimental Farm, (no town) (Imperial Co.); Furnace Creek, Death Valley; Glamis (5 mi. W.); Stove Pipe Wells, Death Valley; Imperial Co. (County record only). COLORADO: Colorado Springs; Denver. IOWA: Sioux City. KANSAS: Aulne; Manhattan; Michigan Co. (County record only); Kalkaska Co. (County record only). MONTANA (State record only) (Holotype). NEBRASKA: Forest Reserve, Halsey; Gothenburg; Niobrara Refuge, Valentine; Rushville. NEVADA: Stillwater (12 mi. E.). NEW MEXICO: Alamogordo (1 mi. S.); Albuquerque; Pinedale; Rosewell; San Mateo. NORTH CAROLINA: Valley of Black Mountains. NORTH DAKOTA: Bismarck; Bottineau; Walcott (11 mi. W.). SOUTH DAKOTA: Brookings; Chamberlain; Elk Point. TEXAS: El Paso; Imperial. WYOMING: Lingle; Tie Hack Campground, Bighorn National Forest (Johnson Co.).

EL SALVADOR: Usulutan.

MEXICO: Anganguco (Type series of *mexicanus);* Concho (Chihuahua); Cuiteco (Chihuahua); Durango (and 6 mi. S.); El Yukon (22 km. W. Toluca) (Mexico); Guadalahara; Hidalgo (6 mi. E. Tulacingo) (Hidalgo); Nombre de Dios (16 mi. S.) (Durango); Petacingo (3 mi. N.) (Puebla); Presidio (Chihuahua); San Jose Viejo (22 mi. S.E. Totalapan) (Oaxaca); Sonoyta (Sonora); Vena de Zopilote (Guerrero).

Floral Records. Alfalfa leaves, *L.* (?) *alyssoides.*

Biology. Unknown. Specimens have been collected up to 8,000 feet (El Yukon, Mexico).

Elampus nitidus californicus subsp. nov.
Figs. 33, 47
Distribution map Fig. 3

Description. Holotype male. Length 4.5 mm. Head green with a black tinge and violet reflections in the ocellar triangle. Lower part of scapal basin brighter green than upper part. Scape brown with a green and violet tinge. Flagellum brown. Pronotum and propodeum green with a black tinge and scattered violet reflections. Mesonotum green. Scutellum and postscutellum largely black with a green tinge and a few violet reflections in punctures of scutellum and basally and laterally on postscutellum. Forewings clear basally, faintly brown beyond venation. Abdomen bright green with extensive copper tinge medially on all tergites. Apical membrane dark brown.

Scapal basin mainly smooth, slightly and indistinctly roughened medially and above antennal sockets. Front with rather indistinct, small to medium, mostly moderately spaced punctures, extending down sides of compound eyes as a few minute, indistinct punctures. Vertex with minute to small, indistinct, sparsely spaced punctures, densely spaced in ocellar triangle. Dorsum of pronotum with small to medium punctures, densely but irregularly spaced. First and second tergites with minute, moderately spaced punctures interspersed laterally with some small to medium ones which are more densely spaced. Punctures around basal pit contiguous. Third tergite with distinct, minute, densely spaced punctures basally; rather indistinct, small to medium and densely spaced laterally and apically. Lateral margins bisinuate, the sinuations subequal. Tarsal claws with three inner teeth. Apical truncation with a relatively shallow incision (Fig. 33). Base of fore femora evenly rounded ventrally. Male genitalia as in Figure 47. Measurements and ratios as follows: width/length of head, 2.2; width/length of pronotum, 1.9; width/length of tergites I, II, III, 2.9, 1.4, 1.6 respectively; width/height of truncation, 1.4; height of truncation/height of incision, 4.0; ratio of flagellomere I/flagellomere II, 1.43; forewing length, 3.3 mm; stigma length, 0.24 mm; radial sector length, 0.22 mm; distance between compound eyes, 0.83 mm; distance from median ocellus to clypeal margin, 0.90 mm; length of scape, 0.45 mm; distance between lateral ocelli, 0.26 mm; distance from compound eye to lateral ocellus, 0.29 mm; diameter of median ocellus, 0.09 mm.

Allotype (female). Length 5.0 mm. Similar to male except for larger size and more intense colour. Head and thorax with more intense and extensive green (with some blue tinge) than holotype. Abdomen deep coppery-red all over with very little green. Scapal basin very evenly and finely striate, smooth above.

Variation. Males: 4.2-5.1 mm ($\bar{X}$ = 4.6 mm, n = 10). Females: 3.8-5.4 mm ($\bar{X}$ = 4.7 mm, n = 10). Other measurements in Table II. Measurements of male genitalia in Table IV. The same variation in colour occurs as in the nominate subspecies. Scapal basin and thorax usually green, sometimes blue-green, rarely violet. Abdomen with more or less copper or reddish-copper, rarely completely green with only a trace of copper. Apical truncation reddish-brown to black. Sternites green, occasionally with blue tinge. Head and thorax in females more frequently blue-green or violet than in males.

Punctation varies slightly in density on the abdomen. The shape of the apical truncation and the depth of the incision vary slightly (Fig. 33).

Diagnosis. The reduced punctation on the front and the almost smooth scapal basin separate most specimens of this subspecies from the nominate subspecies. *E. nitidus californicus* is restricted to coastal California.

Type Material. The California specimen of Aaron's original series of two specimens was selected as holotype of *E. nitidus californicus*. It is labelled as follows: "Cala." (white label)/"Paratype 4910" (blue label). A label indicating the sex and a holotype label were added. The specimen has the left front leg and five flagellomeres of the left antenna missing, otherwise it is in good condition. It is deposited in the Academy of Natural Sciences, Philadelphia. Allotype in University of California, Davis.

Of the remaining 46 specimens, three (from Newhall, Claremont, and Paso Robles) are in poor condition and are not considered as paratypes.

Paratypes. UNITED STATES: CALIFORNIA: Altadena, 15-IV-1944, A. L. Melander (USNM) 1 ♂: Arroyo Mocho (16 mi. S. Livermore), 9-IV-1957, D. Burdick (CAS) 1 ♂; Arroyo Seco Camp (Monterey Co.), 1-V-1960, F. D. Parker, (UCD) 1 ♂; Borrego Valley (San Diego Co.), 18-IV-1957, R. M. Bohart (U. Guelph) 1 ♀; Bradley, 4-IV-1957, R. H. Allen (LINS) 1 ♂; Claremont, no date, Baker, C. H. Muzzall, 3 ♀, 7 ♂, UCR (4), UCD (2), CORN (2), CAS (2); Cronise (San Bernardino Co.), 9-IV-1940, K. S. Hagan (UCD) 1 ♀; Cuyama Valley (Kern Co.), 10-IV-1932, E. P. Van Duzee (CAS) 1 ♂; Grapevine, 12-IV-1932, E. P. Van Duzee (CAS) 1 ♀; Herkey Creek, San Jacinto Mountains, 20-V-1939, E. G. Linsley (UCD) 1 ♀; Lake Mathews, 16-IV-1963, A. L. Melander (USNM) 1 ♂; Newhall (Los Angeles Co.), 20-IV-1940, R. M. Bohart (UCD) 1 ♀; Paso Robles, ?-IV-1928, no name, (CIS) 1 ♀; near Red Rock Canyon (25 mi. N.E. Mojave) (Kern Co.), 14-IV-1962, C. MacNeil, D. Renz, R. Brown (CAS) 1 ♀; Riverside, 21-V-1925, Timberlake (UCR) 1 ♂; San Diego, 5-IV-1891, F. H. Blaisdell (CORN) 1 ♂; Santa Cruz Mountains (Santa Clara Co.), 25-IV-1913, J. C. Bridwell (USNM) 1 ♂; Split Mountain, Anza Desert State Park (San Diego Co.), 1-IV-1955, W. R. M. Mason (CNC) 1 ♀; Yorkville (Mendocino Co.), 24-IV-1928, 7 ♀, 5 ♂ and 17-V-1929, 1 ♀, 2 ♂, E. P. Van Duzee (CAS); San Diego Co. (County record only), no date, R. M. Bohart (CAS) 1 ♂.

Floral Records. *Pacelia* sp.

Biology. One specimen was collected on sand dunes (Borrego Valley, R. M. Bohart). The very early flight period (all specimens collected in April and May) is unusual and shows allochronic separation with *E. nitidus nitidus*.

Elampus viridicyaneus Norton
Figs. 6-10, 15-25, 28, 38, 43, 55, 56, 58, 59, 60, 61, 65, 66, 73
Distribution map Fig. 2

Elampus viridicyaneus Norton 1879: 235; original description.
Notozus viridicyaneus; Aaron 1885: 217, 219; key, redescription.
Notozus viridicyaneus; Cresson 1887: 253; North American list.
Notozus viridicyaneus; Provancher 1889: 220 ,222; Canadian list (?).
Ellampus viridicyaneus; Mocsáry 1889: 77; key, redescription quoted.
Ellampus viridicyaneus; Dalla Torre 1892: 19; world catalogue.
Notozus viridicyaneus; Bischoff 1913: 7; world list.
Notozus viridicyaneus; Viereck 1916: 603; key, Connecticut list.
Notozus viridicyaneus; Taylor 1928: 990; North Carolina list.
Elampus viridicyaneus; Cresson 1928: 30 ; type material.
Elampus viridicyaneus; Bodenstein 1951: 719; North American catalogue.
Elampus viridicyaneus; Krombein 1958: 94; host record.
Elampus viridicyaneus; Krombein 1963: 261; biology.
Notozus viridicyaneus; Evans 1966: 53: host biology.
Elampus viridicyaneus; Kurczewski 1970: 192, 196, 199; ecology.
Elampus spinosus Provancher 1881: 302; key, original description.

Elampus spinosus; Provancher 1883: 581; key, original description quoted.
Notozus spinosus; Aaron 1885: 219; synonomy.
Elampus spinosus; Dalla Torre 1892: 19; synonomy.
Elampus spinosus; Bodenstein 1951: 719; synonomy.
Elampus connexus Viereck 1906: 192; new synonomy.
Notozus connexus; Bischoff 1913: 6; world list.
Elampus connexus; Bodenstein 1951: 519; North American catalogue.

Description. Males. Length 5.3-7.7 mm ($\overline{X}$ = 7.2 mm, n = 10). Other measurements in Table II. Colour dark green, blue-green or blue, often with more or less violet tinge; rarely completely green or violet. Head green often with considerable violet tinge in ocellar triangle, on front, hind margin of vertex and genae, and on scape; often with gold tinge or reflections in scapal basin. Pedicel shiny black usually with green or violet tinge. Flagellum dull black, apical flagellomere sometimes dark brown. Thorax, except for postscutellar blade, green or blue-green with more or less violet tinge. Blade black apically. Wings clear basally, dark brown beyond venation, sometimes brown basally as well. Abdomen, except for black basal pit, green, blue-green or blue with more or less violet tinge especially on dorsum of second tergite, sometimes completely green with no violet or completely violet with no green. Membrane of apical truncation shiny black or very dark brown.

Punctation usually more densely spaced than in other species. Scapal basin striate, striations usually fine, distinct, close together and curved (Fig. 56), less often coarser, further apart and straight (Figs. 8, 9). Front with small to medium, round, distinct, contiguous or, rarely, dense punctures which are slightly smaller posteriorly. Punctures of pronotum medially, small to medium, distinct, mostly densely spaced, sometimes moderately spaced and more or less clumped (Fig. 60). Mesonotum as in Figure 55. Postscutellum and propodeum as in Figure 61. Tarsal claws with three or four inner teeth (Figs. 38, 66). Punctures of abdomen distinct, round, minute on first and second tergites medially, slightly larger and oval laterally, often with two distinct sizes interspersed; puncture density variable — usually dense to moderate medially, dense to contiguous laterally, rarely sparse all over. Punctures on third tergite distinct, angular, contiguous, rarely dense, slightly larger apically and laterally (Fig. 73). Apical snout-like projection broad, short, usually not visible from the side or above, often giving the tergite an evenly rounded appearance. Shape of truncation as in Figure 28. Incision deep, usually greater than half the height of the truncation. Membrane usually concave, and sunk into the apical, snout-like projection, sometimes flat. Third sternite as in Figure 18. Male genitalia as in Figures 43, 58, 59. Measurements in Table IV.

Females. Length 6.8-8.2 mm ($\overline{X}$ = 7.7 mm, n = 10). Other measurements in Table II. Scapal basin dark green to blue-green with more or less violet. Visible sternites and hidden tergites and sternites as in Figures 15-17, 19-25.

Variation. The colour is basically the same in most specimens. However, the amount of violet varies, especially on the abdomen. A few specimens were either completely violet or completely green. The amount of brown on the wings is variable. Most specimens had the basal area hyaline but some had more or less brown. Specimens which were considerably or completely violet often had completely brown wings. Although size is relatively constant and most specimens are large and robust, compared to other species, some specimens are very small, about the same size as *E. marginatus*. The shape of the third tergite and the distinctness of the apical snout-like projection varies from very short and broad to somewhat longer and more prominent. The depth of the incision in the apical truncation is

usually greater than half the height of the truncation but can be less. In general, *E. viridicyaneus* is extremely constant in size, colour, and structure throughout its large range — specimens from Alaska, California, Florida, and Newfoundland being very similar to each other.

Diagnosis. The large, robust appearance; characteristic blue or blue-green colour of the abdomen; relatively short, broad, finely and contiguously punctured third abdominal tergite; very short, broad, apical snout-like projection, hardly visible from above or the side; and the apical truncation filled with dark brown or black, shiny, often sunken (concave) membrane, which has an incision usually greater than half the height of the truncation, are diagnostic. The presence of four inner teeth in the tarsal claw also distinguishes this species but many specimens only have three teeth.

Despite the relatively numerous characteristics which can be used to identify this species, and its relatively constant appearance throughout its range, a number of specimens were very similar to certain specimens of *E. marginatus* and could not be separated from them with certainty.

Type Material. Norton (1879) described *E. viridicyaneus* from a single male specimen (not a female as indicated in his original description). The holotype was examined and is a typical specimen in all respects. Its measurements are given in Table I. The specimen was in excellent condition when examined. Unfortunately it was lost in the mail in March, 1974 during shipment from Guelph to Philadelphia. A neotype was not designated because of the distinctness of this species. The holotype was from Massachusetts, type no. 4920. A male specimen from Edmonton, Alberta, labelled as *viridicyaneus* by two different experts (W. G. Bodenstein and E. H. Strickland) and bearing a label "compared with type" is typical and can be used as a standard for comparison. A female specimen, similarly labelled, is also in the Strickland Collection.

The holotype male of *E. connexus* Viereck was examined. It is definitely a *viridicyaneus*. The apical snout-like projection is more produced than usual and the membrane is flat, dark brown, and has a very shallow incision, but otherwise it is typical of the species. Its measurements are given in Table I. The two apical flagellomeres of each antenna are missing. It is labelled as follows: "Clark Co. Ks., May 1962 ft., F. H. Snow" (white label)/"1062" (white label)/"*Notozus connexus* Vier. Type" (red label). It is deposited in the Snow collection, University of Kansas, Lawrence.

The holotype female of *E. spinosus* Provancher was seen. After describing it as a new species Provancher noted that it was the same as *E. viridicyaneus* Norton and in his unpublished catalogue of his collection and in a later paper (Provancher, 1889) he changed the name *spinosus* to *viridicyaneus*. The specimen is a typical *viridicyaneus*. It is in excellent condition and is labelled as follows: "*Notozus viridicyaneus* Nort." (handwritten by Provancher (?) on white label with double red border)/"990" (yellow label)/"Lectotype 430, *Elampus spinosus* Provancher, Comeau 1940" (red label)/"Holotype, *Elampus spinosus* Provancher, 990, Barron 1971" (red label). It is deposited in the Provancher Collection, Université de Laval, Quebec City.

Material Examined. 263 males, 221 females. Collection dates extend from 25 January (1915, Tallac, Lake Tahoe, California) to 22 September (1961, Central Park, New York City, New York).

CANADA: ALBERTA: Edmonton; Lethbridge, Medicine Hat; Oldman River; Waterton. BRITISH COLUMBIA: Cascade; Oliver (10 mi. N. and Vaiseau

Lake); Revelstoke. MANITOBA: Aweme; Carberry; Wawboden. NEWFOUNDLAND: Aspen Brk. Camp; Buchans; Gander. ONTARIO: Belleville; Bothwell; Brighton; Constance Valley (?); Finland; Guelph; Kearney; Kings Mountain; Madoc; Ottawa (and Mer Bleue); Petawawa; Prescott, Sudbury; Toronto; Trenton. PRINCE EDWARD ISLAND: Alberton. QUEBEC: Abbotsford; Aylmer (Queen's Park); Chelsea; Gatineau Park; Harrington Lake; Hull; Kirk's Ferry; Knowlton; Meach Lake; Montreal; Old Chelsea; Ste. Térèse Island (St. John's Co.); Ville d'Anjour. SASKATCHEWAN: Prince Albert; Willows.

UNITED STATES: ALASKA: Fort Yukon. ARIZONA: Williams. CALIFORNIA: American River (Sacramento Co.); Arroyo Seco Camp (Monterey Co.); Blodgett Forest (12 mi. N.E. Georgetown) (El Dorado Co.); Bridge Creek Camp (Lassen Co.); Brockway; Buck's Lake (Plumas Co.); Camp Angelus (4 mi. S.) (San Bernardino Mountains); Carnelian Bay (Lake Tahoe); Carrville; Carson River (West Fork) (Alpine Co.); Cayton; Chester (6 mi. N.W. Bennett Creek) (Plumas Co.); Clio; Crystal Lake (Los Angeles Co.); Dardanelles (5 mi. E.); Dunsmuir (Siskiyou Co.); Elsinore (4 mi. E.) (River Co.); Fieldbrook; Hallelujah Junction (Lassen Co.); Hat Creek (Shasta Co.); Herkey Creek (San Jacinto Mountains); Huntoon Forest Camp (Mono Co.); Independence Lake (Sierra Co.); Leland Meadow (Tuolumne Co.); Lone Pine; Lost Lake, Quincy (4 mi. W.) (Plumas Co.); McCloud (5 mi. E.) (Siskiyou Co.); Millard Cyn (River Co.); Old Station (Shasta Co.); Pasadena; Red Bluff (Tehama Co.); Red Box; Rock Creek Campground (Mono Co.); Samuel Springs (Napa Co.); San Bernardino Mountains; Sattley (Sierra Co.); Sierraville (Sierra Co.); Strawberry (Tuolumne Co.); Tallac (Lake Tahoe); Trinity River Camp (Trinity Co.); Volcano (Amador Co.); Yreka (Siskiyou Co.); Yuba Pass (Sierra Co.); Mariposa Co. (County record only); Tuolumne Co. (County record only). COLORADO: Boulder (4.5 mi. N.); Manitou; Padre Canyon. CONNECTICUT: Cromwell; Stichfield; Storrs. FLORIDA: Pierce Island Homestead (Alachua Co.); Torreya State Park (Liberty Co.). GEORGIA: Atlanta. DISTRICT OF COLUMBIA: Rock Creek Park; Washington. IDAHO: Chatcolet; Deary; Moscow (and 7 mi. N.E.); Moscow Mountains. ILLINOIS: Giant City State Park (Union Co.); Willow Springs. INDIANA: Hessville. IOWA: Sioux City. KANSAS: Medora; Douglas Co. (County record only). KENTUCKY: Barren Co. (County record only). MAINE: Dryden; Jonesboro; Orono; Washington Co. (County record only). MARYLAND: Cabin John; Laurel; N.W. Branch Park (Montgomery Co.); Plummer Island (Montgomery Co.). MASSACHUSETTS: Beach Bluff; Cambridge; Lexington; Wellesley Hills. MICHIGAN: Bath; Benton Harbour; East Lansing; Galien; Gull Lake Biological Station (Kalamazoo Co.); Midland; Owosso; the following are county records only — Alger Co.; Arena Co.; Berrien Co.; Cheboygan Co.; Chippewa Co.; Clare Co.; Houghton Co.; Leelanau Co.; Manistee Co.; Midland Co.; Missaukee Co.; Monroe Co.; Ontonagon Co.; Osceola Co.; Roscommon Co.; Saginaw Co.; Wexford Co. MINNESOTA: Detroit Lakes; Anoka Co. (County record only). MISSOURI: Joplin (Jasper Co.). MONTANA: Bolton; Sula (Ravalli Co.). NEBRASKA: Sheridan Co. (County record only). NEVADA: Kingsbury (Douglas Co.); Patrick (Washoe Co.); Verdi (Washoe Co.); Yerington. NEW HAMPSHIRE: Hannover. NEW JERSEY: Lawrenceville (Mercer Co.); Princeton; Smate Hill. NEW MEXICO: Loving. NEW YORK: Brainard (Rensselaer Co.); Buffalo; Cherrytown; Cold Spring Harbour (Long Island); Flatbush (Long Island); Flushing (Long Island); Heart Lake (Essex Co.); Hempstead (Nassau Co.); Herkimer; Huntington (Kalbfleisch Research Station); Huyck Preserve; Ithaca (Cornell University Campus, Six Mile Creek, South Hill); Lewisboro (Westester Co.); Minetto; New Rochelle; New York (Central Park, Inwood Hill Park); Rensselaerville; Rochester; Tomkins Co.

(County record only). NORTH CAROLINA: Clayton; Fort Bragg (Cumberland Co.). NORTH DAKOTA: Tower City. OHIO: Barberton; Columbus. OKLAHOMA: Guthrie. OREGON: Belknap Springs (Lane Co.); Butte Falls; Corvallis; Forest Grove. PENNSYLVANIA: Avonia, Erie, Leheigh Gap; Presque Isle State Park (Erie Co.). SOUTH DAKOTA: Fort Thompson. TENNESSEE: Chimneys (Great Smoky Mountains National Park); Knox Co. (County record only). TEXAS: Taylor. UTAH: Fort Duchesne; Park City. VERMONT: Thetford. VIRGINIA: Barcroft; Falls Church Lake; Great Falls. WASHINGTON: Wawawai. WISCONSIN: Clover Leaf Lakes (Shawano Co.); Madison; Shawano Co. (County record only). WYOMING: Easterbrook; Jenny Lake.

Floral Records. *Heracleum lantanum, Melilotus alba, Lyonia ligustrina, Euphorbia* sp.

Ecology. Specimens have been caught up to 6,790 feet (Huntoon Forest Camp, Mono Co.) (California). According to Krombein (1963) this species is multivoltine in Maryland. Kurczewski (1970) suggested that it had a single generation a year at the latitude of Erie Co., Pennsylvania. He also suggested, on the basis of his collection records and records from specimens in Cornell University, that the peak abundance of *E. marginatus* in mid to late July coincided with the wane and eventual disappearance of *E. viridicyaneus*. A comparison of dates of capture of the specimens of *E. marginatus* and *E. viridicyaneus* seen in the present study is given in Table VI. The results support Kurczewski's observations on these two species in Erie Co., Pennsylvania.

A specimen of *E. viridicyaneus* in the USNM labelled "Bred from nests of *Gorytes* (s.l.) from Huntington, L.I. Cocoon March 24, 1924. em. April 30, 1924. S. C. Bridwell" is the only known host record for a North American *Elampus*. Krombein (1958, 1963) determined the host as *Psammecius (Hoplisoides) costalis* Cresson. The distribution of this host is mainly eastern North America. Since *E. viridicyaneus* occurs throughout the continent it must parasitize other species of *Psammecius* or, possibly, other genera.

Elampus marginatus (Patton)
Figs. 29, 37, 40, 41, 44, 52, 53, 62-64, 67, 70, 72, 74
Distribution map Fig. 4

Notozus marginatus Patton 1879: 66; original description.
Notozus marginatus; Aaron 1885: 219; key, redescription.
Notozus marginatus; Cresson 1887: 253; North American list.
Notozus marginatus; Provancher 1889: 220, 320; Canadian list.
Ellampus marginatus; Mocsáry 1889: 78; key, redescription quoted.
Notozus marginatus; Smith 1890: 43; New Jersey list.
Ellampus marginatus; Dalla Torre: 13; world catalogue.
Notozus marginatus; Cockerell 1898: 212; New Mexico list.
Notozus marginatus; Smith 1909: 668; New Jersey list.
Notozus marginatus; Bischoff 1913: 6; world list.
Notozus marginatus; Viereck 1916: 603; key, Connecticut list.
Notozus marginatus; Britton 1920: 322; New York list.
Notozus marginatus; Essig 1926: 869; Western North America.
Notozus marginatus; Taylor 1928: 990; New York list.
Notozus marginatus; Brimley 1938: 435; North Carolina list.
Notozus marginatus; Procter 1938: 431; Maine list.
Elampus marginatus; Procter 1946: 492; Maine list.
Elampus marginatus; Bodenstein 1951: 719; North American catalogue.
Elampus marginatus; Krombein 1958: 94; North American catalogue (supplement).

Elampus marginatus; Gibson and Carillo 1959: 200; Mexican list.
Elampus marginatus; Kurczewski 1970: 192, 196; ecology.

Description. Length: males, 4.8-7.1 mm ($\bar{X}$ = 5.8 mm, n = 10); females, 4.7-6.1 mm ($\bar{X}$ = 5.7 mm, n = 10). Other measurements in Table II. Colour extremely variable. A number of distinct colour forms were recognized and can be separated by the following key.

1. Pronotum distinctly bicolourous, black or deep violet medially, green or blue-green along margins; second abdominal tergite bicolourous, black or violet basally and medially, green or blue-green laterally ..... green-black form
   Pronotum and second abdominal tergite unicolourous, black, blue, violet or green 2
2. Thorax and abdomen black ..... black colour form
   Thorax and abdomen green ..... green colour form
   Thorax and abdomen blue-green, blue or violet ..... other colour forms

Many intermediate combinations occur and it may be difficult to separate the different forms. The distinction between blue-green, blue, and violet is rather arbitrary so these were grouped together as "other colour forms". The green-black form is typical and, with rare exceptions, is the only one occurring in the north-east from where the species was originally described. Each colour form is described separately, followed by a general description of structure.

Green-black Form. Face usually green, rarely violet in males, commonly violet in females, sometimes almost black. Front usually green or blue-green. Vertex greenish-black, sometimes green or violet, usually darker than front. Pronotum usually black medially, sometimes violet or bluish, narrowly green or blue-green anteriorly, laterally, on sides, and sometimes along posterior margin. Mesonotum and scutellum black with green, blue or violet in punctures or a green or violet tinge. Mesopleura and propodeum green, blue-green or violet. Postscutellum black on blade, green and violet in punctures basally and laterally. First tergite more or less black or violet medially, sides green to blue-green. Second tergite broadly black medially along anterior margin, violet to blue-green medially and posteriorly, green or blue-green laterally, especially at postero-lateral corners, occasionally violet. Third tergite black and violet medially at base, blue-green to green apically and laterally, often with violet reflections. Apex of snout-like projection often narrowly brown above. Apical membrane brown with a black border, sometimes completely black, occasionally yellow.

Occasionally, the pronotum may be unicolourous whereas the abdomen is bicolourous or vice versa. Such specimens are considered to belong to this colour form. The amount of black, especially on the abdomen, is extremely variable. Specimens with extensive black approach the black colour form.

Black Colour Form. Face green or blue-green with more or less violet. Front violet, sometimes black. Vertex black occasionally with violet or blue-green tinge. Genae blue-green or violet, occasionally black. Thorax black with variable amounts of green, blue or violet on mesopleura and propodeal spines and sometimes green or violet tinged on the margins of pronotum, mesonotum, scutellum, and postscutellum. Abdomen black, often with a brown underlay which may almost completely replace the black in some specimens [rufinism of Balthasar (1954)]; a deep violet tinge may be present laterally, less frequently a blue or green colour as in the green-black form. Sternites usually brown, sometimes green or blue-green.

Green Form. Face green, often with more or less gold, occasionally bronze, reflections medially, rarely with blue or violet. Front and vertex green sometimes with blue or violet along posterior margin of vertex. Genae green often with gold or brassy tinge below. Pronotum, mesonotum, and mesopleura green often with gold reflections, rarely with blue or violet reflections. Scutellum with green in punctures and black rims. Some specimens had considerable copper on the mesonotum. Propodeum green, often with blue or violet tinge. Abdomen green, sometimes with gold reflections, less often with a bluish tinge.

Other Colour Forms. These are similar to the green form but the green is replaced by blue, blue-green or violet, without gold reflections. Various shades of blue are most common and violet appears least often.

Structure. Scapal basin usually striate, striations rather wavy, uneven, indistinct or distinct, and straight or curved, often becoming rugose laterally and below. Front with distinct, round, medium to large, contiguous to densely spaced punctures. Pronotum with round, usually indistinct, medium, densely spaced punctures, often clumped medially. Tarsal claws with three inner teeth (Figs. 37, 67). Fore femora of males rounded ventrally at base (Fig. 41), more or less projecting in females (Fig. 40). Wings clear basally, faintly to distinctly brown beyond venation. Punctation of thorax and abdomen similar to *E. nitidus nitidus*. Shape of abdomen, especially third tergite, variable, relatively long and narrow to relatively short and broad. Lateral margins bisinuate. Third tergite with margins convex as seen from above. Apical snout-like projection distinct, readily visible from the side or from above with a few exceptions. Apical truncation with incision less than one-half height of apical truncation (Figs. 29, 74), occasionally deep, not as shallow as in *E. hyalinus* except in some southern specimens. Male genitalia as in Figure 44. Measurements in Table II.

Variation. The most noticeable variation is in colour as described above. The green-black form and the black form appear to be a sub-group of their own and the green form and other colour forms make up another sub-group. Structurally, no consistent differences were found among the different colour forms. Similarly, no consistent, structural differences were found between the green form of *marginatus* and *E. nitidus nitidus*. Since there is close similarity among specimens of the latter without copper colour and green specimens of the former it could be argued that they form one species. However, until information on the biology of the different colour forms of these two species is available and perhaps shows that they are the same they will be considered as separate. It could be argued that *E. nitidus nitidus* and *marginatus* form one species as the computer analysis separated them only partially, thus showing their close relationship. The separation is sufficient, however, to warrant keeping the two as species distinct (Table VII). The geographical distribution of *E. nitidus nitidus* and the green form of *marginatus* is somewhat different (Figs. 3, 4). There is also a tendency for geographical separation of the other colour forms of *marginatus*. The black form is restricted essentially to British Columbia, Washington, Oregon, and Idaho. The green-black form is mainly north-eastern and northern. The green form and the other colour forms are mainly western and southern. However, with the possible exception of the black colour form, the distributions of each form are throughout North America and they all overlap broadly.

There is considerable variation in the shape of the abdomen and in size of the whole insect. The black colour form tends to have a relatively narrow body, and the green colour form has a robust appearance somewhat similar to that of *E. viridicyaneus* in some instances. There is great variation in the shape of the third

tergite, which may be relatively broad and short or relatively long and narrow, and in the distinctness of the apical snout-like projection. However, the variation is subtle and apparently continuous and no constant differences could be found among different populations.

A number of specimens from Arizona, New Mexico, and Mexico have dense to contiguous punctures on the abdomen and the density of punctures on the remainder of the body is greater than normal. The punctures on the third tergite also average larger than normal, being distinct, angular, medium rather than indistinct and small), contiguous and clearly differentiated from the small basal punctures. In these specimens the apical truncation usually has a very shallow incision as in *E. hyalinus*. A similar situation with regard to punctation density, shape of apical truncation, and geographical distribution occurs in *E. nitidus nitidus* as discussed above.

E. marginatus is an extremely variable, widespread, and relatively common species as considered here. In eastern North America it is relatively uniform in colour and structure but in western North America it becomes relatively more complex. Possibly a number of closely related species actually occur there and may be distinguished eventually.

Diagnosis. The three inner teeth of the tarsal claw, the striate scapal basin (not as distinctly striate as in *viridicyaneus),* the distinctly visible apical snout with an apical truncation having an incision less than half the height of the truncation and the characteristic colours of the different colour forms are diagnostic.

A number of specimens appear very similar to small specimens of *viridicyaneus*. Some specimens of the green colour form may be confused with green *E. nitidus nitidus* but the strongly contrasting colour of the abdomen and propodeum of the latter species should distinguish them.

Type Material. Patton (1879) described *E. marginatus* from a single specimen from Waterbury, Connecticut. His collection, including the type, was destroyed (Britton and Howard, 1921). The original description does not give the sex but mentions "face . . . with a violet reflection" and "anterior femora angulated beneath", thus indicating that the original specimen was likely a female. Of the seven specimens seen from Connecticut in the present study, one was chosen as neotype. It is a female in good condition and is labelled as follows: "Conn. Riverbank, E. Hartford, Ct., Aug. 18, 1947, Howard E. Evans./CORN". A label indicating the sex and a red neotype label "Neotype *Notozus marginatus* Patton, 1879, Designated by Huber, 1975" were added. The neotype is deposited at Cornell University, Ithaca. The specimen agrees fairly well with the original description and is a green-black colour form. Its measurements are given in Table I.

Material Examined. 467 males, 657 females (black form, 22 ♂♂, 17 ♀♀; green form 70 ♂♂, 100 ♀♀; green-black form, 160 ♂♂, 240 ♀♀; other forms, 215 ♂♂, 300 ♀♀). Collection dates extend from 26 March (Wood Lake, Tulare Co., California) to 22 October (Austin, Texas).

Colour forms are indicated after each collection locality by the following symbols: B black form, G green form, O other forms, T typical green-black form.

CANADA: ALBERTA: Banff (G); Beaverlodge (T); Bilby (T); Brooks (O); Clyde (G); Drumheller (T); Edmonton (G, T, O); Empress (T); Fort McMurray (G, T); Grande Prairie (G, T); Grimshaw (G, T); High Prairie (T); Lethbridge (G, T); Lundbreck (G); Medicine Hat (T); Onefour (T); Red Deer (T); Rycroft (T, O); Steveville (G); Wabamun (T); Wainwright (T). BRITISH

COLUMBIA: Bowser (T); Cheekye (B); Chilcotin (G, T, O); Clinton (B); Grand Forks (O); Hargreaves (Soda Creek) (O); Hat Creek (T); Hatzic Lake (B); Howser (Selkirk Mountains) (B); Kamloops (G, T, O); Kaslo (B); Keremeos (O); Lytton (6 mi. N.) (O); MacGillivary Creek Game Reserve (Chilliwack) (B); Manning Park (G); Milner (B); Mission City (B); Nelson (T); Nicola (T, O); Oliver (G, T, O); Osoyoos (G, O); Pavilion (T); Pavilion Lake (T); Princeton (4 mi. W.) (G); Quesnel (B, T, O); Richter Pass (Osoyoos) (G, T, O); Rolla (T); Salmon Arm (B); Salmon River (Glenemma) (B, T); Sicamous (T, O); Soda Creek (B, T); Stoner (O); Summerland (O); Terrace (B); Vaiseau Lake (Oliver) (G); Vernon (G, O); Victoria (G); Walhachin (G, T); Westwick Lake (Cariboo) (G, T); White Lake (Oliver) (G). MANITOBA: Aweme (T); Carberry (O); Gillam (T); Ninette (T); Souris (T); The Pas (T); Virden (T); Waboden (T); Winnipeg (T). NEW BRUNSWICK: Fredericton (Acadia Experimental Station) (T); Nerepis (T). NOVA SCOTIA: Kentville (T); Truro (T). ONTARIO: Bancroft (T); Chatterton (T); Coniston (T); Dorset (T); Harrow (T); Hepworth (T); Kearney (T); Kendal (T); Kincardine (O); London (T); Madoc (Crystal Beach) (T); Midland (T); Muskoka (T); New Glasgow (T); Ottawa (T); Primrose (T); Salines (T); Shetland (T); Strathroy (T); Swansea (T); Toronto (T); Tweed (T). PRINCE EDWARD ISLAND: Bradley Beach National Park. QUEBEC: Brysonville (5 mi. E.) (T); Duchesnay (T); Forestville (B); Fort Coulonge (T, O); Hemmingford (T); Knowlton (T); Ladysmith (T); Megantic (T); Richmond (T); Shawville (T); Ste. Anne de Bellevue (T). SASKATCHEWAN: Assiniboia (T, O); Big River (G, T, O); Canora (T); Christopher Lake (G, T); Elbow (G, T); Lebret (T); Lumsden (T); Melfort (T); Prince Albert (G, T); Saskatoon (G, T); Stockholm (T); White Fox (T).

UNITED STATES: ALABAMA: Montgomery (G). ALASKA: Burkville (G); Fairbanks (T). ARIZONA: Buckeye (5 mi. S.) (G); Continental (G); Douglas (San Bernardino Ranch and 3 mi. N.) (O); Flagstaff (G, O); Florence (O); New River (10 mi. W.) (G); Oak Creek Canyon (O); Sacaton (O); San Francisco Mountains (O); White Mountains (O). CALIFORNIA: Almanor Dam (1 mi. W.) (Plumas Co.) (T, O); Alpine Creek (Tahoe) (O); Bairsden (O); Barton Flats (San Bernardino Co.) (G); Big Flat, Coffee Creek (Trinity Co.) (O); Big Sandy Flat (Madera Co.) (O); Boca (T); Bridge Creek Camp (Lassen Co.) (O); Bridgeport (Mono Co.) (O); Buck's Lake (Plumas Co.) (O); Carnelian Bay (Lake Tahoe) (O); Carville (Trinity Co.) (O); Claremont (G, O); Coffee Creek Research Station (10 mi. N.) (Trinity Co.) (O); Cottonwood Creek (Mono Co.) (O); Dardanelle (G, O); Davis (T, O); Davis Creek (Madoc Co.) (T); Dos Pasos (O); Echo Lake (El Dorado Co.) (O); El Centro (G); Felton (O); Fresno (O); Fuller Lake (Nevada Co.) (O); Glennville (O); Gold Lake (Sierra Co.) (O); Grapevine (O); Green Mountain (Madoc Co.) (O); Hallelujah Junction (Lassen Co.) (O); Hat Creek (Shasta Co.) (T, O); Hat Lake (Lassen Co.) (O); Hemet (G, O); Hesperia (G); Holtville (and 2.5 mi. E.) (G); Hope Valley (Alpine Co.) (G, O); Huntington Lake (Fresno Co.) (T, O); Independence Lake (Sierra Co.) (O); Indio (Keosegan Ranch) (G, O); Jackson Lake (Nevada Co.) (O); Kennedy Meadow (T, O); Lassen Park (Shasta Co.) (T); Lake Tahoe (O); Lindsay (O); Little Lake (Inyo Co.) (O); Little Rock (1 mi. W.) (G); Lone Pine (O); Los Angeles (4 mi. E.) (O); Mather (T); Meyers (T) (and 2 mi. S.) (G); Mira Loma (1 mi. N.) (O); Montebello (O); Moose Camp (Shasta Co.) (O); Mountain Meadow Ranch, Coffee Creek (Trinity Co.) (O); Newark (O); Niles (O); Oasis (O); Olancha (O); Old Station (Shasta Co.) (O); Onion Valley (Plumas Co.) (O); Palm Springs (G, O); Palo Verde (3 mi. S. and 2 mi. W.) (O); Patterson (T); Placerville (O); Pleasanton (O); Red Lake (1.5 mi. N.E.) (Alpine Co.) (G, O); Ripley (O); Riverside (G, O); Russell Valley

(Nevada Co.) (T); Sacramento (T) (and 7 mi. N.) (O); Sagehen Creek (near Hobart Mills) (Nevada Co.) (G, O); San Diego (G); San Gabriel River (Los Angeles Co.) (G); Sattley (O); Sierraville (O); Silver Lake (El Dorado Co.) (O); Smith Meadow (9 mi. Canyon) (5 mi. E.) (Tulare Co.) (O); Spaulding (G); Strawberry (G, O); Summit Camp (Lassen Co.) (O); Susan River Camp (Lassen Co.) (T, O); Tallac Lake Tahoe (G); Tamarack Lake (G); Thermal (G); Thousand Palms (O); Three Rivers (O); Tracey (T, O); Tragedy Springs (6 mi. W.) (Amador Co.) (O); Vail Lake (Riverside Co.) (G); Volcano (O); Westley (O); Westwood (O); White Mountains (and Blanco's Corral) (Mono Co.) (O); Woodlake (Tulare Co.) (O); Yosemite National Park (G, O) (and Crane Flat) (O); Yuba Pass (Sierra Co.) (O). The following are county records only: Los Angeles Co. (O); Plumas Co. (O); San Bernardino Co. (0); Shasta Co. (T); Siskiyou Co. (O). COLORADO: Boulder (T); Buena Vista (G); Clark (O); Florissant (G); Estes Park (G, T, O); Golden (4 mi. S.W.) (T); Gothic (Elk Mountains) (O); Idaho Springs (3 and 5 mi. S.W.); Jefferson (G); Kremmling (G); Lyons (O); Mount Evans (Doolittle Ranch) (T); Nunn (Owl Creek) (G); Pine Cliffe (G); Poudre River Canyon (T); State Bridge (O); Westcliffe (O). CONNECTICUT: E. Hartford (and riverbank) (T); New Haven. DISTRICT OF COLUMBIA: Washington (G, O). FLORIDA: Arcadia (T). GEORGIA: Chattooga River (Addie Branch, East Fork) (T); Medonough (G); Toccoa (G); Warwoman Creek (Rabun Co.). IDAHO: Bovill (G); Caldwell (O); Cambridge (8 mi. S.) (O); Challis (O); Filer (O); Glenns Ferry (T); Granite (G); Hagerman (O); Jerome (O); Kimberly (O); Lake Fork (O); Paris (O); Potlach (O); Rock Creek Research Station (Minidoka National Forest) (O); Tuttle (T, O); Twin Falls (B, O). ILLINOIS: Carbondale (G); Meredosia (G). IOWA: Pleasant Valley (T); Sioux City (T, O); Sgts. Bluff (?) (O). KANSAS: Manhattan (O); Sumner Co. (County record only) (O). LOUISIANA: (State record only). MAINE: Dryden (T); Salisbury Cove (T). MARYLAND: Crownsville (G); Oakland (G). MASSACHUSETTS: Bedford (T); Lexington (O); Woods Hole (T). MICHIGAN: Atlanta (T); Benton Harbour (T); Block Lake (T); Cedarville (T); Detroit (T); Dexter (T); Douglas Lake (T); East Lansing (T); Escanaba (T); Gull Lake Biological Research Station (Kalamazoo Co.) (T); Kalamazoo (T); Marquette (T); Sleeping Bear (G); Van Riper State Park (Marquette Co.) (T); Welderness Park (Emmet Co.) (T). The following are county records only: Cheboygan Co. (G); Delta Co. (T); Dickinson Co. (T); Ingham Co. (T); Kalkasha Co. (T); Muskegon Co. (T); Osceola Co. (T); Wexford Co. (T). MINNESOTA: St. Peter (T). MONTANA: Jefferson Island (T). NEBRASKA: Oshkosh (8 mi. N.E.) (O). NEVADA: Beatty (A); Beowawe (O); Kingsbury (O); Mount Rose (summit) (Washoe Co.) (O); Orovada (Patrick Co.) (T, O); Wine Cup Ranch (Elko Co.) (O); Winnemucca (G); Yerington (O). NEW HAMPSHIRE: Durham (T); Etna (T); Gorham (T); Lancaster (T); Meredith (T). NEW JERSEY: Englewood (T); Riverton (G). NEW MEXICO: Alamagordo (O); Albuquerque (G); Animas (O); Cloudcroft (T, O); Hot Springs (Truth or Consequences) (O); Jemez Springs (G); Las Cruces (O); Loving (G); Pinedale (O); Rodeo (G); White Sands National Monument (Otero Co.) (G). NEW YORK: Adiron Mountains (Axton) (T); Allegheny State Park (T); Cherrytown (T); Flatbush (T); Flushing (T); Ithaca (T); Kalbfleisch Research Station (Huntingdon, L.I.) (T); Karner (T); Lake Wacabuc (T); Lynbrook (T); N. Fairhaven (T); Pocantin Hills (T); Potsdam (T); Powder Mills (T); Riverhead (Long Island) (T); Sloansville (B, T); Saint Mary's Pond (Oswego Co.) (T); Long Island (County record only). NORTH CAROLINA: Highlands (and Horse Cove) (T); Holly Shelter (G); Jacksonville (G); Nance (?) (G); Raleigh (G). NORTH DAKOTA: Dickinson (O); Elbowoods (T); Tower City (T); Walcott (11 mi. W.) (G). OKLAHOMA: Lake Texoma (2 mi.

E. Wallis) (G); Lawton (O); Leflore (O). OREGON: Catherine Creek State Park (Union Co.) (O); Corvallis (B, G, O); Lake of the Woods (O); Santiam Pass (O); Siskiyou (G); Tall Gate (Blue Mountain) (O). PENNSYLVANIA: Lingelstown (T); Pittsburg (T); Presque Isle State Park (Erie Co.) (T); Wintergreen Gorge (1 mi. S. Erie) (T). SOUTH CAROLINA: Seneca (G). SOUTH DAKOTA: Custer (G); Hecla (G); Warren Woods (White) (T). TEXAS: Austin (G); Imperial (G); Mason (12 mi. N.) (O). UTAH: Cedar Breaks (O); Cedar Breaks National Monument (10 mi. N.) (Iron Co.) (G, O); Duck Creek Camp (Kane Co.) (G, O); Echo (Glenwood Co.) (O); Green Lake (Daggett Co.) (G); Greenriver(O); Leeds(O); Lehi(O); Logan-Cache Airport(1 mi. W). (Cache Co.) (O): Lost Creek, Uinta Mountains (O); Monte Cristo (O); Navajo Lake (O); Panguitch Lake (Garfield Co.) (O); Saint George (O); Topaz (O). VERMONT: E. Thetford (T); Jamaica (T); Wildham Co. (County record only) (T); Windsor (County record only) (T). WASHINGTON: Almota (O); Coulee City (O); Easton (G); Grand Coulee Dam (Harrah Co.) (O); Irrigation Experimental Station (Benton Co.) (O); Lake Chelan (Chelan Co.) (B); Lind (O); Moses Lake (O); O'Sullivan Dam (Grant Co.) (O); Othello (2 mi. N.) (O); Palouse (O); Pullman (G, T, O); Quincy (O); Roy (B); Spanaway (B, T); Toppenish (O); Uniontown (G); Vancouver (O); Wawawai (O); White Swan (G); Yakima (O). WEST VIRGINIA: Lost River State Park (Hardy Co.) (T). WISCONSIN: Madeline Lake (Oneida Co.) (T); Mountain (G); Razorback Lake (G); Shawano Co. (County record only) (T). WYOMING: Bighorn National Forest (Tie Hack Campground) (Johnston Co.) (G); Green River (G); Jackson (6 mi. N.) (G, O); Jackson Hole Research Station and Jenny Lake (Grand Teuton National Park) (G); Laramie (40 mi. N.E.); Little America (22 mi. W.) (G); Newcastle (6 mi. N.W.) (O); Yellowstone National Park (Roosevelt Lodge and Turbid Lake) (O).

MEXICO: Escalon (12 mi. N.) (Chihuahua) (O).

Floral Records. *Beta vulgaris, Iva axillaris, Lepidium thurberi, Medicago sativa, Melilotus alba, N(orta)? altissima, Polygonella polygama, Solanum tuberosum, Trifolium pratense, Vigna sinensis, Actinea, Chrysothamnus, Euphorbia, Helianthus, Populus, Symphoricarpos, Trifolium, Carduus.*

Biology. Specimens of *E. marginatus* have been collected up to 10,000 feet (10 mi. N. Cedar Breaks National Monument, Iron Co., Utah).

Kurczewski (1970) collected *marginatus* on sand and on gravel at edges of woodlands. The present author has seen specimens being collected near a stand of young poplar on sand dunes covered with sparse, low-growing vegetation at Hepworth, Ontario. Records from five pinned specimens seen in this study indicate that they were collected on sand dunes or dune associations. Collection dates of *marginatus* seen in the present study are given in Table VI. The somewhat later flight period of *marginatus* compared to *viridicyaneus* is evident although the different geographical areas covered do not make the results strictly comparable. No hosts have yet been recorded.

Elampus aaroni Bodenstein
Figs. 34, 35
Distribution map Fig. 5

Notozus productus Aaron 1885: 219; key, original description (nec Dahlbom 1854: 44).
Elampus productus; Mocsáry 1889: 78; original description and key quoted.
Ellampus productus; Dalla Torre 1892: 14; world catalogue.
Notozus productus; Bischoff 1913: 6; world list.
Notozus productus; Cresson 1928: 30; type material.

Notozus productus; Brimley 1938: 435; North Carolina list.
Elampus productus; Bodenstein 1951: 719; North American catalogue.
Elampus aaroni Bodenstein 1951: 719; new name, North American catalogue.

Redescription of Male Paratype. Length 5.3 mm. Other measurements in Table I. Face bright green with gold reflections. Front, genae, and vertex green with violet reflections in ocellar triangle and posterior margin of vertex. Thorax green with a black tinge on pronotum and violet reflections on pronotum and laterally on mesonotum. Posterior part of scutellum and postscutellar blade dark brown. Wings hyaline with a faint brownish tinge beyond venation of forewing. Abdomen green with a faint blue tinge and scattered violet reflections and a distinct brown underlay, especially laterally. Apical membrane brown with a similarly coloured band above apical snout-like projection, extending laterally in groove above the apical, lateral sinuation.

Structure and punctation very similar to *marginatus* except for the abdomen. Scapal basin with wavy, rather indistinct striations. Front with distinct, medium, mostly contiguous punctures becoming smaller posteriorly. Pronotum with distinct, medium, mostly contiguous punctures. First tergite with mostly minute to small, moderately spaced punctures. Second tergite with small, oval to elongate, densely spaced punctures medially, contiguous and less distinct laterally, giving an almost rugose appearance. Third tergite with small, oval, densely spaced to contiguous punctures basally becoming medium and less distinct apically. Apical truncation as in Figure 34. Ratio of width of truncation to width of third tergite, 0.38. Tarsal claws with three inner teeth. Male genitalia as in Figure 45 and measurements in Table I.

Female Paratypes. Length 5.1-6.1 mm (n = 3). Other measurements in Table II. Ratio of width of truncation to width of third tergite: m 0.34, S.D. 0.03 (n = 3).

Variation: Apart from slight size differences there is very little variation among the four paratypes. A few specimens which were placed tentatively under this species differ in colour, size, and distinctness of the punctation of the abdomen.

Diagnosis. The relatively broad apical truncation in relation to the width of the third tergite ($\frac{W_t}{W_{III}}$ = 0.32 approximately) is considered as diagnostic. In addition, the relatively evenly tapering sides of the third tergite (compared to the usually convex sides in other species) may help to distinguish this species but this character is variable and subjective.

Type Material. Aaron (1885) described *productus* on the basis of five specimens from Montana. Four of these (one male, three females) were examined. they are in fairly good condition. Both antennae of one specimen and one antennae of two other specimens are missing. The right fore and hind wing of one specimen are also missing. Each specimen is labelled "Montana"/"3 teeth" (pink label/ "Paratype 4913" (blue label). A label indicating sex was added to each specimen. One specimen also bears a white label *"Notozus productus* Aaron". Aaron did not designate a holotype. However, Cresson (presumably) chose one specimen as holotype and labelled the others as paratypes. The "holotype" must be considered as a lectotype. The type series is deposited in the Academy of Natural Sciences, Philadelphia.

Aaron (1885), in his key to North American species, distinguishes this species on the basis of the shape of the abdomen and third abdominal tergite as

"abdomen longer and narrower, the snout-like projection larger in relation to the third segment than in other species" compared to "abdomen, in shape, ordinary; about as long as wide . . .; the snout-like projection also median in size." Actually, the abdomen only appears longer due to the odd shape of the third tergite but, by measurement, it is the same size in relation to the size of the thorax as in *marginatus* or similar species. However, the shape and proportions of the third tergite are important. A number of specimens were placed tentatively under *aaroni* on the basis of the evenly tapering sides of the third tergite. These specimens had separate, distinct punctures on the abdomen and varied in colour from bright green to blue-green, violet or bi-coloured (as in the green-black form of *marginatus).* Measurements of the abdomen revealed that the apical truncation was not much larger in relation to the third tergite than in other species. Ratios for these specimens were: m = 0.26, S.D. = 0.02, min. = 0.23, max. = 0.28 (n = 13) compared to m = 0.24 (n = 131) for *marginatus* and m = 0.33 (n = 4) for the types of *aaroni.* One other specimen (from Casselton, North Dakota) had a ratio of 0.38 and on this basis was considered to be *aaroni* whereas the others with a ratio below 0.30 were not considered to be *aaroni.* No other useful characters were found to identify this species. *E. versicolor* also has a $\frac{W_t}{W_{III}}$ ratio greater than 0.32 and the types of the two species are fairly similar in structure although some of the measurements are not (Table I). Both species appear to have a relatively rugose abdomen but this is less pronounced in *aaroni.* On the basis of the relative width of the apical truncation compared to the third tergite, *aaroni* could be synonomized with *versicolor.* However, because of the few, rather arbitrary and poor characteristics used to identify these two species and to separate them from others, they will be considered as separate.

Species incertae sedis
Elampus versicolor Norton
Fig. 35
Distribution map Fig. 5

Elampus versicolor Norton 1879: 235; key, original description.
Notozus versicolor; Aaron 1885: 218; key, redescription.
Ellampus versicolor; Mocsáry 1889: 77: key and redescription quoted.
Ellampus versicolor; Dalla Torre 1892: 18; world catalogue.
Notozus versicolor; Cockerell 1898: 212; New Mexico list.
Notozus versicolor; Bischoff 1913: 7; world list.
Elampus versicolor; Cresson 1928: 30; type material.
Elampus versicolor; Bodenstein 1951: 719; North American catalogue.

Redescription of Holotype Male. Length 6.2 mm. Other measurements in Table I. Head green with violet tinge on scapal basin, clypeus, in ocellar triangle, posteriorly on vertex and genae. Thorax mainly violet with green anteriorly and laterally on pronotum and mesonotum, below on mesopleura, and laterally on propodeum. Blade of postscutellum and part of scutellum, black. Wings hyaline basally, apices missing (presumably brownish). First tergite green basally around black basal pit, a narrow, longitudinal streak medially, blue-violet elsewhere. Second tergite blue-violet with a narrow, longitudinal, blue-green, median streak fading apically. Third tergite blue-violet, distinctly bright yellow at apex of snout-like projection. Apical membrane bright yellow with distinct, contrasting dark brown border. Sternites violet to blue-green.

Scapal basin indistinctly striate, becoming rugose laterally. Front with distinct, medium, contiguous punctures. Pronotum with medium to large, mostly contiguous

punctures as large as on the scutellum. Base of fore femora evenly rounded below. Tarsal claws with three inner teeth. First tergite with small, round, densely spaced punctures medially near posterior margin, sparsely spaced sub-laterally, indistinct, round to elongate, and larger laterally. Second tergite appearing much more rugose than the first, punctures small, very indistinct, dense, XX-shaped and larger, more distinct laterally. Punctures on third tergite more distinct than those on second, oval, medium, densely spaced to contiguous, still appearing somewhat rugose. Ratio of width of apical truncation to width of third tergite, 0.34. Apical truncation as in Figure 35.

Variation. Only one specimen was seen which agreed closely with the type except for a few, minor differences. The metallic colour was generally more intense. The colour of the apical membrane was brown with a narrow, black border and a very narrow, but distinct, brown border above the apex of the apical snout-like projection. Measurements are given in Table II. The ratio of the width of the apical truncation to the width of the third tergite is 0.33.

A number of other specimens were seen which had the characteristic yellow or brown membrane and apex of the snout-like projection contrasting sharply with the colour of the remainder of the third tergite, as given by Aaron (1885) to distinguish *versicolor* from other species of *Elampus*. Structurally, however, these specimens were similar to *marginatus*.

Diagnosis. The relatively broad apical truncation in relation to the width of the third tergite (0.33) is considered as diagnostic. The colour difference given in the key to separate *versicolor* from *aaroni* likely only applies to the few specimens seen in the present study and will eventually prove to be useless. The roughened tergites which do not appear distinctly punctate and the rather broad, distinct band of brown or yellow on the apex of the snout-like projection may help to distinguish this species but these characteristics are subjective and also occur in other species.

Type Material. Norton (1879) described the species on the basis of one specimen from Dakota. The type was examined and was in good condition except for the forewings, one of which was missing and the other missing the apex. The type was lost in the mail when being returned to the National Academy of Sciences, Philadelphia. Its measurements are given in Table I. No neotype was designated.

Discussion. The specific status of *E. versicolor* is uncertain. On the basis of the original description there are four possible characteristics for separating it from other species. These are (1) the wings which are only "faintly clouded apically", (2) the yellow membrane and yellow band on the snout-like projection, (3) the yellow tarsi, and (4) the abdomen with a roughened surface but without distinct punctures. Norton (1879) used the characteristics "tergum roughened, without distinct punctures; wings hyaline" to separate *versicolor* from *viridicyaneus,* the only other species of the group keyed under this section B *(Elampus).* Aaron (1885) compared the holotype with a specimen from Montana which he considered as being *versicolor* and noted differences in colour and in distinctness of punctation on the abdomen. This specimen was seen but is missing the abdomen. In his key to North American species, Aaron used the diagnostic characteristic "the snout-like projection at abdominal apex with its closing membrane semi-transparent brown, and with a band of the same colour before its apical margin" to separate *versicolor* from other species in which the closing membrane was "black, concoloured before its apical margin".

The roughened appearance of the punctation of the tergites of the type specimen may be abnormal and an extreme form of a densely or contiguously

punctured abdomen. Only one other specimen (discussed above) was seen which had similar punctation. The punctation of the type series of *aaroni* approaches that of *versicolor* but is more distinct. The characteristics of the wing colour and colour of the tarsi are vairable, shared by other species, and subjective. Similarly, the colour of the apical membrane and apex of the snout-like projection, used by Aaron for distinguishing *versicolor,* are variable and subjective. Two series of specimens from Bard, California and Yuma, Arizona, respectively, had membrane colours ranging from bright yellow to brown with similarly coloured bands on the apical snout-like projection. These specimens, and a number of similarly coloured specimens identified as *versicolor* by previous workers, had wing colour and punctation of the abdomen as in *marginatus,* to which they likely belong.

One characteristic of *versicolor,* not mentioned by Norton, is the relatively wide apical truncation compared to the width of the third tergite. This characteristic was selected in the present study as being diagnostic for *versicolor* although *E. aaroni* also shares it. Colour differences were used to separate these two species in the key but may prove to be inadequate. Unfortunately, because the type was lost it cannot be re-examined for further characteristics which might solve the problem of the specific status of *versicolor.* The specimen discussed under Variation (above) which could serve as a neotype was collected at Florissant, Colorado and is deposited in the United States National Museum. At present, it is not designated as a neotype in the hope that further information or specimens will become available for study, or the type will be found.

Conclusions

The distribution of species of *Elampus* in North America is similar to the distribution of *Parnopes* (Telford, 1964), *Chrysura* (Horning, 1969) and *Omalus* (Bohart and Campos, 1960) in that most species occur in the west or south-west. In the north-east only two species of *Elampus* — *E. marginatus* and *E. viridicyaneus,* are collected commonly. *E. nitidus nitidus* is common in the west. *E. aaroni* and *E. versicolor* are only known from their types and a few possible additional specimens from Montana, "Dacota", and Colorado. The remaining species occur mainly in the south-west. A few possible, additional species were segregated but are not described or named herein. These possible species occur in the south-west from Texas to California and more material from this area is needed to evaluate them properly. They would key out to *E. marginatus.* On the basis of characteristics such as the shape of the apical truncation, the number of inner teeth in each tarsal claw, and the relative lengths of the digiti, cuspides, and parameres of the male genitalia, and on geographical distribution, *E. rotundus,* and to a lesser extent, *E. hyalinus,* are related to South American species whereas the other North American species appear to be more closely related to Palaearctic species.

Discriminant analysis of eight measurements and ratios of males and females of six of the eight taxa described in this paper *(E. versicolor* and *E. aaroni* excluded) showed that the taxa could be distinguished from each other with a high degree of accuracy using quantitative data alone (Table VII). However, the samples on which this analysis was based were relatively small and biased in that only specimens which were considered typical of each taxon, and which could be distinguished readily using qualitative characteristics only, were chosen for measurement. Further statistical studies using larger samples and including specimens or populations which cannot be placed readily in one or another taxon may be useful in clarifying species limits especially in *E. marginatus.* Biological studies and knowledge of hosts would be particularly useful in helping to clarify the relationships in some species.

Acknowledgments

Sincere thanks are extended to the curators of the various institutions from which specimens were borrowed. In particular, thanks are extended to Dr. C. Besuchet, Muséum D'Histoire Naturelle, Geneva, for making the facilities and collections available to the senior author during the stay of the senior author in Geneva and to Dr. J. M. Peron, Université de Laval, Quebec City, Dr. G. W. Byers, University of Kansas, Lawrence, and Dr. W. M. Moss, Academy of Natural Sciences, Philadelphia, for allowing the examination of type material from their respective institutions. We thank Dr. J. Smart, Insect Museum, Cambridge University, and Mr. L. A. Mound, British Museum (Natural History), for allowing the study of the collections under their care. We are very grateful to Mr. R. Hurst for doing the illustrations except for the outline drawings. We are indebted to Dr. B. L. Raktoe and Dr. N. T. Ison of the Mathematics and Statistics Department and Institute of Computer Science respectively, and to Mr. G. Umphrey, University of Guelph, for doing the discriminant analysis and interpreting the results. Financial support by the Canada Department of Agriculture, Grant No. 4033, and the National Research Council, Grant No. A9552, is gratefully acknowledged.

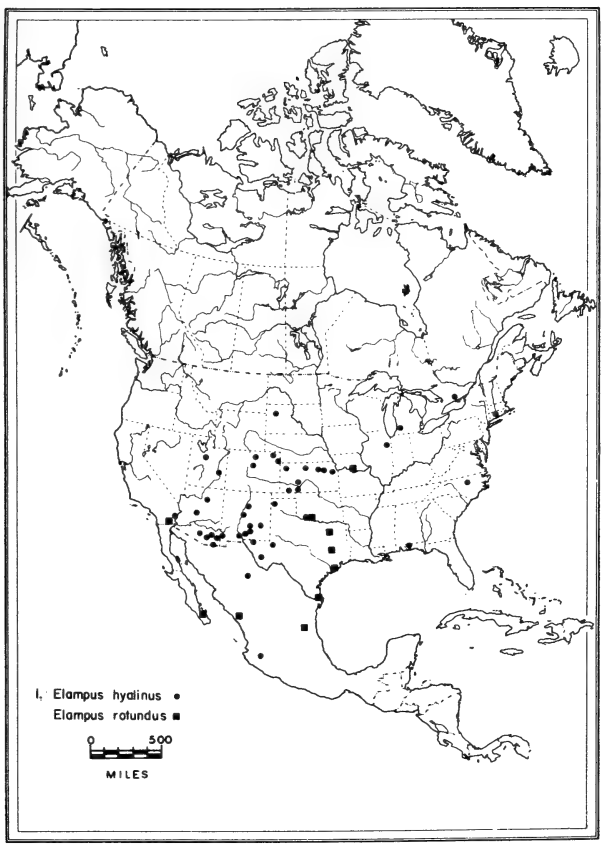


FIG. 1. Distribution of *Elampus hyalinus* (Aaron) and *E. rotundus* sp. nov. (Hymenoptera, Chrysididae).

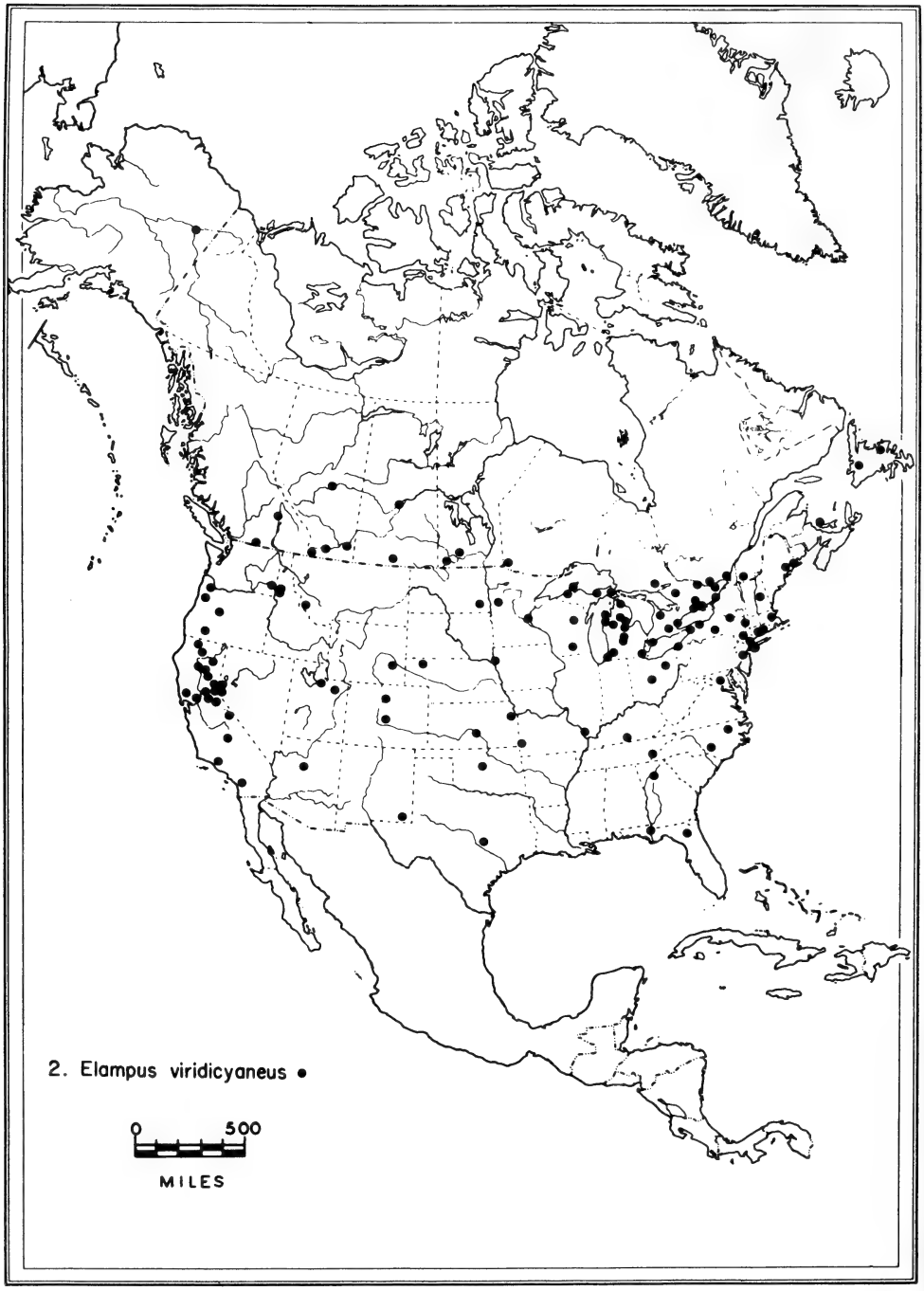


FIGURE 2. Distribution of *Elampus viridicyaneus* Norton (Hymenoptera, Chrysididae).

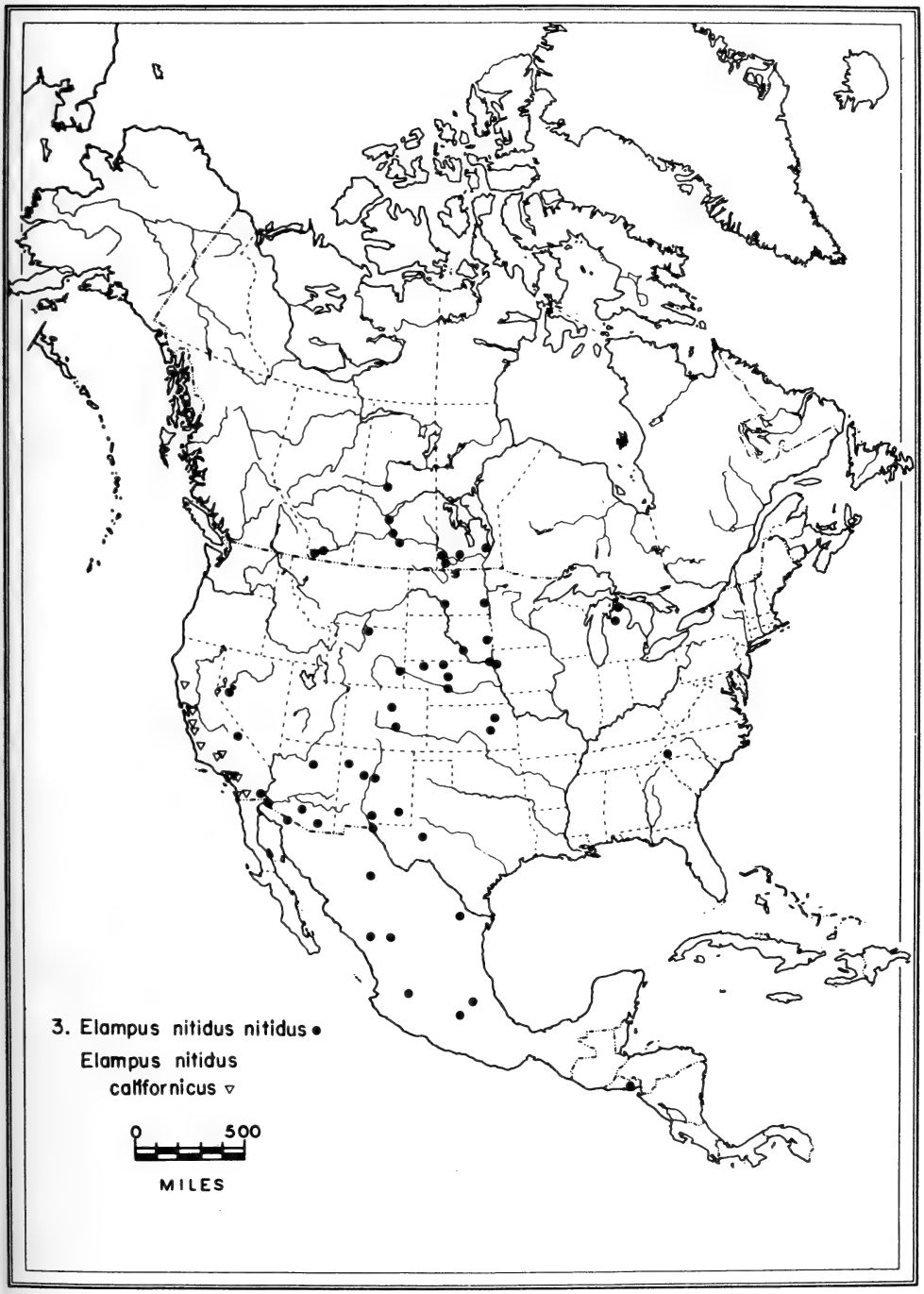


FIGURE 3. Distribution of *Elampus nitidus nitidus* (Aaron) and *E. nitidus californicus* subsp. nov. (Hymenoptera, Chrysididae).

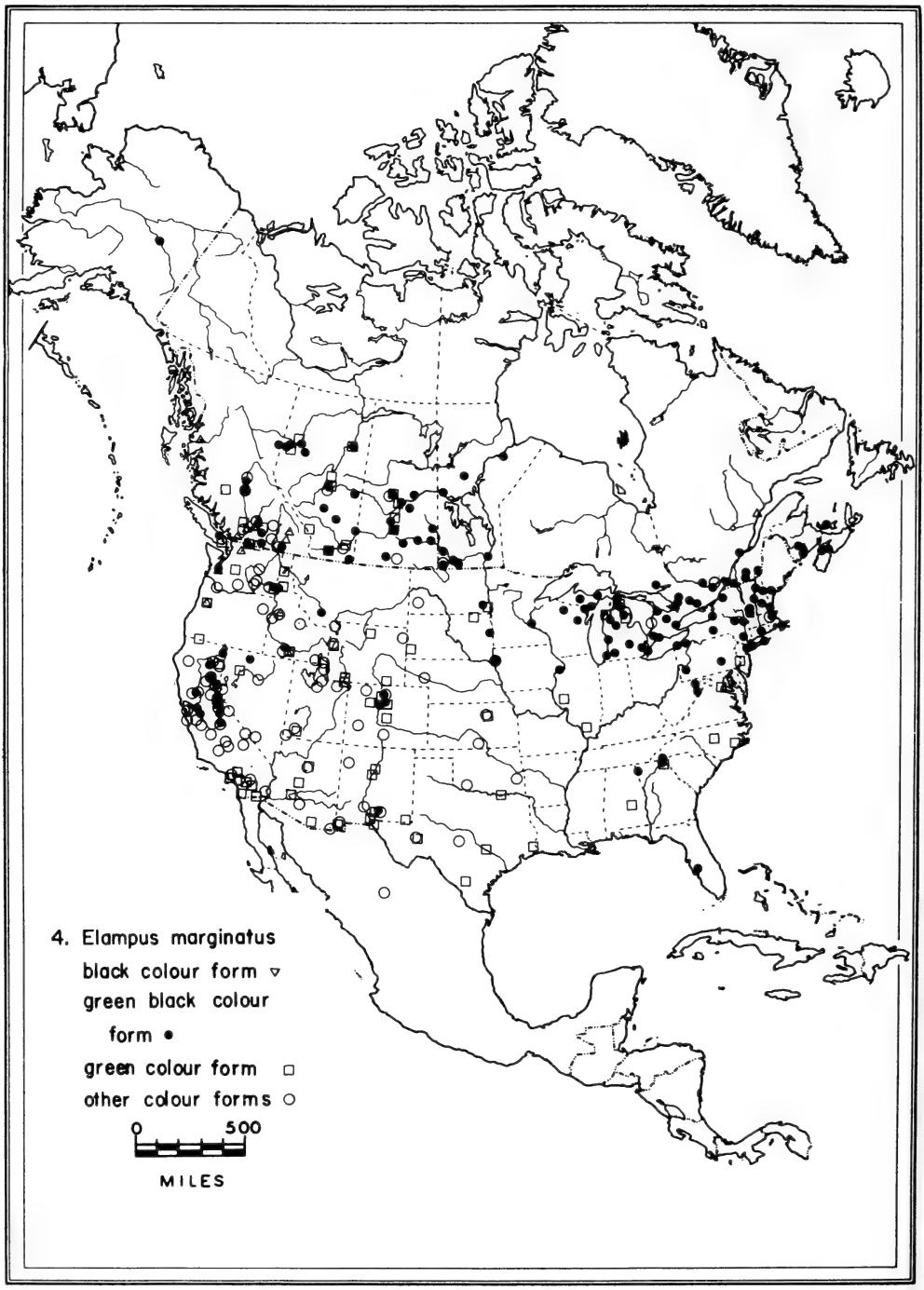


FIGURE 4. Distribution of the colour forms of *Elampus marginatus* (Patton) Hymenoptera, Chrysididae).

FIGURE 5. Distribution of *Elampus aaroni* Bodenstein and *E. versicolor* Norton (Hymenoptera, Chrysididae).

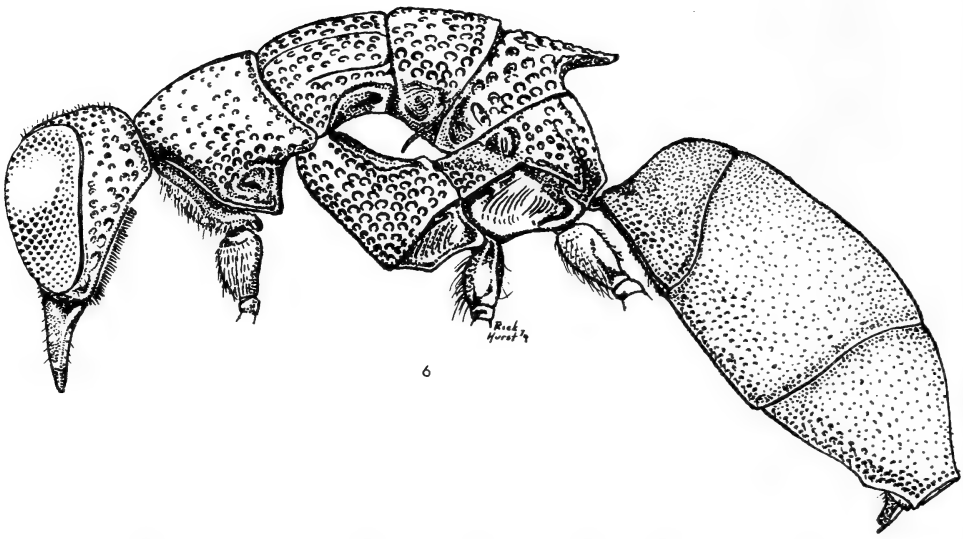


FIGURE 6. Habitus drawing of *Elampus viridicyaneus* Norton (Hymenoptera, Chrysididae). Lateral view.

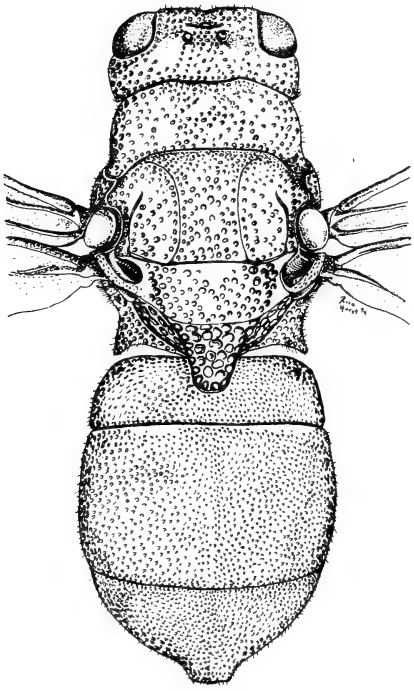
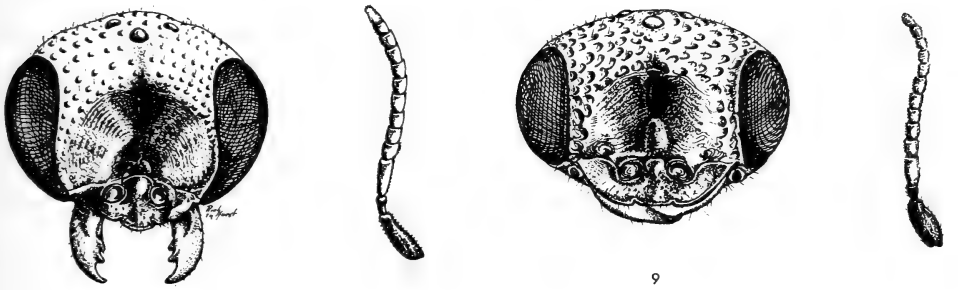


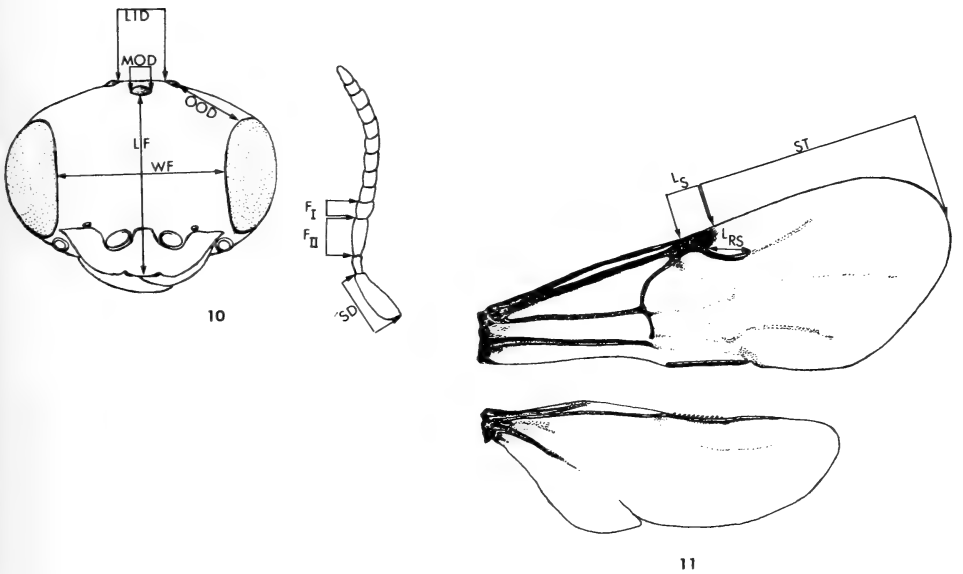
FIGURE 7. Habitus drawing of *Elampus viridicyaneus* Norton (Hymenoptera, Chrysididae). Dorsal view.



8 9

FIGURE 8. Drawing of head and antenna of female *Elampus viridicyaneus* Norton (Hymenoptera, Chrysididae). Front view.

FIGURE 9. Drawing of head and antenna of male *Elampus viridicyaneus* Norton (Hymenoptera, Chrysididae). Front view.



10 11

FIGURE 10. Diagram of head and antenna of *Elampus viridicyaneus* Norton (Hymenoptera, Chrysididae) showing measurements taken.

FIGURE 11. Diagram of forewing and hind wing of *Elampus* sp. (Hymenoptera, Chrysididae) showing measurements taken.

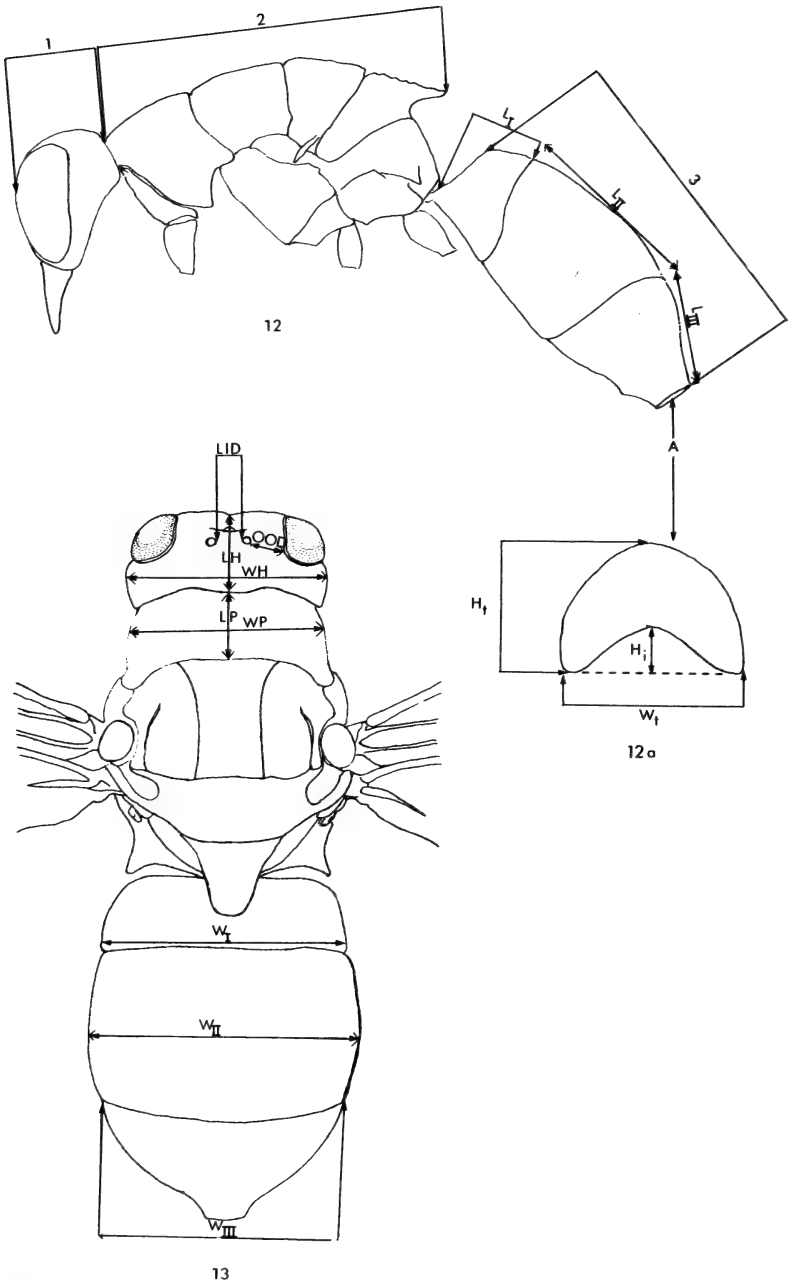


FIGURE 12. Diagram of *Elampus* sp. (Hymenoptera, Chrysididae) showing measurements taken. Lateral view.

FIGURE 12a. Diagram of apical truncation of *Elampus* sp. showing measurements taken.

FIGURE 13. Diagram of *Elampus* sp. showing measurements taken. Dorsal view.

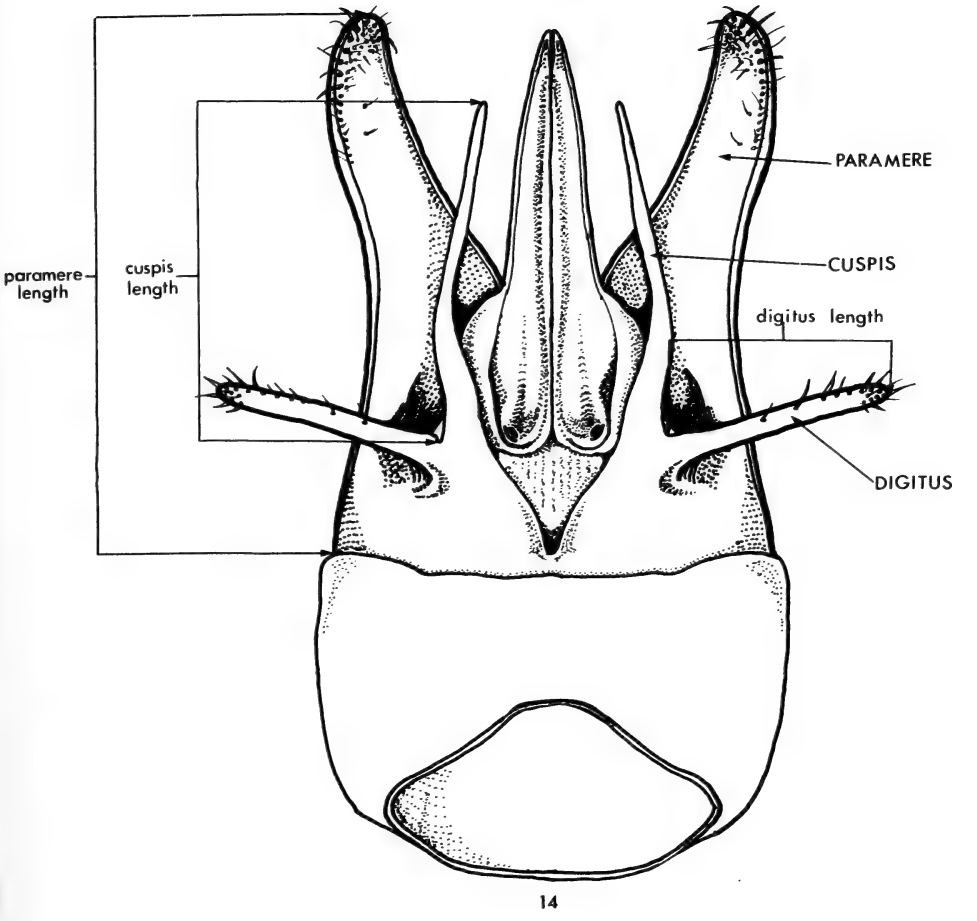
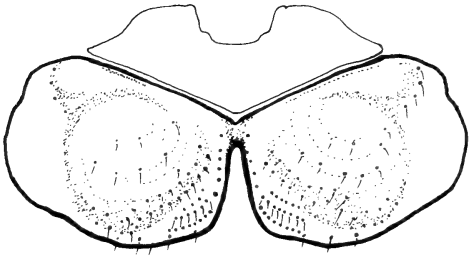
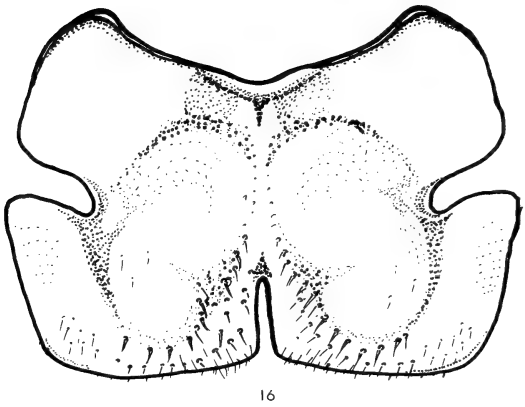
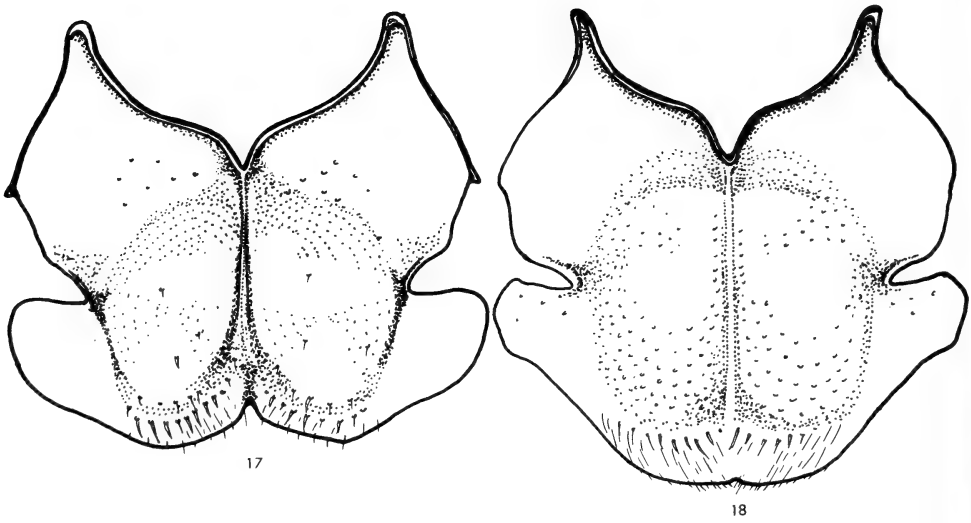


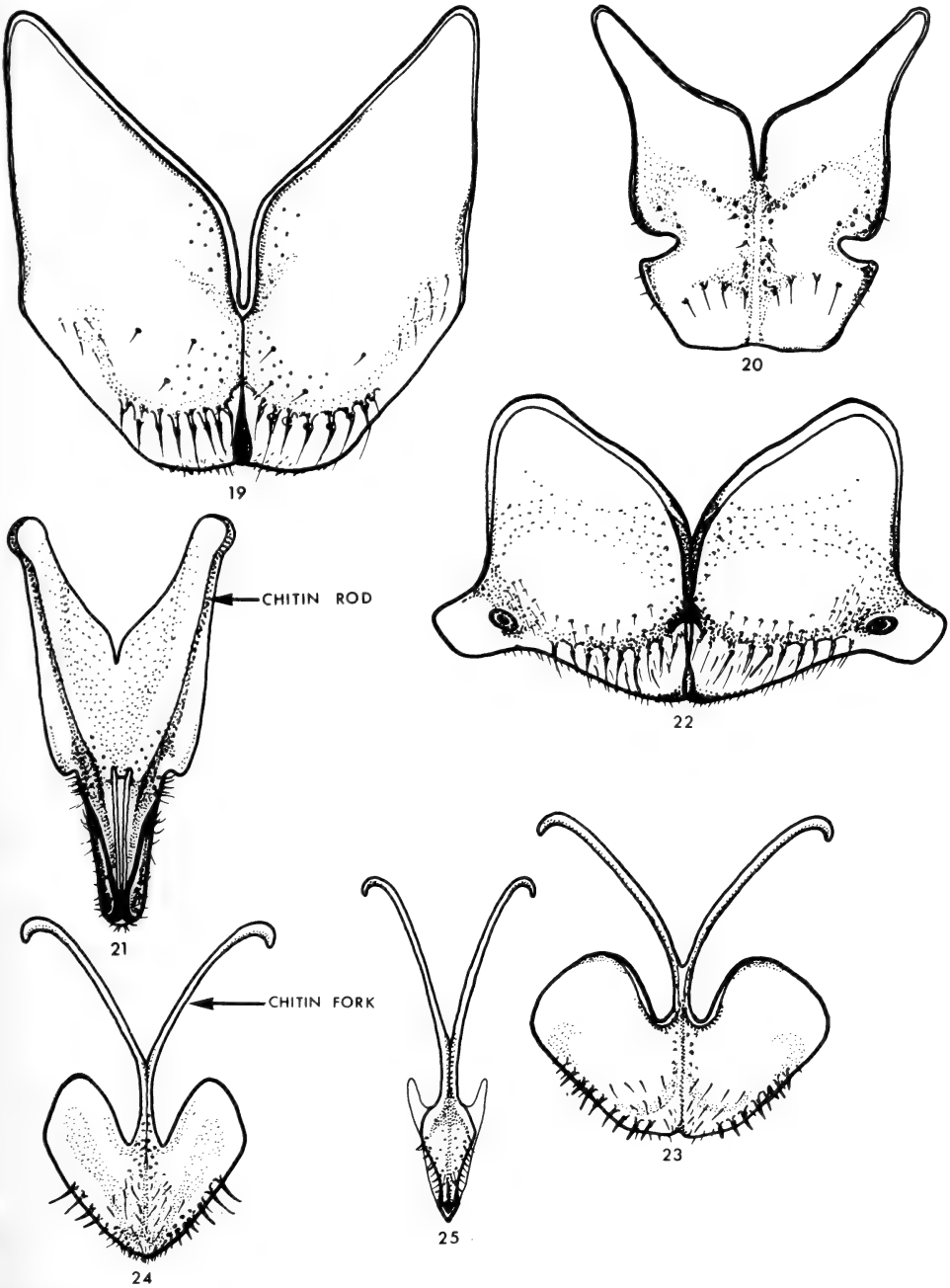
FIGURE 14. Drawing of male genitalia of *Elampus* sp. (Hymenoptera, Chrysididae) (from scanning electron microscope photograph).







FIGURES 15-18. Visible sternites of *Elampus viridicyaneus* Norton ♀ (Hymenoptera, Chrysididae). Fig. 15, Sternite I. Fig. 16, Sternite II. Fig. 17, Sternite III. Fig. 18, Sternite III ♂.



FIGURES 19-21. Hidden sternites of *Elampus viridicyaneus* Norton ♀ (Hymenoptera, Chrysididae). Fig. 19, Sternite IV. Fig. 20, Sternite V. Fig. 21, Sternite VI.

FIGURES 22-25. Hidden tergites of *Elampus viridicyaneus* Norton ♀ (Hymenoptera, Chrysididae). Fig. 22, Tergite IV. Fig. 23, Tergite V. Fig. 24, Tergite VI. Fig. 25, Tergite VII.

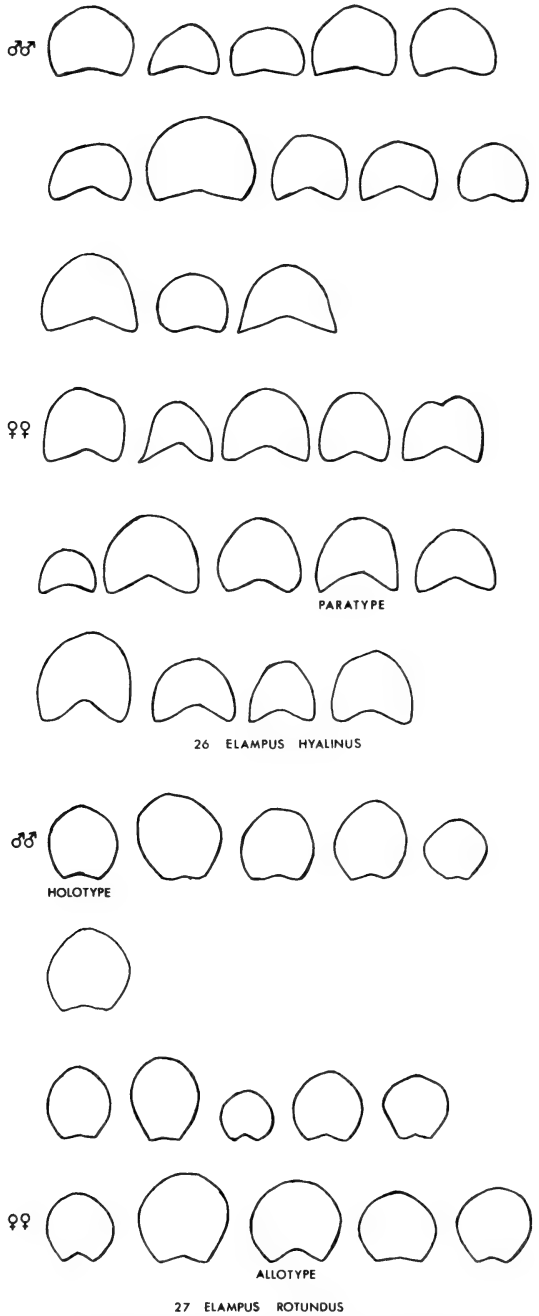


FIGURE 26. Variations in the shape of the apical truncation of *Elampus hyalinus* (Aaron) (Hymenoptera, Chrysididae).

FIGURE 27. Variations in the shape of the apical truncation of *Elampus rotundus* sp. nov. (Hymenoptera, Chrysididae).

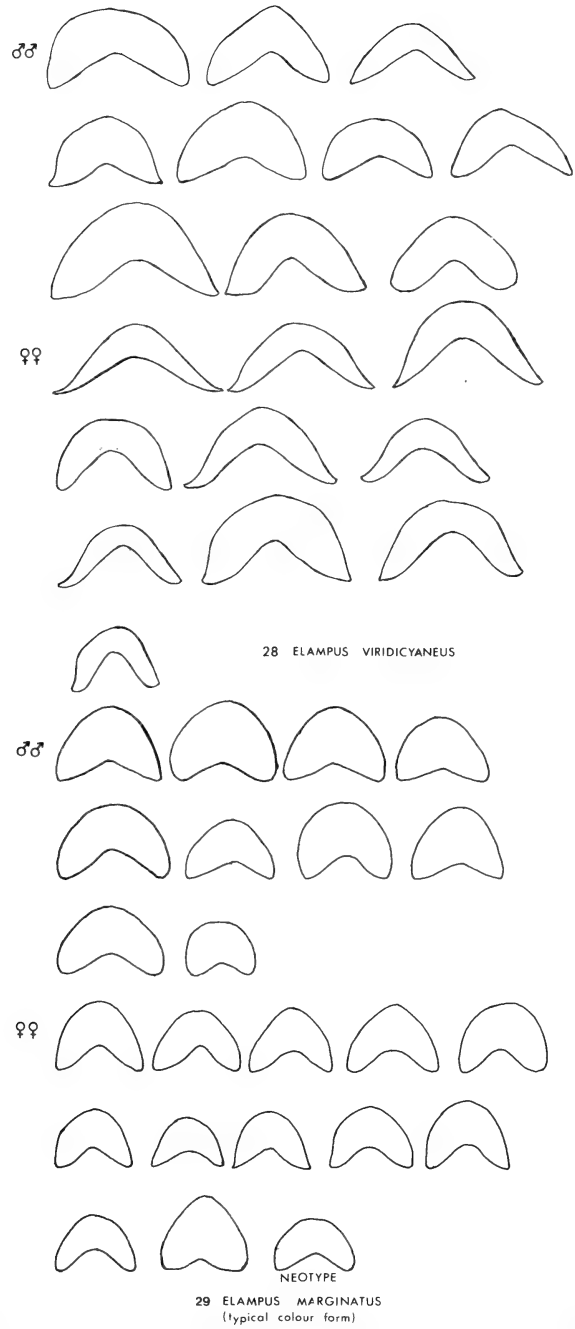


FIGURE 28. Variations in the shape of the apical truncation of *Elampus viridicyaneus* Norton (Hymenoptera, Chrysididae).

FIGURE 29. Variations in the shape of the apical truncation of *Elampus marginatus* (Patton) (typical form)(Hymenoptera, Chrysididae).

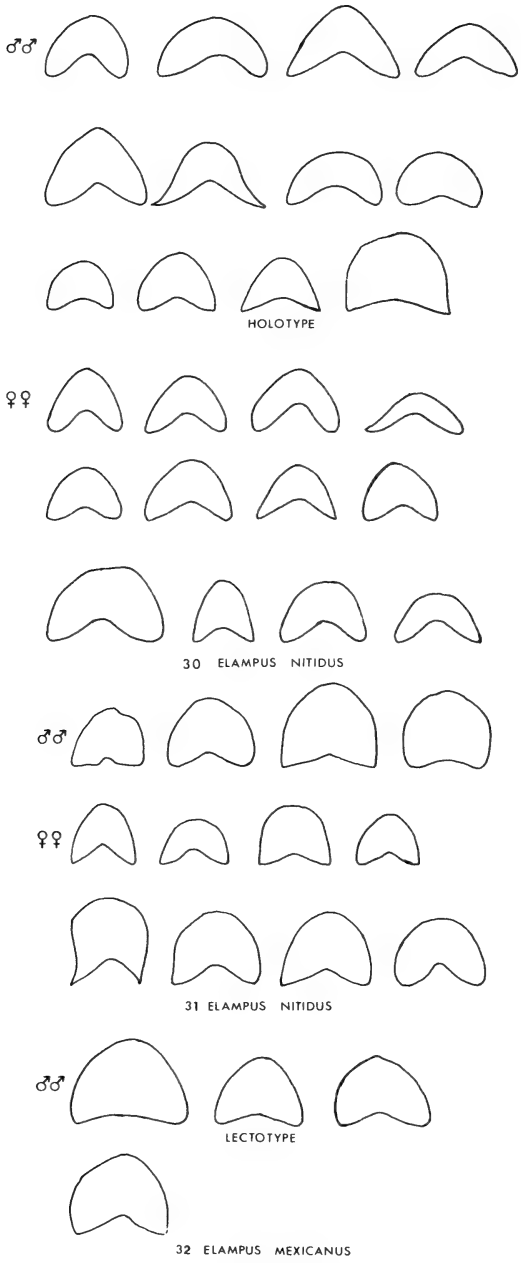


FIGURE 30. Variations in the shape of the apical truncation of *Elampus nitidus nitidus* (Aaron) (Hymenoptera, Chrysididae) from Canada and U.S.A.

FIGURE 31. Variations in the shape of the apical truncation of *Elampus nitidus nitidus* (Aaron) (Hymenoptera, Chrysididae) from Mexico.

FIGURE 32. Variations in the shape of the apical truncation of *Elampus mexicanus* Mocsáry (newly synonomized under *E. nitidus nitidus).*

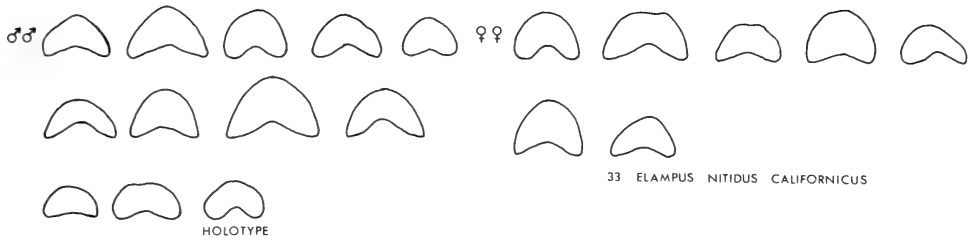


FIGURE 33. Variations in the shape of the apical truncation of *Elampus nitidus californicus* subsp. nov. (Hymenoptera, Chrysididae).

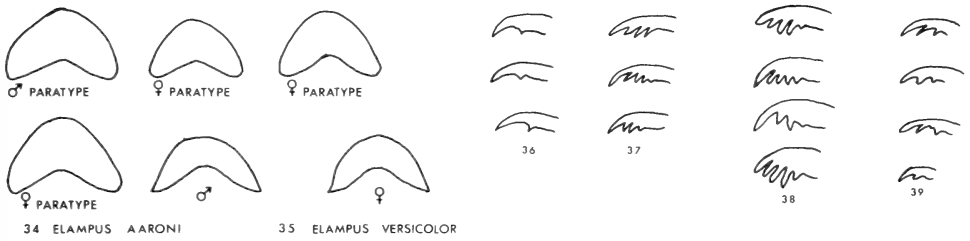
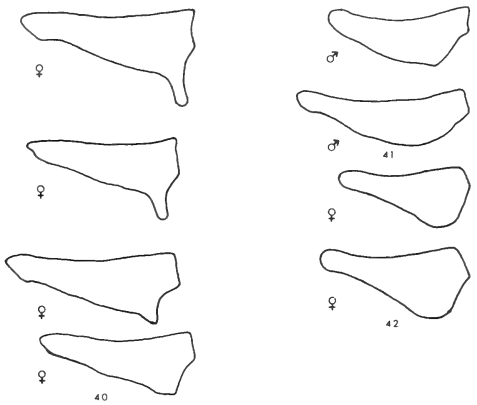


FIGURE 34. Variations in the shape of the apical truncation of *Elampus aaroni* Bodenstein.

FIGURE 35. Shape of apical truncation of *Elampus versicolor* from Florissant, Colorado.

FIGURES 36-39. Variations in the shape of the tarsal claws of *Elampus* spp. (Hymenoptera, Chrysididae). Fig. 36, *Elampus rotundus* sp. nov. Fig. 37, *Elampus marginatus* (Patton). Fig. 38, *Elampus viridicyaneus* Norton. Fig. 39, *Elampus hyalinus* (Aaron).



FIGURES 40-42. Variations in the shape of the fore femore of *Elampus* spp. (Hymenoptera, Chrysididae). Fig. 40, *Elampus marginatus* (Patton) (♀♀). Fig. 41, *Elampus marginatus* (Patton) (♂♂). Fig. 42, *Elampus hyalinus* (Aaron) (♀♀).

PLATE I

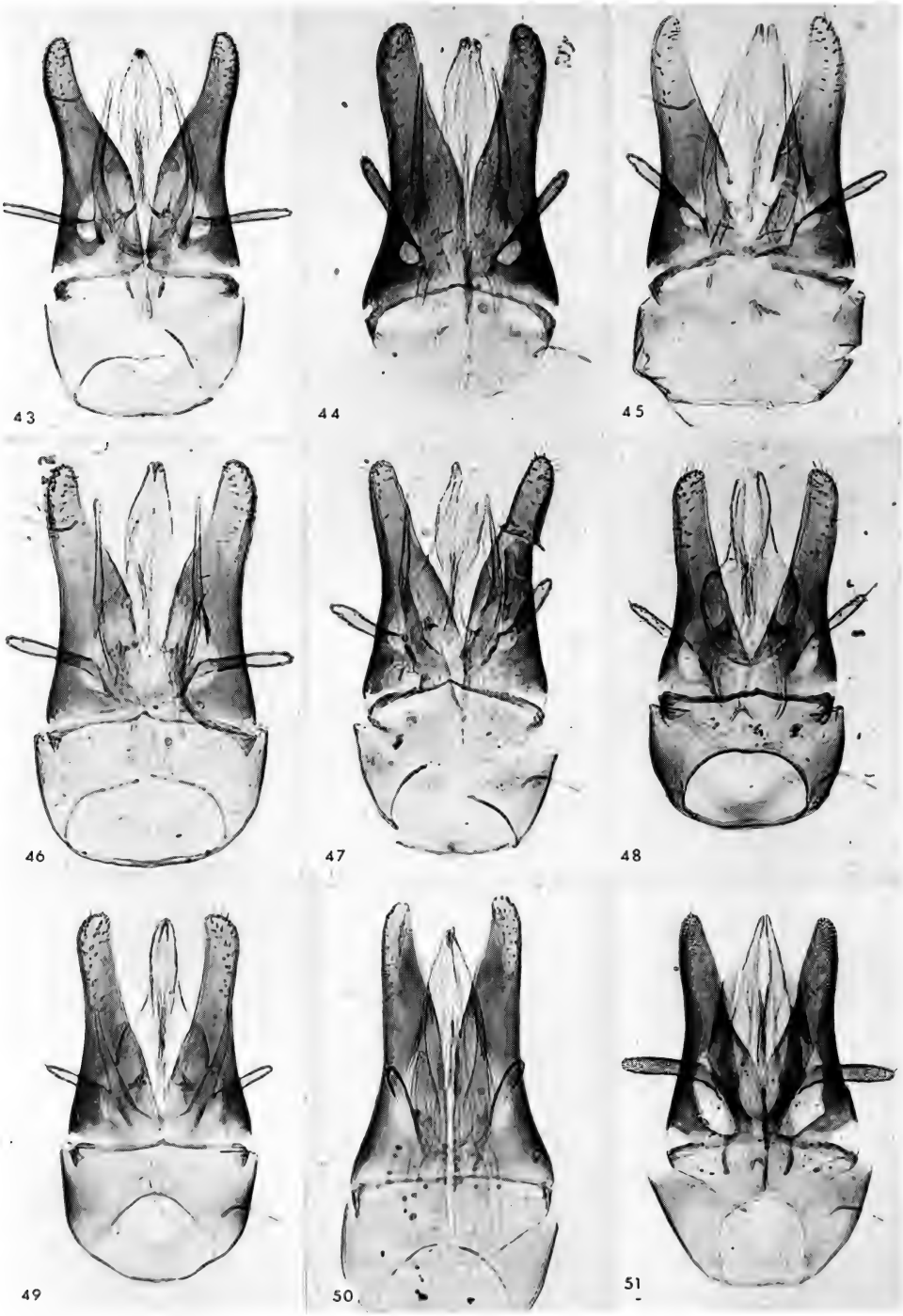


PLATE I

Male genitalia of *Elampus* spp. (43-50) and *Omalus seminudus* (Aaron) (51) (Hymenoptera, Chrysididae). Slide mounts.

43. *E. viridicyaneus* Norton.

44. *E. marginatus* (Patton).

45. *E. aaroni* Bodenstein.

46. E. *nitidus nitidus* (Aaron).

47. *E. nitidus californicus* subsp. nov.

48. *E. hyalinus* (Aaron).

49. *E. rotundus* sp. nov.

50. *E. gayi* Spinola.

51. *O. seminudus* (Aaron).

PLATE II

Elampus specimens (Hymenoptera, Chrysididae) coated with gold/palladium and photographed in an ETEC Autoscan microscope.

52. *Elampus marginatus* (Patton) ♀. Lateral view of gena and compound eye. About 112x.

53. *Elampus marginatus* (Patton) ♂ (ex. Midland, Ont.). Lateral view of gena and compound eye. About 87x.

54. *Elampus nitidus nitidus* (Aaron) (ex. Elbow, Sask.). Mandible and part of clypeus. About 68x.

55. *Elampus viridicyaneus* Norton (ex. Verdi, Nev.). Dorsal view of mesonotum. About 24x.

56. *Elampus viridicyaneus* Norton (ex. Varney, Ont.). Front view of face. About 29x.

57. *Elampus rotundus* sp. nov. (ex. Texas). Front view of face. About 63x.

PLATE II

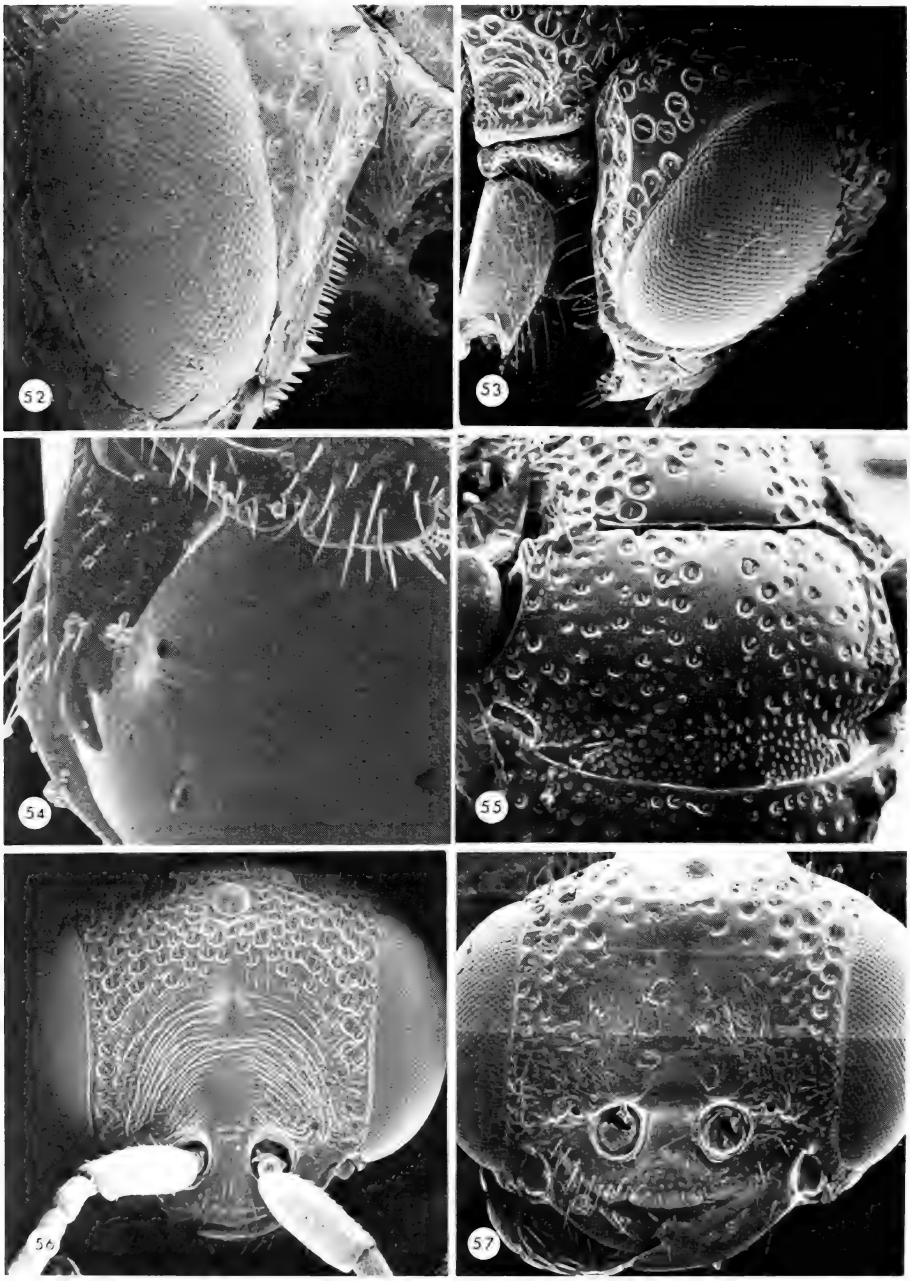


PLATE III

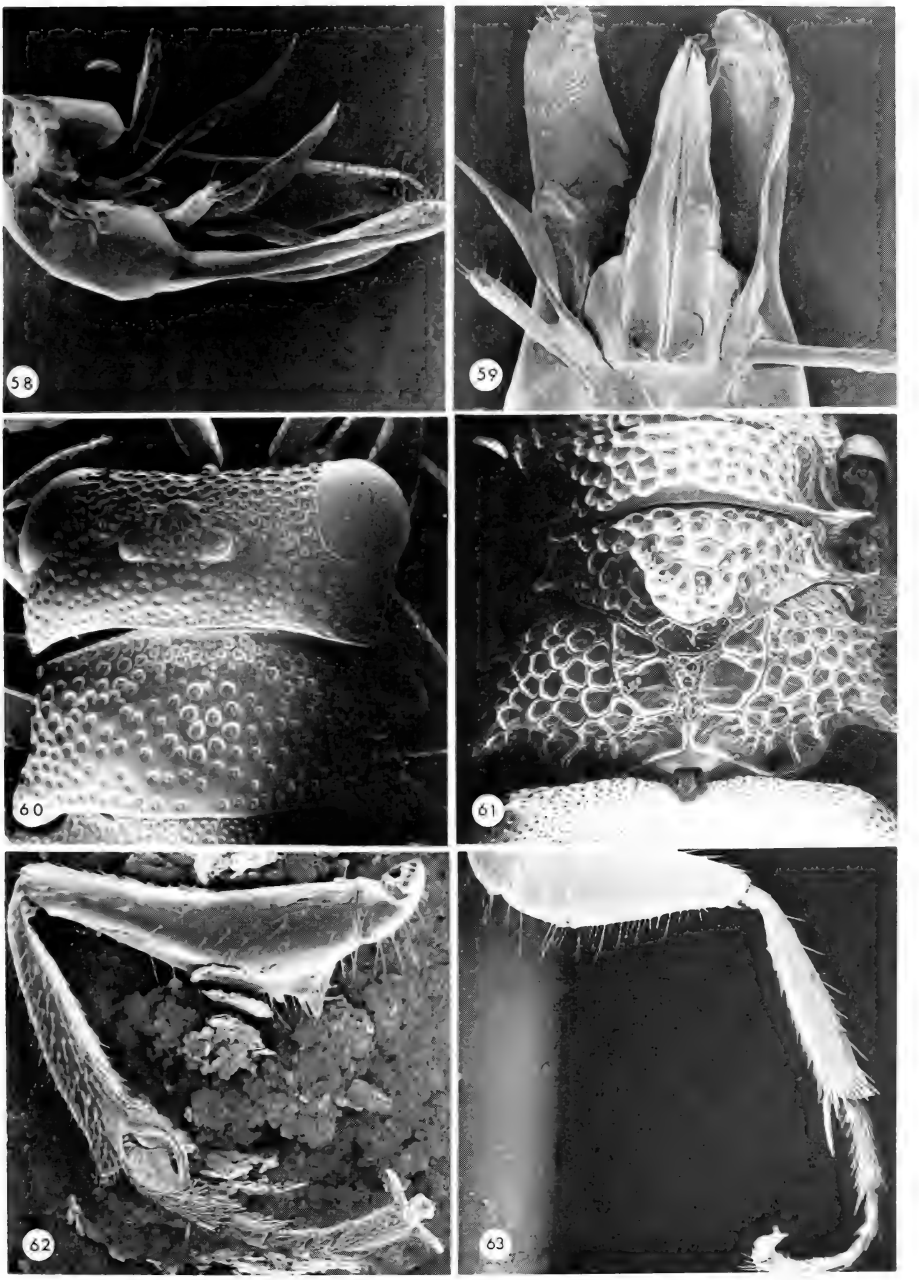


PLATE III

Elampus specimens (Hymenoptera, Chrysididae) coated with gold/palladium and photographed in an ETEC Autoscan microscope.

58. *Elampus viridicyaneus* Norton. Ventrolateral view of ♂ genitalia. About 47x.

59. *Elampus viridicyaneus* Norton. Ventral view of ♂ genitalia. About 47x.

60. *Elampus viridicyaneus* Norton (ex. Varney, Ont.). Dorsal view of head and pronotum. About 39x.

61. *Elampus viridicyaneus* Norton (ex. Varney, Ont.). Propodeum. About 17x.

62. *Elampus marginatus* (Patton) (ex. Midland, Ont.). Anterior view of right foreleg. About 68x.

63. *Elampus marginatus* (Patton) (ex. Midland, Ont.). Posterior view of right mid leg. About 62x.

PLATE IV

Elampus specimens (Hymenoptera, Chrysididae) coated with gold/palladium and photographed with an ETEC Autoscan microscope.

64. *Elampus marginatus* (Patton) (ex. Midland, Ont.). Posterior view of right hind leg. About 44x.

65. *Elampus viridicyaneus* Norton (ex. Varney, Ont.). Antenna. About 48x.

66. *Elampus viridicyaneus* Norton. Tarsal claw. About 227x.

67. *Elampus marginatus* (Patton). Tarsal claw. About 386x.

68. *Elampus hyalinus* (Aaron). Tarsal claw. About 483x.

69. *Elampus rotundus* sp. nov. Tarsal claw. About 483x.

PLATE V

Elampus specimens (Hymenoptera, Chrysididae) coated with gold/palladium and photographed in an ETEC Autoscan microscope.

70. *Elampus marginatus* (Patton) (ex. Midland, Ont.) ♂. Ventral view of abdomen. About 18x.

71. *Elampus hyalinus* (Aaron) (ex. Menlo, Kansas). Lateral view of abdomen. About 21x.

72. *Elampus marginatus* (Patton) (ex. Midland, Ont.). Lateral view of thorax. About 55x.

73. *Elampus viridicyaneus* Norton (ex. Varney, Ont.). Dorsal view of abdomen. About 14x.

74. *Elampus marginatus* (Patton) (ex. Midland, Ont.). Apical truncation of tergite III. About 32x.

75. *Elampus rotundus* sp. nov. (ex. Texas). Apical truncation of tergite III. About 37x.

PLATE IV

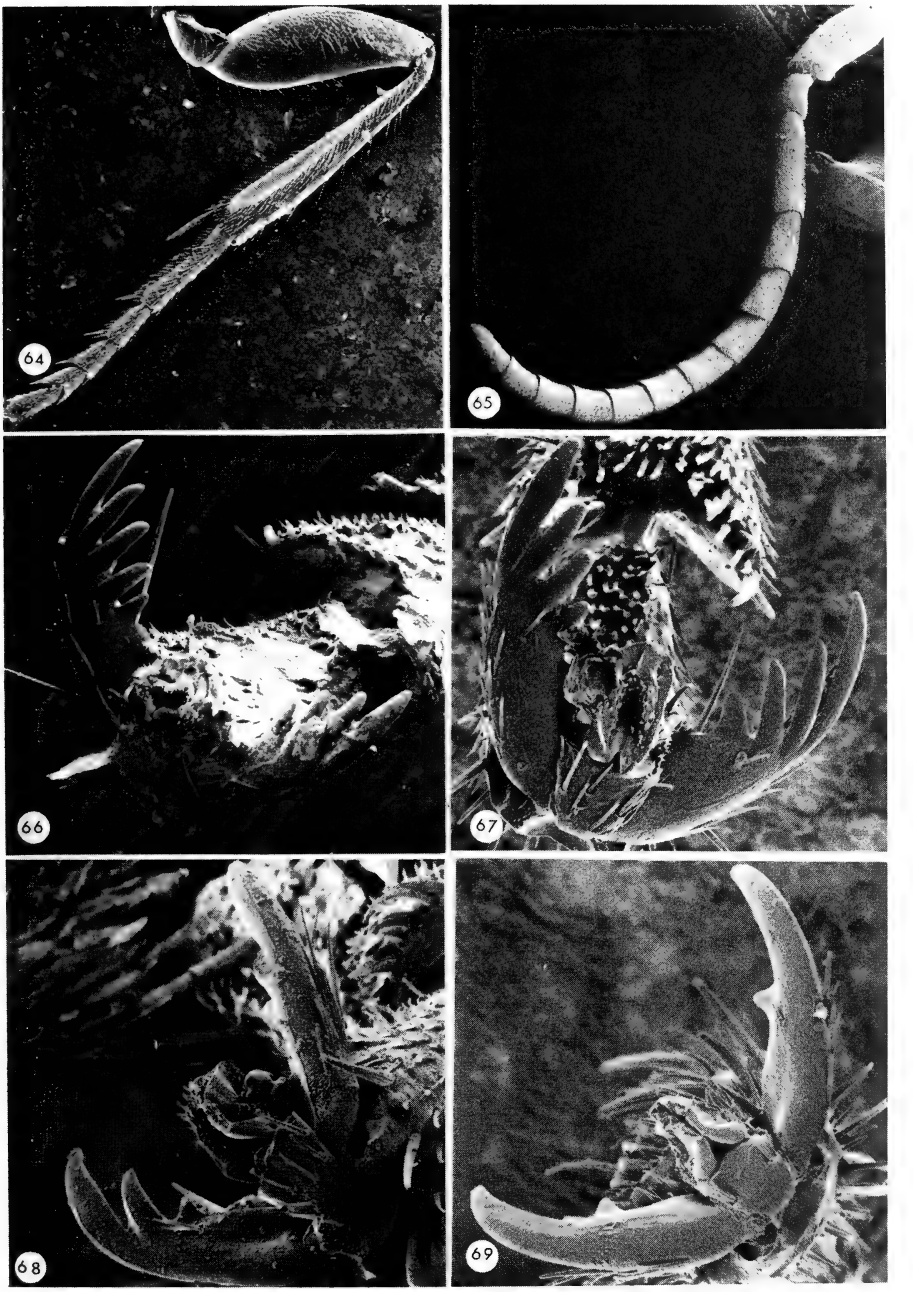
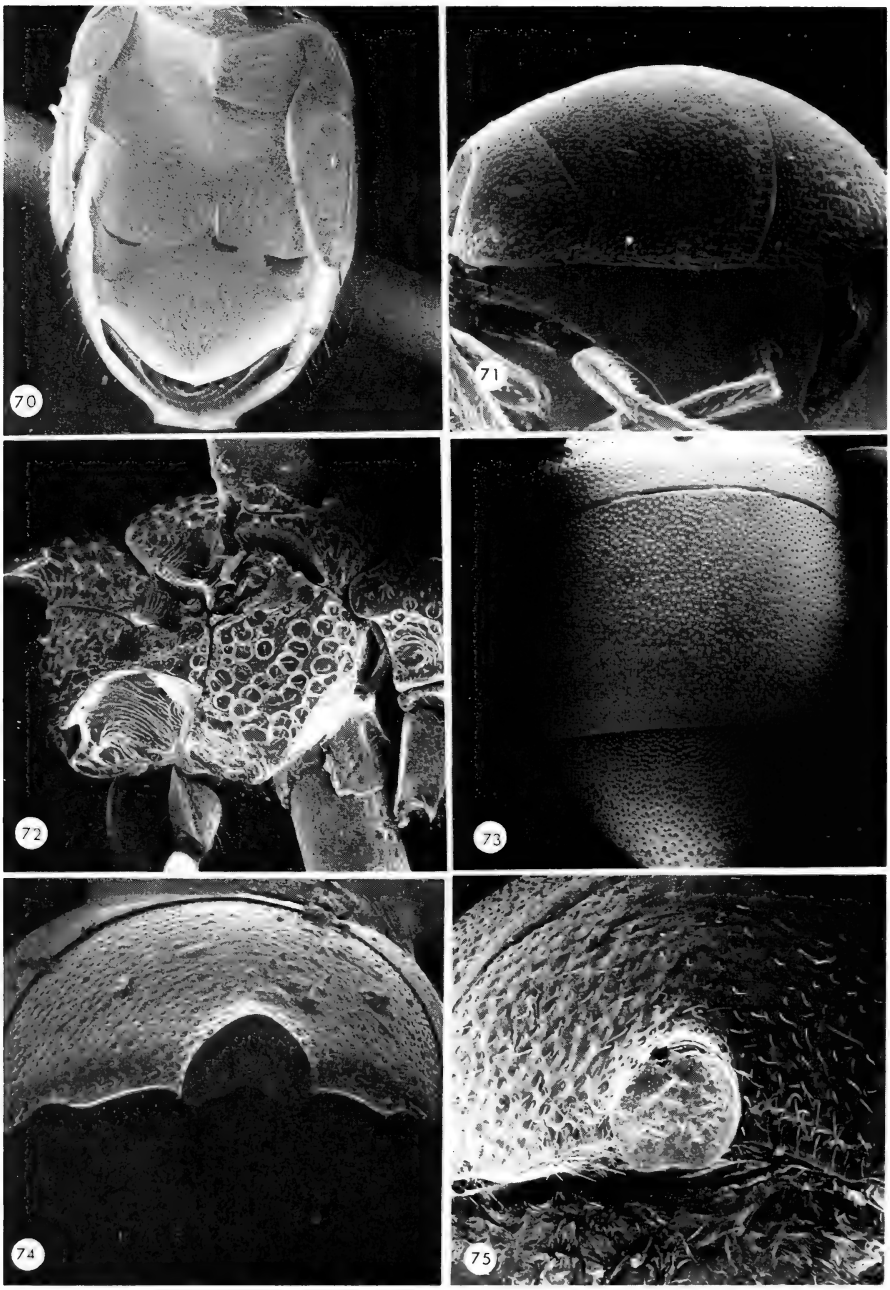


PLATE V



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HARVESTMEN (PHALANGIDA) OF DUNN TOWNSHIP, HALDIMAND COUNTY, ONTARIO, CANADA

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Abstract

Collections of harvestmen were made in 1977 in Dunn Township, Ontario, Canada. Species collected were *Odiellus pictus* (Wood), *Phalangium opilio* L., *Opilio parietinus* (DeGeer), *Hadrobunus maculosus* (Wood), *Leiobunum longipes* Weed, *Leiobunum politum* Weed, *Leiobunum vittatum* (Say). Observations on the distribution of the species in the township and on their habits are included.

Introduction

In earlier publications accounts were given of the distribution of butterflies (Judd, 1963a, 1970), dragonflies and damselflies (Judd, 1968a) and water-slaters and sowbugs (Judd, 1977) in Dunn Township, Haldimand County, Ontario. In 1977 it was determined to study the distribution of harvestmen in the township which has recently been annexed to the town of Dunnville as Ward 1 of that town. A description of the physical features of the township is included by Judd (1963a). The map, (Figure 1), shows the township, bordered on the north and east by the Grand River, on the south by Lake Erie and on the west by the road separating it from South Cayuga Township. It also includes a grid system (lettered A to L at the left; numbered 1 to 12 at the bottom) used in defining localities, e.g. the airdrome of Dunnville is located in grid-squares G10 and G11. There are two communities in the township, Port Maitland at the mouth of the Grand River (I12) and Byng about five miles upriver.

Methods

From July 13 to September 4, 1977 collections of harvestmen were made through the township, the land area of which includes 86 grid-squares. They were looked for under trash at roadsides, under bark of trees and logs, in rotting logs, on low vegetation and on trees and around cottages and foundations of abandoned buildings. They were identified with keys in Bishop (1949), Edgar (1966) and Levi and Levi (1952). Specimens of the seven species collected are deposited in the collection of the Department of Zoology, University of Western Ontario. A spider, *Achaearanea tepidariorum* (C. L. Koch), found preying on a harvestman, was identified by Dr. Robin Leech, Alberta Environment, Edmonton, Alberta.

The numbers of specimens actually captured and examined were: *Odiellus pictus* — 17, *Phalangium opilio* — 15, *Opilio parientinus* — 36, *Hadrobunus maculosus* — 1, *Leiobunum longipes* — 83, *Leiobunum politum*—17, *Leiobunum vittatum* — 24.

Account of Species Collected

Odiellus pictus (Wood) — This species was found under boards (H2), under logs (H10) and in woods (I2). The largest concentration was under boards and logs adjacent to an old well by a collapsed building under moderate tree cover (G6). When a board or log at this site was turned over a harvestman would be found closely applied to the lower surface of the structure with its legs spread. It

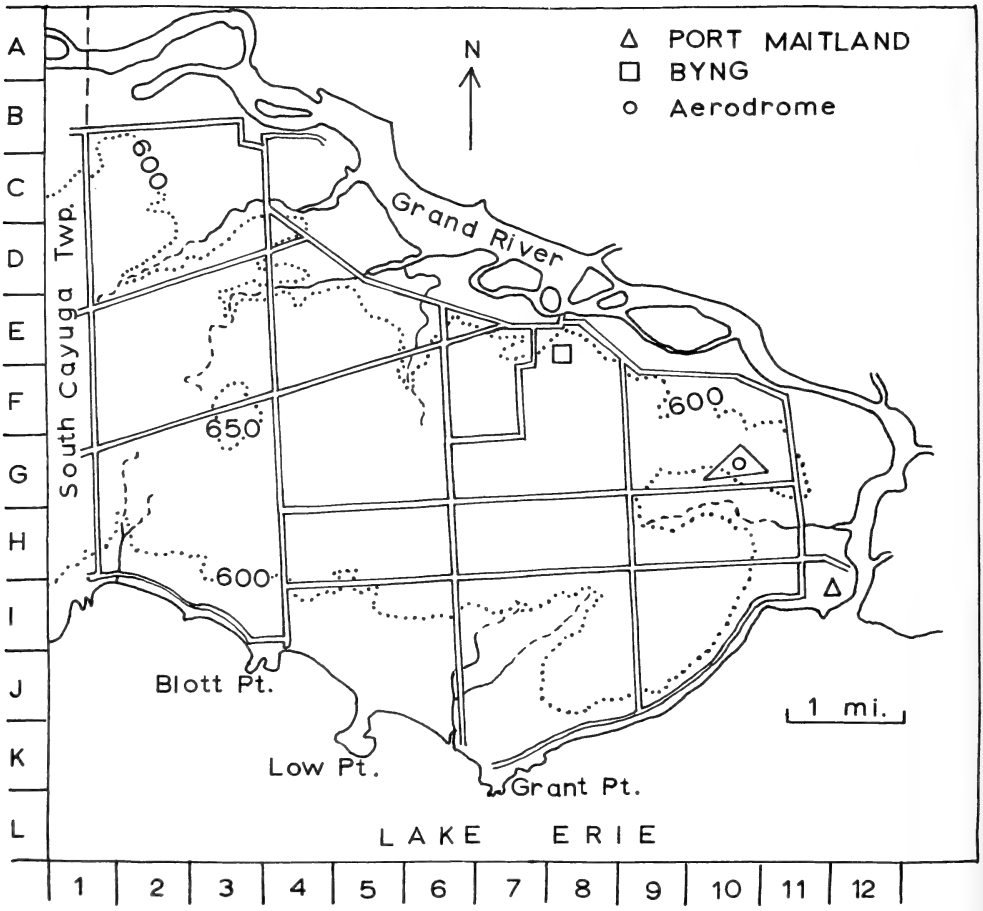

FIGURE 1 — Map of Dunn Township, Haldimand County, Ontario.

would remain motionless, evidently relying on camouflage for protection, and only when poked would it scuttle over the edge of its support. Edgar (1966, 1971) reports this species from the edges of forests under moderately dense canopy. It has been reported from New York (Bishop, 1949), Wisconsin (Levi and Levi, 1952) and Ontario (Edgar, 1966). It was found in the fabric of nests of the cardinal at London by Judd (1962, 1963b).

Phalangium opilio L. — This species was particularly to be found around two cottages in the south end of H2, sitting motionless on the walls of the buildings out of reach of direct sunlight. Solitary individuals were found on plants near the buildings, such as saplings of basswood, raspberry canes, goldenrod, thistles and New England aster. One was found on August 1 on a plant of the orchid, *Epipactis helleborine,* with its legs sprawled over several flowers. On August 8 one was found, partly devoured, in the grip of a female spider, *Achaearanea tepidariorum* (Koch), in the spider's web beneath a board leaning against a cottage. This spider is widely distributed in North America and occurs so regularly about human dwellings that it is commonly called the Domestic Spider (Comstock, 1967).

The presence of this harvestman around cottages is in accord with the reports of several authors (Clingenpeel and Edgar, 1966; Edgar, 1966, 1971; Edgar and Yuan, 1968) that it is found around human habitations. It has been reported from New York (Bishop, 1949), Wisconsin (Levi and Levi, 1952) and Ontario (Edgar, 1966). At London it was found on the wooded slopes of the Byron Bog (Judd, 1965) and perched on milkweed leaves and flowers (Judd, 1968b).

Opilio parietinus (DeGeer) — This species was found infrequently under logs in woods (e.g. G7), the great majority being found on the walls of cottages and outbuildings in H2 or under boards adjacent to these structures. In such situations they were frequently found huddled in a cluster in the early morning, e.g. six on a patch of wall of a few square inches on the side of a cottage on July 27 and eight under a board on August 12.

The presence of this harvestman around cottages is in agreement with the reports of Edgar (1966, 1971) that it is associated with buildings and shaded, cool cement walls. It has been recorded from New York (Bishop, 1949), and Wisconsin (Levi and Levi, 1952). At London it was found on an insect trap on a pond (Judd, 1961) and in nests of several cardinals (Judd, 1963b).

Hadrobunus maculosus (Wood) — One male was found in H9 on damp soil beneath a log by a lane leading into a farmhouse. Its presence at this site is in accord with reports of Edgar (1966, 1971) that this species occurs in stone piles and in piles of boards in wet areas. It has been reported from New York (Bishop, 1949).

Leiobunum longipes Weed — This species was the commonest one collected, found about cottages (H2), under boards (G6, I3, I4), in woods (I2) and under logs (G7, H10). These harvestmen were particularly abundant on the walls of cottages, huddled motionless in groups on the vertical outside walls in early morning, e.g. ten in a cluster on July 27. In woods they were found under loose bark of logs of basswood and white elm and were frequently seen running rapidly up and down the trunks of trees and along logs. A few isolated individuals were found on vegetation such as burdock, New England aster and raspberry canes. On July 13 two were found dead in a spider's web on a cottage wall.

This species has been recorded from New York (Bishop, 1949), Ontario (Edgar, 1966) and Wisconsin (1952). Bishop (1949) refers to the habit of this harvestman running rapidly about on trees.

Leiobunum politum Weed — Although found in the vicinity of houses (H2) and in an abandoned roothouse (I12), this species occurred most commonly in woods (e.g., C1, D4, G7, I2, I3, H9, H10 etc.). They were under the loose bark of stumps and fallen logs in woods, particularly those of dead white elms. When routed from its resting place beneath a shelter one would run off rapidly into the surrounding vegetation.

This harvestman occurs in New York (Bishop, 1949), Ontario (Edgar, 1966) and Wisconsin (Levi and Levi, 1952). Its close association with wooded areas with a dense canopy and undercover has been noted by Clingenpeel and Edgar (1966) and Edgar (1971).

Leiobunum vittatum (Say) — Although found on cottage walls (H2) and beneath boards (G6) and logs (H10), this harvestman was most prevalent on leaves of vegetation in comparatively open situations, sometimes well up in trees. It was found on goldenrod, raspberry canes, milkweed and leaves of basswood trees.

The specimens collected showed the considerable variation in the ground colour of the body noted by Bishop (1949), from golden yellow to deep red brown. In those specimens with the yellowish body colour, the legs were light brown with black patellae and dark tips on the tibiae, while in those with the body colour deep brown, the legs were dark brown, verging on black.

This species has been recorded from New York (Bishop, 1949), Ontario (Edgar, 1966) and Wisconsin (Levi and Levi, 1952) and from the Byron Bog at London where it lives particularly on the shrubs on the open *Sphagnum* mat (Judd, 1965).

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OBSERVATIONS ON THE INCIDENCE RATES OF *NOSEMA FUMIFERANAE* (MICROSPORIDA) IN A SPRUCE BUDWORM, *CHORISTONEURA FUMIFERANA,* (LEPIDOPTERA: TORTRICIDAE) POPULATION

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Abstract

Examination of living spruce budworm, *Choristoneura fumiferana,* collected in the field over a six-year period indicated that infections caused by *Nosema fumiferanae* increased as the age of the infestation increased. The levels of infection increased from 35.9% in 1973 to 69.0% in 1978.

Introduction

The spruce budworm, *Choristoneura fumiferana* (Clem.) population in the Uxbridge Forest of Southern Ontario was examined for the microsporidia *Nosema (Perezia) fumiferanae* from 1955 to 1959 by Thomson (1960). Examination at this same site and presumably the same population was resumed again in 1973, in an attempt to determine the seasonal incidence of the parasite and its buildup over a long term, and what effect this might have on a population of spruce budworm in the field. The adverse effects of *N. fumiferanae* on the spruce budworm, such as reduced fecundity, and shortened adult life have been demonstrated by Thomson (1958) and Wilson (1977).

Materials and Methods

From 1973 through 1978 collections of living spruce budworm were made primarily in June from white spruce *(Picea glauca)* trees. A sample consisted of branch tips cut from several host trees, which were examined in the laboratory and the spruce budworm removed. The larvae were then stored at —4°C until they could be examined. In 1973 two samples were taken at different times to determine if the levels of *N. fumiferanae* increased during the summer. Individual larval specimens were smeared on slides and examined microscopically with phase optics. Diagnosis of the parasite was based upon the presence or absence of spores in each specimen.

Results and Discussion

The collection dates, predominate instars, numbers examined, and percent infection are given in Table I. Incidence of *N. fumiferanae* increased from 35.9 in 1973 to 69.0% in 1978 as the spruce budworm infestation persisted during these years. The spruce budworm population levels remained at moderate to severe throughout this time period with slight reductions in the area infested. Reports

based on the Survey Bulletin, Forest Insect and Disease Conditions in Ontario, Summer 1978, Great Lakes Forest Research Centre, indicates a decrease in infestations throughout most of southern Ontario. The two samples taken in 1973 indicate that the incidence of *N. fumiferanae* increases with the age of the larvae during the summer. A similar increase was recorded for microsporidia levels in budworm examined in Parkinson Township, Ontario during the summers of 1971 through 1973 (Wilson, 1973). Wilson (1973) suggested that the increase in levels of microsporidia toward the end of summer may have been due to some light infection which was overlooked in younger larvae. However as pointed out by Chapman (1974), the incidence of microsporidian infection in mosquitoes, especially in older larvae could be higher since the infections prolong larval development beyond that of the uninfected larvae. This could also be the case for infected spruce budworm. Kramer (1968) examined samples of adult black blowflies, *Phormia regina,* for the presence of the microsporidian parasite *Octobsporea muscaedomesticae* from April through October in Urbana, Illinois for the years 1963 and 1964. In 1963, he noted that the monthly rate of parasite incidence steadily increased with the progression of the seasons while the fly population declined over the same period.

Thomson (1960) measured the levels of *N. fumiferanae* in overwintering populations of the spruce budworm in the Uxbridge Forest from 1955 to 1959 and recorded an increase in infection from 36.4 to 81.3% over the five year period. Thomson (1960) suggested that *N. fumiferanae* was probably responsible for the decrease in egg numbers in 1959 and the subsequent low larval populations the following year. The budworm population in the Uxbridge Forest will continue to be monitored to determine if the levels of microsporidia increase and if the infestation will continue to decline.

TABLE I. Percentage *Nosema fumiferanae* in spruce budworm collected in Uxbridge Municipal Forest during the summers of 1973 to 1978.

Year	Collection date	Predominate instars	Number examined	Percent infection
1973	May 29	III - V	216	12.9
	June 29	IV - P	354	35.9
1974	June 4	V - VI	231	18.6
1975	June 5	VI - P	467	43.0
1976	June 9	VI - P	341	56.0
1977	June 1	VI - P	434	56.2
1978	June 14	VI - P	258	69.0

Acknowledgment

The technical assistance of Miss E. Young is gratefully acknowledged.

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III. INDEX

AUTHOR'S GUIDE

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III. SCIENTIFIC NOTES

I. THE SOCIETY

THE JOAN F. BRONSKILL MEMORIAL FUND

Joan Bronskill, a very active and longtime member of the Society, passed away in April, 1978. Some of her friends and colleagues established a special fund as a memorial to Joan. This fund is to provide an annual cash award to the best female student in biology (Grade 12 or 13) in Hastings County, Ontario.

We have been advised by Helen Salkeld, a former close colleague of Joan's, that the first presentation of this award was made in August 1978 to Miss Lynn Martin, a student graduating from the Quinte Secondary School, Belleville, Ontario. Miss Martin, who is presently attending Queen's University, obtained a 96% average in Grade 13 biology last year.

The award this year was in the amount of $250.00.

Donations are still being received and it is hoped the award can be increased next year.

Donations may be sent to: Dr. H. Salkeld, Experimental Taxonomy Section, Biosystematics Research Institute, Central Experimental Farm, Ottawa, Ontario K1A 0C6.

PRESIDENT'S PRIZE — 1978

Editor's Note: Since its inception in 1961, the presentation of student papers in the President's Prize competition has been one of the highlights of the annual meeting of the Entomological Society of Ontario. However, it is usually only those members present at the annual meeting who are aware of the winner and his topic. In an effort to bring this information to the whole membership, we propose to include a brief write-up on each student winner in the Proceedings. The first of these follows.

Béla A. Nagy, Department of Zoology, University of Western Ontario, won this year's "President's Prize" for the best student paper presented at the Annual Meeting at the Point Pelee Motor Inn, Leamington, Ontario. His paper, entitled "External Morphology of Antennae and their Sensilla in the Oriental Fruit Moth *Grapholitha molesta* (Busck)", was judged the best of eight in this year's competition.

Mr. Nagy was born in Sopron, Hungary in 1950. With his family he emigrated to France in 1956, then to Canada in 1960, and became a Canadian citizen in 1965. Since the age of eight, Bela has been a collector of insects. He has a well kept personal collection of about 6,000 specimens of Canadian insects which he continues to add to by collecting and rearing.

The objectives of Mr. Nagy's graduate studies and research under the direction of Professor John A. George, University of Western Ontario are: 1) to describe the gross morphology of the antennae of the Oriental fruit moth, in terms of types, numbers and distribution of sensilla, 2) to determine by bioassay which sensilla are olfactory and, 3) to describe the fine structure of the olfactory sensilla. His enthusiasm and determination to pursue a study of insects qualifies him well to accomplish the objectives of his research.

This is the second award for Mr. Nagy this year. He recently received the Canadian Entomological Society's graduate student award.

II. SUBMITTED PAPERS

ESTABLISHMENT OF AN INTRODUCED WEEVIL, *RHINOCYLLUS CONICUS* (COLEOPTERA: CURCULIONIDAE) FOR THE BIOLOGICAL CONTROL OF NODDING THISTLE, *CARDUUS NUTANS* (COMPOSITAE) IN SOUTHERN ONTARIO[1]

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Abstract

Rhinocyllus conicus Froelich (Curculionidae) was released at Guelph, Ontario in 1975 for the control of nodding thistle, *Carduus nutans* L. The weevil has become established in this area and has dispersed several km from the release site. *R. conicus* infested 95% of the thistles in the release site three years after the release. Eighty per cent of the weevil eggs were found on the terminal and first two lateral thistle heads. Heads containing seven or more pupal cells of *R. conicus* had their seed production significantly reduced.

Introduction

Rhinocyllus conicus Froelich, a seed-feeding weevil, was first introduced into Canada (Belleville, Ontario and Regina, Saskatchewan) from Europe in 1968 for the biological control of nodding (= musk) thistle *(Carduus nutans* L.) and plumeless thistle *(Carduus acanthoides* L.) (Harris and Zwolfer 1971). These releases followed extensive studies of *R. conicus* in Europe on its potential as a biological control agent (Zwolfer 1967). The weevil is established in the areas of both Belleville, Ontario and Regina, Saskatchewan (P. Harris, personal communication[2]). Successful releases for control of thistles in the genus *Carduus* also have been reported in Montana (Hodgson and Rees 1976), Quebec (Letendre *et al.* 1976), Missouri (Puttler *et al.* 1978), and Virginia (Surles *et al.* 1974). Reduction of the reproductive potential of *Carduus* thistles, via direct seed destruction and lowered viability, has been demonstrated clearly (Surles and Kok 1978). After six years, mean reduction of thistle density was 95% in Virginia (Kok and Surles 1975).

Eggs of *R. conicus* are laid on the involucral bracts of thistles. When the eggs hatch, the larvae burrow into the receptacle where they form cells in which they mature while feeding on the developing achenes. Adults emerge *ca.* six weeks after egg deposition and search for overwintering sites in the soil and leaf litter.

In 1975, adults of *R. conicus* were released in the Guelph area. This study reports the establishment, infestation and dispersal of the weevil in this area of southern Ontario.

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[1]Received for publication Dec. 14, 1978.
[2]Dr. P. Harris, Research Station, Agriculture Canada, Regina, Saskatchewan.

Materials and Methods

On June 10, 1975, adults of *R. conicus* (received from Dr. P. Harris, Agriculture Canada, Regina, Saskatchewan) were released at two sites. The first release site was a pasture on the University of Guelph campus with a scattered population of *ca.* 150 nodding thistles. The second site was an open field located in the Kortright Waterfowl Park in which the nodding thistles were abundantly distributed, ranging from dense patches to single, isolated plants. A total of 2,185 adults were released on these two sites; 335 at the first site and the remaining 1,850 at the second site. Thistles at both sites were at a suitable stage of development for oviposition.

In late July, 1975, 43 randomly selected, terminal capitula with weevil eggs were collected at Kortright Park and dissected to assess the extent of larval feeding damage. The number of larval feeding chambers and the number of fully-developed seeds were recorded for each capitulum.

Surveys to monitor the establishment of *R. conicus* were conducted from 1976 to 1978. In early June 1976, all thistles over 30 cm in height along a fenceline at the Kortright Park site were numbered for sampling the eggs. As well, five transect lines were chosen, radiating from a point in the centre of the release plot. At every 5 m along each transect the closest flowering thistle within a 1.5 m radius was examined for eggs of *R. conicus*. After a second egg count in the middle of July 1976, all infested, terminal heads from both sampling methods were covered with fine mesh bags. These heads were collected when mature and held individually in containers in the laboratory for adult emergence. Thistle density at Kortright Park in 1976 was determined from thistle counts in 101 quadrats (1 sq m) randomly chosen within the release area.

A total of 75 of these laboratory-reared adults were returned to the release site at Kortright Park. To extend the weevils distribution, another release plot was chosen on Maplehurst Farm, Arkell Road, Guelph. A total of 109 adults were placed on a small population of nodding thistles at this location on August 9, 1976.

To determine if *R. conicus* would produce a second generation, as suggested in the literature (Zwolfer 1967), adults that emerged and mated in the lab were caged with uninfested nodding thistles in early August 1976 on the University of Guelph campus. These caged thistles and thistles at the two original release sites and at the Maplehurst Farm plot were periodically checked for oviposition until September 1976.

Because of low thistle density at the Maplehurst Farm in 1978, all infested plants could be staked, numbered and examined for eggs. Egg-infested nodding thistles were also detected in a pasture at the neighbouring farm (Staples Farm) and sample plots were similarly established there. Uninfested thistles at both sites were counted and checked during the summer for subsequent oviposition. Terminal, first and second lateral capitula from the Maplehurst Farm plot were bagged after the second egg count and removed to the lab when mature. The number of emerged adults and the number of weevil pupation chambers found from dissections of these heads were recorded for an analysis of mortality. In 1978, patches of thistle at the Kortright Park site were randomly staked and numbered and two sampling surveys for eggs were conducted over the summer.

Weevil dispersal was monitored by examining thistles in the Guelph area and noting the maximum distance from the original release sites at which eggs and/or adults were detected.

Results and Discussion

Three years after its release, *R. conicus* is well established around Guelph, Ontario. Infestation of plants at the Kortright Park site increased from 67% in 1976 to 95% in 1978 (Table I). Infestation of terminal heads was 100% in 1978

TABLE I. Infestation of nodding thistle by *Rhinocyllus conicus*, Guelph, Ontario.

Location	Year	No. plants in sample	Mean no. eggs/plant	Max. no. eggs/plant	% Plants infested
Kortright Park	1976	69	13.7	99	67
	1978	73	46.1	378	95
Maplehurst Farm	1978	80	14.5	98	53
Staples Farm	1978	52	14.0	72	24

(Table II). First and second lateral head infestations increased from 39 and 28% in 1976 to 62 and 58%, respectively, in 1978. Mean number of eggs per plant increased from 13.7 in 1976 to 46.1 in 1978. Mean numbers of eggs on the terminal, first and second lateral heads increased *ca.* four-fold over the three years (Table II). Heavy infestations caused the abortion of many of these heads and very few viable seeds were produced. The fact that many eggs were deposited in large clumps and on leaves near the heads was evidence that suitable oviposition sites were scarce due to the high density of weevils in 1978. Although eggs were found as far down as the 14th lateral head, *ca.* 80% of the total eggs were consistently deposited on the terminal and first two lateral heads in 1976 and 1978 in all sample plots. Infestation of plants at the Maplehurst and Staples Farm plots in 1978 were 53 and 24%, respectively.

Although Kok (1974) has shown that spring releases are more efficient in successful colonization of *R. conicus,* the presence of eggs and adults at the Maplehurst Farm site in the spring of 1978 indicated that the late summer release in 1976 was successful.

Comparison of the mortality of *R. conicus* from thistle heads collected in 1978 from the Maplehurst Farm plot showed that although mean percent mortality of pupae and adults appeared to increase from terminal to first and second lateral heads, the differences were not significant at $P < 0.05$ using the Kruskal-Wallis test (Table IV). The low mortality found between pupae and adults indicated that most of the mortality occur in the egg and larval stages. No correlation was found between weevil mortality and number of eggs per head. No mortality from native parasitoids was observed in this study.

A total of 223 thistles were counted in 101 quadrats at Kortright Park in 1976, giving an average density of 2.2 nodding thistles per sq m. Fifty-five of the 101 quadrats contained no thistles. Quadrat samples were not taken during 1978, but the abundance of flowering and non-flowering thistles was noticeably reduced. Accurate assessment of the impact of *R. conicus* on nodding thistles at the major release site at Kortright Park was difficult for several reasons. Firstly, some thistles in the release area were selectively cut by park personnel in 1978 before sampling could begin. Secondly, a large percentage of thistles were attacked by lepidopterous larvae. Larval feeding by the artichoke plume moth, *Platyptilia carduidactyla* Riley (Pterophoridae), and a noctuid stalk borer, likely *Papaipema negris* Guen., caused many capitula to turn black and wither before the seeds matured. Dissections of infested terminal heads collected in 1975 showed, however, that feeding by larvae of *R. conicus* significantly reduced seed production (Table III).

TABLE II. Infestation of heads of nodding thistles by *R. conicus*, Guelph, Ontario.

Location	Year	Head Location	No. heads in sample	Mean no. egg/head	Max. no. eggs/head	% Heads infested	% of total eggs
Kortright Park	1976	Terminal Head	69	7.3	64	61	53
		1st Lateral Head	69	2.2	19	39	16
		2nd Lateral Head	69	1.5	20	28	11
	1978	Terminal Head	70	27.2	93	100	57
		1st Lateral Head	71	8.1	54	62	17
		2nd Lateral Head	71	5.7	46	58	12
Maplehurst Farm	1978	Terminal Head	80	7.5	49	84	52
		1st Lateral Head	80	2.2	11	51	15
		2nd Lateral Head	80	1.8	15	46	13
Staples Farm	1978	Terminal Head	42	9.3	49	90	54
		1st Lateral Head	50	2.5	23	62	17
		2nd Lateral Head	51	1.5	10	43	11

TABLE III. Seed reduction by larval feeding of *R. conicus*, Kortright Park, Guelph, Ontario, 1975.

No. pupal cells/head	Total no. heads	Total no. seeds	Mean no. seeds/head[a]
0-6	33	7,510	227.6 a
7-12	5	311	62.2 b
13-18	5	282	56.4 b

[a] Means followed by the same letter are not significantly different at $P < 0.05$ (Scheffé's Test).

TABLE IV. Pupal and adult mortality of *R. conicus*, Guelph, Ontario.

Head location	No. heads	No. eggs	No. pupae	% Mortality	No. adults	Total % mortality
Terminal	29	368	238	35.3	235	36.1
1st Lateral	20	96	57	40.6	56	41.7
2nd Lateral	23	95	41	56.8	41	56.8

No second generation of *R. conicus* was observed during this study, unlike the finding of Harris and Zwolfer (1971) at Belleville, Ontario. Adult weevils, which emerged early in the summer, did not oviposit until the following year. No new eggs were observed on the plants after the beginning of August. Newly emerged, mated females that were caged with uninfested nodding thistle at the beginning of August 1976 produced no eggs during August or September, 1976.

Dispersal of the weevils was noted at all release sites. Despite the fact that nodding thistles in the Guelph area were in low numbers and widely scattered, field observations in 1978 indicated that *R. conicus* had dispersed to cover an area within a 6 km radius of its release at Kortright Park. Single larval cells of *R. conicus* were also found in several heads of bull thistle, *Cirsium vulgare* (Savi) Tenore, collected at a point 5.7 km from the release site at Kortright Park.

Acknowledgments

This study was supported by the Ontario Ministry of Agriculture and Food. The authors wish to acknowledge the cooperation of Dr. Peter Harris and Dr. D. Peschken (Agriculture Canada, Regina). Thanks are extended to Mrs. K. O. Hammill of the Kortright Waterfowl Park and Mrs. M. W. Staples for permission to release and monitor the weevils on these properties.

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INTEGRATED PEST MANAGEMENT — INSECTICIDES AND NATURAL PREDATOR POPULATIONS ON APPLE[1]

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Abstract

The number of predacious arthropods in orchards treated with insecticides (azinphosmethyl, phosmet and phosalone) were generally lower than those in which chemicals were not applied for insect control. However, in both cases, the numbers of predators present were too low to control or regulate the major insect pest populations. It is suggested that if these biological control agents are to be effectively manipulated, augmentation of their natural populations will be required.

Introduction

Selection of insecticides for use in integrated pest management programs for apples in Ontario has been largely based on their efficacy against the three major pests namely, the codling moth, *Laspeyresia pomonella* (L.); the apple maggot, *Rhagoletis pomonella* Walsh; and the plum curculio, *Conotrachelus nenuphar* (Hbst.); and their effects on predacious mites particularly, *Amblyseius fallacis* Garman, the major predator of the European red mite, *Panonychus ulmi* Koch. Azinphosmethyl and phosmet are the main materials used and are supplemented, when pest occurrence and activity warrants, with phosalone, endosulfan, and occasionally superior oil and diazinon. During 1973-5 observations were made in several orchard blocks under integrated pest management programs and in others sprayed only with fungicides, to assess the effect of some of these materials on the occurrence of natural predators and on their potential as biological control agents. The results obtained are reported in this paper.

Materials and Methods

The study blocks were located in orchards at Vineland, Jordan Station and Fonthill on the Niagara Peninsula, Ontario. The Vineland blocks were comprised of standard trees (120-136/ha) about 35-40 years old mainly of the cultivars McIntosh and Northern Spy and were 0.50-0.75 ha in size. One block, A, was on a pest management program in which phosmet (50% WP), phosalone (30% WP) and azinphosmethyl (50% WP) were the insecticides used (Tables I-III). A second block, B, separated from block A by a buffer zone of three rows of trees (*ca.* 32 m wide) received only fungicide sprays (difolatan 4.8F, and cyprex 65% WP) in both 1973 and 1974 and two insecticide sprays late in the season in 1975. The third block, C, was separated from Block A by an area of grassland and grapes about 64 m wide. This block was sprayed only with fungicides (difolatan 4.8F and cyprex 65% WP). Block D, under a pest management program, was located at Fonthill and consisted of 40-yr.-old standard trees (125/ha) mainly of the cultivars McIntosh, Red Delicious, Northern Spy and Courtland. The same

[1]Received for publication Jan. 2, 1979.

TABLE I. Amount of pesticides (kg product/ha) applied to experimental apple blocks in 1973.

Date	ORCHARD BLOCKS			
	VINELAND			FONTHILL
	A	B	C	D
19 Apr.				Difolatan (45.0 litre)
30 Apr.	Cyprex (2.4)	Cyprex (2.4)	Cyprex (2.4)	
9 May	Azinphosmethyl (0.5)			Azinphosmethyl (0.3)
16 May	Cyprex (1.7)	Cyprex (2.4)	Cyprex (2.4)	
24 May	Cyprex (1.7)	Cyprex (2.4)	Cyprex (2.4)	Cyprex (1.1)
7 June	Phosmet (2.4)			Cyprex (0.9)
	Cyprex (1.7)	Cyprex (2.4)	Cyprex (2.4)	Azinphosmethyl (1.0)
14 June	Phosmet (2.4)			Cyprex (0.9)
21 June	Cyprex (1.7)	Cyprex (2.4)	Cyprex (2.4)	Cyprex (0.7)
29 June				Azinphosmethyl (1.0)
4 July	Cyprex (1.7)	Cyprex (2.4)	Cyprex (2.4)	Cyprex (0.9)
9 July				Cyprex (1.9)
19 July	Phosmet (2.4)			Cyprex (1.1)
	Cyprex (1.7)	Cyprex (2.4)	Cyprex (2.4)	Omite (2.7)
24 July	Phosmet (2.4)			Cyprex (1.1)
9 Aug.	Phosmet (2.4)			Azinphosmethyl (1.0)
	Cyprex (1.7)	Cyprex (2.4)	Cyprex (2.4)	Cyprex (0.9)

TABLE II. Amount of pesticides (kg product/ha) applied to experimental apple blocks in 1974.

	ORCHARD BLOCKS					
	VINELAND			FONTHILL	JORDAN	
Date	A	B	C	D	E	F
24 Apr.				Difolatan (45.0 litre)	Difolatan (22.5 litre)	Difolatan (45.0 litre)
26 Apr.	Difolatan (22.5)					
30 Apr.		Cyprex (2.4)	Cyprex (2.4)			
31 May	Phosalone (2.8) Cyprex (2.4)	Cyprex (2.1)	Cyprex (2.4)	Cyprex (1.0) Phosalone (1.9) Cyprex (1.0)	Phosalone (2.8) Cyprex (1.3)	
1 June						
7 June						
13 June	Cyprex (2.4)				Cyprex (1.3)	
14 June				Cyprex (1.0)		
20 June					Phosmet (2.6) Cyprex (1.3)	Cyprex (1.5)
21 June	Phosmet (2.6) Cyprex (2.4)	Cyprex (2.4)	Cyprex (2.4)			
22 June				Azinphosmethyl (0.9) Cyprex (1.0)		
10 July					Phosmet (2.6) Cyprex (1.3)	Cyprex (1.5)
11 July	Phosmet (2.6) Cyprex (1.6)	Cyprex (1.6)	Cyprex (1.6)			
13 July				Azinphosmethyl (0.9) Cyprex (0.8) Omite (4.9)		
30 July		Cyprex (0.8)	Cyprex (0.8)		Cyprex (1.3)	
31 July	Phosmet (2.6) Cyprex (0.8)					
1 Aug.				Azinphosmethyl (0.9) Cyprex (1.3)		
14 Aug.	Cyprex (0.8)	Cyprex (0.8)	Cyprex (0.8)			
20 Aug.					Phosmet (2.6) Cyprex (0.65)	
21 Aug.				Azinphosmethyl (0.9)		
22 Aug.	Phosmet (2.4)					

TABLE III. Amount of pesticides (kg product/ha) applied to experimental apple blocks in 1975.

	ORCHARD BLOCKS					
		VINELAND		FONTHILL	JORDAN	
Date	A	B	C	D	E	F
25 Apr.	Difolatan (22.5 litre)	Difolatan (22.5 litre)	Difolatan (22.5 litre)			
28 Apr.					Difolatan (22.5 litre)	Difolatan (45.0 litre)
3 May				Difolatan (45.0 litre) Azinphosmethyl (0.9)		
29 May	Phosmet (2.6) Cyprex (2.4)	Cyprex (2.4)	Cyprex (2.4)	Cyprex (1.0)		
2 June					Phosmet (1.1) Cyprex (1.3)	
5 June				Dikar (3.3)		
13 June				Dikar (3.3)		
19 June				Cyprex (1.0) Azinphosmethyl (0.9)		
20 June	Phosmet (2.6) Cyprex (2.4)	Cyprex (2.4)	Cyprex (2.4)			
23 June					Phosmet (1.1) Cyprex (1.3)	
11 July	Phosmet (2.6)	Phosmet (2.6)	Cyprex (2.4)	Cyprex (1.0) Azinphosmethyl (0.9)		
18 July					Phosmet (1.1) Cyprex (1.3)	
2 Aug.				Cyprex (1.0) Azinphosmethyl (0.9)		
5 Aug.	Cyprex (2.4)	Phosmet (2.6) Cyprex (2.4)	Cyprex (2.4)			
8 Aug.					Phosmet (1.1) Cyprex (1.3)	

pesticides were used in this block although azinphosmethyl was the standard insecticide and dikar (80% WP) was used in 1975 for disease control. Blocks E and F were located on the Agriculture Canada Experimental Farm at Jordan Station. Block E consisted, at the commencement of the study, primarily of 4-yr.-old, semi-dwarf McIntosh trees (240/ha) with cv. Scotia as pollinator (Holliday and Hagley 1978). This block was under a pest management program in which phosmet (50% WP) was the main insecticide used. Block F contained 12-yr.-old, semi-dwarf McIntosh and Red Delicious trees at a density of 115/ha. Sample trees in this block received fungicide sprays (difolatan 4.8F and cyprex 65% WP) only.

Predators were collected twice weekly by tapping the foliage of 20 individual trees per orchard using a 45 cm^2 cloth catch tray and bamboo stick, and on yellow rectangular cardboard sticky traps (22.5 x 13.8 cm) placed just within the periphery of the tree canopy. Also ten fruit and leaf clusters per sample tree were examined for predators at weekly or twice weekly intervals throughout the season. Clusters were either examined in situ or removed from the tree and examined under a microscope in the laboratory.

All pesticides were applied by a hydraulic Swanson sprayer (model 530 MH) at rates of 252 and 315 l/ha at a pressure of 1380 kPa.

Analyses of variance were carried out on the transformed data and means separated by Duncan's multiple range test.

Results

In all blocks, predator populations were low (Tables IV-VI). In the untreated blocks total predators varied between 4.0 and 8.8/tree at Vineland and 0.09 and 0.24 at Jordan Farm. In the treated blocks during the same periods, predator numbers varied between 2.1 and 5.9 at Vineland, 1.1 and 4.1 at Fonthill and .04 and .08 at Jordan. In 1973 (Table IV), the numbers of predators, especially chrysopids, coccinellids and spiders, were significantly lower in the treated blocks, Vineland (A) and Fonthill (D), compared to those in the untreated block Vineland (B), but not in Vineland (C). In 1974 (Table V), there were no significant differences in predator numbers between the untreated and treated blocks at Vineland or at Jordan. However, the number of predators at Fonthill was significantly lower compared to that in the untreated block, Vineland (B). There were no differences in predator numbers between the Vineland untreated and treated blocks and the Fonthill blocks in 1975 (Table VI). All these blocks were significantly different from the Jordan blocks.

Considerable differences were observed in the predominant predator species in individual blocks in different years. In 1973, the coccinellid, *Hippodamia tredecimpunctata tibialis* (Say) was predominant in one untreated block, while *Adalia bipunctata* (L.) predominated in both treated blocks irrespective of the insecticide used. In 1974, *A. bipunctata,* and in 1975, *H. tredecimpunctata tibialis,* were generally predominant in all blocks. Gratwick (1965) has reported that azinphosmethyl was highly toxic to larvae of *A. bipunctata* and they were rarely found in the treated blocks in this study.

Phytocoris sp. was the most abundant Hemiptera in 1973 and was recovered in all blocks. In 1974, the same species was predominant only in the untreated blocks, while in the treated blocks *Deraeocoris fasciolus* Knight predominated. *Plagiognathus obscurus* Uhl. also occurred in relatively large numbers at Fonthill where azinphosmethyl was the main insecticide used. In 1975, *D. fasciolus* pre-

TABLE IV. Av. total no. predators/tree in treated[a] and untreated[b] orchard blocks in 1973.

	ORCHARD BLOCKS			
	Untreated		Treated	
Predator Group	Vineland B (8)[c]	Vineland C (6)	Vineland A (8)	Fonthill D (12)
Chrysopidae	11.3	0.7	0.5	1.7
Hemerobiidae	9.9	5.0	6.6	7.3
Coccinellidae	4.9	0.0	0.9	0.8
Hemiptera	15.4	12.8	6.3	10.7
Syrphidae	7.9	8.7	5.4	1.0
Araneidae	3.1	0.8	0.1	0.3
Total:	52.5	28.0	19.8	21.8
Mean:	8.8 a[d]	4.7 b	3.3 b	3.6 b

[a] Insecticides, fungicides, and miticides applied for pest control.
[b] Fungicides only applied for disease control.
[c] No. sample trees.
[d] Means followed by the same letter not significantly different (P = .05).

TABLE V. Av. total no. predators/tree in treated[a] and untreated[b] orchard blocks in 1974.

	ORCHARD BLOCKS					
	Untreated			Treated		
Predator Group	Vineland B (5)[c]	Vineland C (5)	Jordan F (8)	Vineland A (8)	Fonthill D (12)	Jordan E (16)
Chrysopidae	0.2	0.6	0.00	0.0	0.5	.01
Hemerobiidae	7.8	4.0	0.09	1.9	0.3	.01
Coccinellidae	9.2	0.0	0.20	9.3	2.8	.07
Hemiptera	9.2	19.0	1.30	2.6	0.9	.28
Syrphidae	1.4	3.6	0.02	0.8	1.9	.11
Araneidae	1.4	1.4	0.03	0.6	0.1	.01
Total:	29.2	28.6	1.64	15.2	6.5	.49
Mean:	4.9 a[d]	4.8 ab	0.24 cd	2.5 abc	1.1 bcd	.08 d

[a] Insecticides, fungicides and miticides applied for pest control.
[b] Fungicides only applied for disease control.
[c] No. sample trees.
[d] Means followed by the same letter not significantly different (P = .05).

TABLE VI. Av. total no. of predators/tree in treated[a] and untreated[b] orchard blocks in 1975.

	ORCHARD BLOCKS					
	Untreated		Treated			
Predator Group	Vineland C (6)[c]	Jordan F (8)	Vineland A (8)	Vineland B (6)[d]	Jordan E (16)	Fonthill D (7)
Chrysopidae	2.70	0.01	3.1	2.7	0.01	1.7
Hemerobiidae	0.30	0.20	1.5	10.7	0.00	5.4
Coccinellidae	0.02	0.08	0.8	0.0	0.04	0.9
Hemiptera	13.30	0.13	4.8	4.0	0.18	5.3
Syrphidae	1.50	0.06	1.0	2.8	0.04	4.7
Araneidae	1.10	0.06	1.1	1.0	0.01	0.7
Cantharidae	9.20	0.06	2.5	19.8	0.02	9.8
Total:	28.12	0.60	14.8	41.0	0.30	28.5
Mean:	4.01 a[e]	0.09 b	2.1 a	5.9 a	0.04 b	4.1 a

[a] Insecticides, fungicides and miticides applied for pest control.
[b] Fungicides only applied for disease control.
[c] No. sample trees.
[d] Phosmet (2.6 k/ha) applied on 11 July and 5 August.
[e] Means followed by the same letter not significantly different (P = .05).

TABLE VII. Species of Hemiptera and Coleoptera collected in the test blocks.

Specie	ORCHARD BLOCK AND YEAR						
	Untreated				Treated		
	Vineland B 1973-74	Vineland C 1974-75	Jordan E 1974-75	Vineland A 1973-74-75	Vineland B 1975	Fonthill D 1973-74-75	Jordan D 1974-75
Coleoptera:							
Coccinellidae:							
Adalia bipunctata (L.)	x x	x —	x x	x x x	x	x x x	x x
Anatis quindecimpunctata (Oliv.)	— —	— —	— —	— — —	x	— — —	— —
Chilocoris bivulneratus Mul.	— x	— —	x —	— — —	—	— — —	— —
Coccinella transversoguttata richardsoni Brown	x —	— x	— x	x — x	x	— — x	x x
Coccinella undecimpunctata L.	— x	— —	— —	— — —	—	— — —	— —
Coleomegilla maculata lengi Timb.	x x	— —	x —	— — —	—	x — x	— —
Cycloneda munda (Say)	x —	— —	— —	x x x	—	x — —	— —
Hippodamia tredecimpunctata tibialis (Say)	x x	— —	— —	x — x	x	— x x	— —
Hyperaspis undulata (Say)	— —	— —	— —	— — —	—	x — —	— —
Neomysia sp.	— —	— —	— —	x — —	—	— — —	— —
Hemiptera:							
Anthocoridae:							
Anthocoris nemoralis (F.)	— —	— —	x x	— — —	—	— — —	— —
Miridae:							
Campylomma verbasci (Meyer)	— x	x —	— x	— — x	—	— x x	— x
Deraeocoris fasciolus Knight	x —	— —	— —	— x x	x	— — x	— x
Hyalioides vitripennis (Say)	— x	— x	— —	— — —	—	— — —	— —
Phytocoris sp.	x x	x x	x x	— x x	x	x x —	x x
Plagiognathus sp.	x x	x —	— x	x — —	—	x x x	x —
Pentatomidae:							
Podisus sp.	x x	— —	— —	— x x	x	— — —	x —
Reduviidae:							
Acholla multispinosa (DeGeer)	— x	x x	x x	— x —	x	— x x	— —
Reduviuus personatus (Linn)	— —	— x	— —	— — —	—	— — x	— —

dominated in the treated blocks at Vineland and Fonthill, and *Hyalioides vitripennis* (Say) in the untreated block at Vineland. These data sunbstantiate earlier reports by MacPhee and Sanford (1961) of the relatively high toxicity of azinphosmethyl to *Phytocoris* sp. and its low toxicity to *D. fasciolus* and *P. obscurus*.

Although predominant species varied considerably between blocks, the total number of species present was not significantly different (Table VII). Also, the Neuroptera, *Chrysopa oculata* (Say) and *Hemerobius humulinus* (L.); the syrphids, *Metasyruphus americanus* (Wied.) and *Allograpta obliqua* (Say); and the cantharids, *Cantharis* sp. and *Podabrus* spp. were common to all blocks.

The occurrence of large numbers of suitable prey also greatly influenced the species of predators present. In 1974, large numbers of the green apple aphid, *Aphis pomi* DeGeer, were present in both blocks on the Jordan Farm and several aphidophagous species, absent in the other blocks, were present in large numbers. These included the mullein bug, *Campylomma verbasci* (Meyer), and *Pilophorus perplexus* Dove and Scott in both blocks. The coccinellids, *C. transversoguttata richardsoni* and *C. novemnotata* Herbst, were recovered from the untreated but not the treated block. In the untreated block *Hemerobius* sp. and the reduviid, *Acholla multispinosa* (DeGeer), were also present in large numbers. The predacious thrips, *Thrips calcaratus* Uzae, was only recovered from the untreated block while *Haplothrips faurei* Hood and *H. subtilissimus* (Haliday) were present in low numbers in both the treated and untreated blocks. In 1975, *C. verbasci* was again one of the most abundant aphidophagous predators. The coccinellid, *C. transversoguttata richardsoni,* was also numerous in the treated block and was of equal occurrence with *A. bipunctata* in the untreated block. *Hemerobius* sp. and *A. multispinosa* were not captured in the treated block.

The effects of individual spray applications on predator numbers are summarized in Tables VIII-X. There was little difference in the numbers of predators in the treated and untreated blocks except in the latter part of July in 1974 and 1975.

Discussion

Phosmet and azinphosmethyl at the rates used retain their efficacy against most pest species for 20-25 days (Hagley and Chiba unpublished). As shown in Tables VIII-X spray intervals of this duration generally did not seriously affect the rate at which adult beneficial insects re-entered the treated blocks. However, in the treated blocks immature stages of the predators were scarce although eggs of some species were present, and the collection of adults suggested that most species had immigrated from outside, untreated areas. It is unlikely, therefore, that natural populations of predators will survive and increase to sufficient numbers to control or regulate pest populations under current pest management programs.

Herne and Putman (1966) reported similar results in peach orchards on the Niagara Peninsula. These authors also stated that intensive spraying over a large acreage resulted in the elimination of areas where the predators could survive to reinvade the orchard after dissipation of pesticide residues. While careful selection and use of available insecticides might in some cases enable predators to survive and be manipulated, they must be present in sufficiently large numbers to affect the pest populations. The data presented in Tables IV-VI substantiate an earlier report (Hagley 1975) that the numbers of predators observed are too low even in unsprayed orchards to control or regulate insect pest populations. In addition to the adverse effects of pesticides, the numbers of predators in the ecosystem is also

TABLE VIII. Av. no. predators collected/day/tree between insecticide applications in treated[a] blocks Vineland A and Fonthill D in 1973.

Date Spray Applied	Days to next spray	AV. NO. PREDATORS/DAY/TREE			
		Untreated Blocks[b]		Treated Blocks	
		Vineland B	Vineland C	Vineland A	Fonthill D
7 June	13	0.36	0.10	0.19	0.33
21 June	17	1.84	0.88	2.16	0.89
19 July	20	4.05	1.87	2.74	1.33
9 Aug.	Obs. ceased 30 Aug.	1.32	0.93	2.76	0.13
Total:		7.57	3.78	7.85	2.68
Mean:		1.89 a[c]	0.95 b	1.96 a	0.67 b

[a] Insecticides, fungicides and miticides applied for pest control.
[b] Fungicides only applied for disease control and data included for comparison.
[c] Means followed by the same letter not significantly different (P = .05).

TABLE IX. Av. no. predators collected/day/tree between insecticide appli cations in treated[a] blocks Vineland A and Fonthill D in 1974.

Date Spray Applied	DAYS TO NEXT SPRAY		AV. NO. PREDATORS/DAY/TREE			
	Vineland A	Fonthill D	Vineland B	Vineland C	Vineland A	Fonthill D
31 May	20		0.20	0.28	0.28	
1 June		21				0.15
21 June	19		0.16	0.20	0.06	
22 June		20				0.13
11 July	19		0.34	0.16	0.04	
13 July		18				0.06
31 July	19		0.14	0.28	0.04	
1 Aug.						0.01
21 Aug.)	Obs. ceased					0.05
)	9 Sept.					
)						
22 Aug.)			0.32	0.76	0.08	
Total:			1.16	1.68	0.50	0.40
Mean:			0.23 ab[c]	0.34 a	0.10 b	0.08 b

[a] Insecticides, fungicides and miticides applied for pest control.
[b] Fungicides only applied for disease control and data included for comparison.
[c] Means followed by the same letter not significantly different (P = .05).

TABLE X. Av. no. predators collected/day/tree between insecticide applications in treated[a] blocks Vineland A and Fonthill D in 1975.

Date Spray Applied	DAYS TO NEXT SPRAY		AV. NO. PREDATORS/DAY/TREE			
			Untreated Block[b]	Treated Blocks		
	Vineland A	Fonthill D	Vineland C	Vineland A	Vineland B	Fonthill D
29 May	21	20	0.35	0.21	0.62	0.69
19 June		21				0.20
20 June	20		0.10	0.24	0.22	
11 July	24	21	0.33	0.10	0.15	0.17
2 Aug.)	Obs. ceased					0.24
)	3 Sept.					
)						
5 Aug.)			0.38	0.08	0.13	
Total:			1.16	0.63	1.12	1.30
Mean:			0.29 a[c]	0.16 a	0.28 a	0.33 a

[a] Insecticides, fungicides and miticides applied for pest control.
[b] Fungicides only applied for disease control and data included for comparison.
[c] Means followed by the same letter not significantly different (P = .05).

greatly influenced by climatic factors and perhaps more importantly by the availability of a food supply. The latter factor probably resulted in the large number of different predator species present in closely situated orchard blocks at Vineland and Jordan (Table VII). Also, it is evident that in a crop such as apple in which fruit damage tolerances approximate zero for most major pests, the numbers of the latter required to provide food for the predators are likely to cause economic damage to the crop. Some alternate food source seems essential to the successful manipulation of predators in such crop ecosystems. As reported by Herbert and Sanford (1969) the successful utilization of predators of the European red mite, *Panonychus ulmi* (Koch), is largely dependent on the alternate food supply provided by the apple rust mite, *Aculus schlechtendali* (Nalepa) which sustains the predator populations when red mite numbers are low. Such a large alternate food source is not readily available to the many insect predators that occur on apple and which consequently tend to disperse rapidly from the crop ecosystem.

It is evident, therefore, that the numbers of natural predators must be augmented if these beneficial species are to be effectively utilized as a control strategy in integrated pest management programs. The success of such a strategy will be largely dependent on an understanding of the biology and host relationships of these biological control agents and the toxicity of current pesticides to their life stages.

Acknowledgments

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OBSERVATIONS ON THE COPULATORY BEHAVIOUR OF *PERILITUS COCCINELLAE* (HYMENOPTERA: BRACONIDAE)

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Perilitus coccinellae (Shrank)i s a common parasite of many species of coccinellids (Richerson 1970). It is parthenogenic and thelytokous, unmated females producing only female progeny. Only four males have been recorded, one of which is in the Canadian National Collection, Ottawa (Hudon 1959). During studies on the population dynamics of the spotted lady beetle, *Coleomegilla maculata lengi* Timberlake (Wright 1978), one male *P. coccinellae* was reared from an overwintered adult beetle in 1978. This male parasite differed in appearance from the female in several ways. The abdomen was narrow and black, whereas that of the female was broad and bore rusty yellow-brown areas near the tip. The legs of the female were rusty yellow-brown but those of the male were much darker brown. The female also had an area of lighter colouration on the prothorax near the base of the fore-coxae where the male was totally black.

Pre-copulatory behaviour by the male was observed in the laboratory and involved vibrating the wings rapidly to the side of the body while walking in tight circles in an area of about 3 cm^2. The male mounted the female from the rear and assumed the dorsal position for copulation that is generally seen in braconids (Matthews 1974). The male mated with four females and the duration of copulation for three of the matings was 18, 20 and 20 minutes. This is a long copulatory period since most braconids copulate for less than one minute (Matthews 1974). Seventy-four beetles were offered to the four mated females. Only 24 were parasitized and three of these died. From the remaining beetles, 11 adult parasites were reared successfully and all were female. Sex determination in the parasitic Hymenoptera is usually haplodiploidy parthenogenesis where unfertilized eggs produce males and fertilized eggs produce females. In this species fertilized eggs may produce both males and females but this now appears unlikely, assuming that this was a functional male. The mechanism of sex determination in *P. coccinellae* will remain obscure until males can be cultured.

The male specimen has been placed in the permanent collection of the Department of Environmental Biology, University of Guelph, Guelph, Ontario.

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THE CURRENT STATUS IN ONTARIO OF *TETRASTICHUS JULIS* (HYMENOPTERA: EULOPHIDAE), A PARASITOID OF THE CEREAL LEAF BEETLE[1]

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Abstract

Tetrastichus julis (Walker) has followed its host, the cereal leaf beetle, *Oulema melanopus* (L.), into the area north of Lake Huron. In this region, the beetle was found in 4 of 10 fields sampled and the parasitoid was present in three of these with rates of parasitism ranging from 19 to 90%. Sweepnet surveys in parts of Ontario where the exotic parasitoid has been established since 1975, and where populations of the beetle have concurrently remained at sub-economic levels, showed that rates of parasitism averaged 65%. It is concluded that *T. julis* has the capacity to maintain itself as an effective biological control agent at very low host densities.

Introduction

The cereal leaf beetle (CLB), *Oulema melanopus* (L.), (Coleoptera: Chrysomelidae) was first found in southwestern Ontario in 1965 and by 1975 it had occupied most of Ontario south of Hwy. 17. Populations reached economic levels in 1973, and in 1974 chemical treatment was required in ca. 75 fields within the triangular area bounded by the counties of Lincoln, Grey and Durham (Bereza 1974). In 1976, the only economic damage was on Manitoulin Island and in 1977 the pest was found north of Lake Huron but no damage occurred.

The exotic larval parasitoid *Tetrastichus julis* (Walker) was first released in southern Ontario in 1974 but it had undoubtedly spread into the province from earlier releases made in the United States (Harcourt *et al.* 1977). In 1975, these authors found it throughout southern Ontario and the overall rate of parasitism was 84%. No releases of the parasitoid have been made since 1974.

This paper is a follow-up report on *T. julis* in Ontario. Reported here is the rate of parasitism in the area north of Lake Huron where the cereal leaf beetle became established in 1975 and where no releases of the parasitoid had been made. Also reported is a study of host density and rates of parasitism in areas of southern Ontario where the host and parasitoid have been established the longest.

Materials and Methods

CLB larvae were collected from oats and barley from mid to late June by sweeping a 38-cm net through a 180° arc. In each area, sampling began prior to pupation, when 3rd- or 4th-instar larvae were in peak numbers. Most of the specimens were preserved in 70% ethyl alcohol and later dissected to determine rates of parasitism (Montgomery and DeWitt 1975); however, some were reared

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to maturity to confirm the identity of the immature parasitoid found and to check for the establishment of other exotic species. Following the methods of Gruber *et al.* (1972), these larvae were placed on stems of oats in plastic boxes at room temperature. The pupal cells were later recovered from the light soil in the boxes and held separately at room temperature in gelatin capsules for emergence. The cases were dissected and examined for parasitoids about three months later.

Results and Discussion

Establishment north of Lake Huron

The 1976 infestation on Manitoulin Island was investigated by means of sweepnet samples on June 23 and 29 when it was estimated that 10 larvae/plant had developed on oats and 2 to 3 larvae/plant on barley. Parasitoids were not present at this time but samples taken post-peak, *viz.*, at mid-July, showed a parasitism rate of 87%. This outbreak, the only one in the province in 1976, caused concern that the parasitoid would not keep up with its host as it spread through northern Ontario. The latter disperses independently of its host, and because grain fields are widely scattered in northern Ontario some difficulty in establishment was expected.

In early 1977, the cereal leaf beetle was reported from Bar River, near Sault Ste. Marie (Bereza 1977). Following this report, surveys at 10 sites north of Lake Huron, involving *ca.* 600 sweeps per field, detected infestations of the beetle at Massey, and close to Verner and Monetville, near Sturgeon Falls (Fig. 1). The

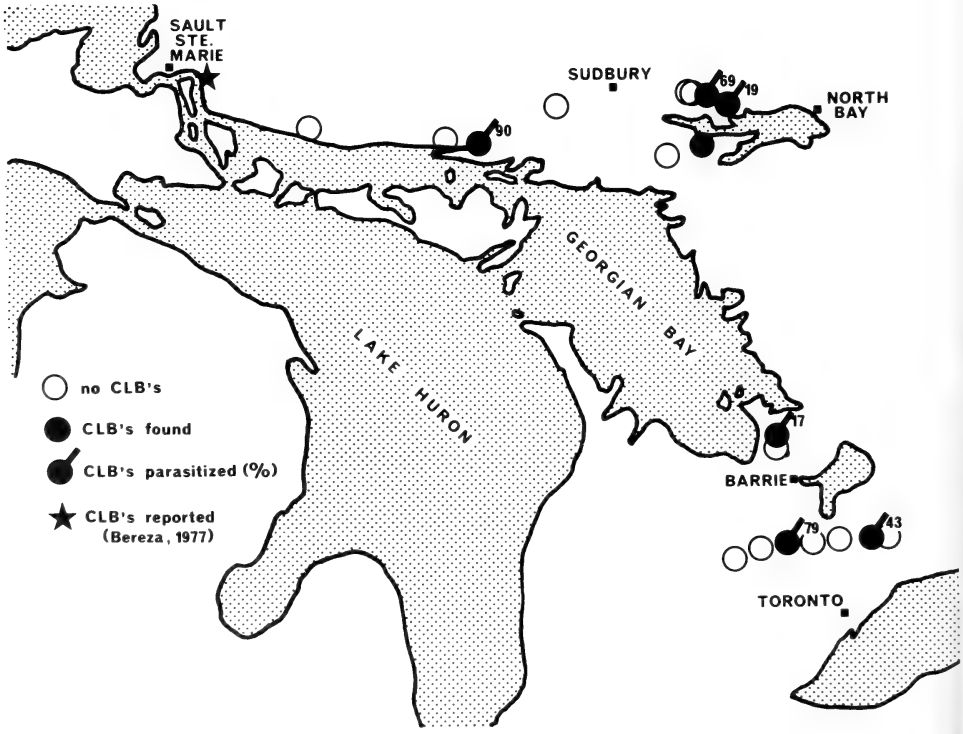

FIG. 1. Cereal leaf beetle (CLB) survey and rates of parasitism by *T. julis* in the area north of Lake Huron and south of Georgian Bay in 1977.

populations at Massey (ca. 1/8 sweeps) and just north of Verner (ca. 1/6 sweeps) were among the highest in the Province in 1977 but were well below the economic threshold. The populations south of Verner and at Monetville were 1/20 sweeps and 1/200 sweeps, respectively.

Tetrastichus julis was recovered from three of the four fields where its host was found. Rates of parasitism ranged from 19 to 90% with an overall rate of 70% for the pooled sample. This was comparable to the 17 to 79% parasitism rate found in the area south of Georgian Bay (Fig. 1). In this area as well, the host was present in less than half of the fields sampled and, where found, host density was < 1/20 sweeps. Rearing failed to recover other species of larval parasitoids.

Rates of parasitism in other parts of Ontario

Since 1974, there have been no reports of economic damage by the cereal leaf beetle in Ontario other than on Manitoulin Island. In many fields, it was difficult to find larvae (< 1/100 sweeps). This raised fears that the host population might become too low to maintain the parasitoid which would in turn lead to a resurgence of the pest. For this reason, extensive sampling was undertaken in other parts of Ontario during 1977. A total of 39 samples (200 sweeps per field) was taken in 9 areas (Table I). Maximum CLB densities occurred between June

TABLE I. Parasitism of the cereal leaf beetle by *T. julis* in Ontario in 1977 as compared to 1975.

Area	No. of samples 1977[a]	% Parasitism Range of values 1977	Pooled values 1977	Pooled values 1975[b]
Essex Co.	11	91 - 100	95	89
Elgin-Middlesex Cos.	6	69 - 89	85	92
Regional Niagara-Wentworth Co.	4	50 - 64	60	96
Northumberland Co.	2	69 - 88	79	55
Hastings Co.	2	60 - 72	66	43
Wellington Co.	8	22 - 64	35	84
Carleton-Renfrew Cos.	4	36 - 50	43	15
York Co.	1	—	79	83
Ontario Co.	1	—	43	73
Mean of pooled values			65	70

[a]200 sweeps per sample
[b]from Harcourt *et al.* (1977)

15 and 29 but numbers were usually below 1 larva/10 sweeps, except in Essex (7 fields) and Wellington (2 fields) where the beetle was most numerous. In no case did densities of the CLB attain economic levels. Rates of parasitism, based on pooled samples, ranged from 35-95% with an overall mean of 65% (Table I). A comparison with data obtained for the same areas in 1975 (Harcourt *et al.* 1977) shows that rates of parasitism did not decline significantly during this two-year period.

Conclusions

Tetrastichus julis dispersed well through the area north of Lake Huron even though fields of grain were scattered and host populations were low. It will not be

necessary to release *T. julis* in this region and indications are that biological control will be adequate to maintain pest populations at sub-economic levels. The rates of parasitism throughout Ontario were similar to those found by Harcourt *et al.* (1977) in studies two years earlier. The fact that host populations have remained sub-economic and rates of attack have not declined below 50% indicates that *T. julis* has the capacity to maintain itself as an effective biological control agent at very low host densities. There was no indication of a resurgence of CLB populations and no damage from the pest was reported in Ontario during 1977 or 1978.

Acknowledgments

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THERMAL REQUIREMENTS FOR DEVELOPMENT OF THE CEDAR LEAFMINERS *ARGYRESTHIA THUIELLA* (LEPIDOPTERA: YPONOMEUTIDAE) AND *PULICALVARIA THUJAELLA* (LEPIDOPTERA: GELECHIIDAE) IN ONTARIO[1]

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Abstract

Developmental thresholds for the post-overwintering stages of two species of cedar leafminers, *Argyresthia thuiella* (Pack.) and *Pulicalvaria thujaella* (Kft.) were determined to be 8.1 and 6.2°C, respectively. Field emergence of adult moths was monitored using yellow sticky traps to verify the accuracy of these heat-unit predictions. Emergence of 50% of *A. thuiella* moths was observed to occur 15.5% and 4.9% earlier than predicted in 1976 and 1977, respectively, while 50% emergence of *P. thujaella* occurred 0.1 and 3.8% earlier than expected in 1976 and 1977, respectively.

Thermal requirements for each life stage were estimated from field sampling and the degree-days required for a complete generation of each species were established. The degree-days required for the period from 50% of egg hatch to 50% adult emergence for *A. thuiella* were 1450 ± 19.4 while the degree-days required for the same period for *P. thujaella* were 1658 ± 25.4.

Introduction

In Ontario, four species of univoltine leafminers infest eastern white cedar, *Thuja occidentalis* L. Three species, *Argyresthia thuiella* (Pack.), *Argyresthia canadensis* Free and *Argyresthia aureoargentella* Brower, are yponomeutid moths while a fourth species, *Pulicalvaria thujaella* (Kft.) is a gelechiid moth. *A. thuiella* and *P. thujaella* were the dominant species in the Guelph, Ontario area during this study. Larvae of *A. thuiella* enter the winter months as fifth instars while those of *P. thujaella* enter as fifth- and sixth-instar larvae (Bazinet and Sears, unpublished).

Emergence of cedar leafminer moths varies considerably within the range of its host plant. In New Brunswick, 50% emergence of *A. thuiella* adults ranged from June 27 to July 5 during the summers of 1950 to 1953. During the same period, the occurrence of 50% emergence of *P. thujaella* adults ranged from July 1 to July 16 (Silver 1957). *A. thuiella* moths were reported to emerge about one

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month earlier in Connecticut (Britton and Zappe 1922). In Quebec, 50% emergence of *A. thuiella* moths occurred about the third week in June in 1970, while 50% emergence of *P. thujaella* moths occurred at the beginning of July in the same year (Brillon 1971).

An accurate method for predicting emergence would be useful in developing a control program. The objective of this study was to establish developmental thresholds and degree-day requirements for the overwintering stages of both species and to test the accuracy of degree day predictions in the field by monitoring adult emergence with yellow sticky traps.

Materials and Methods

In January 1977, cedar branches were randomly selected to obtain samples of overwintering larvae of leafminers from a stand in the University of Guelph Arboretum. Branches were cut with a pole pruner from three sampling sites along the east face of a mature stand and from the cardinal points around two, adjacent, isolated trees. The branches were taken at 1.8 m intervals from the ground to a height of 9 m. A subsample, measuring 8 cm in length, was picked at random from each branch. The mines within each subsample were dissected to identify the larvae and to determine their instar. Cuttings, each containing a single larva, were placed in plastic vials. The vials were covered with fine-meshed screens to permit air circulation. Vial bottoms were perforated and Perlite® was placed in each vial to a depth of 1 cm to facilitate water uptake from a shallow pan of water in which the vials were placed. Six environmental chambers were adjusted to constant temperatures of 13.8, 16.2, 18.5, 20.1, 24.3 and 26.4 $\pm$ 0.5°C, and a relative humidity of 90 $\pm$ 5% was maintained. The chambers were programmed for a 14:10 LD photoperiod. One hundred larvae of *A. thuiella* and of *P. thujaella* were reared to emergence in each chamber.

A Log.-probit method was used to estimate the degree-days required for 50% moth emergence (Messenger and Flitters 1958). The Log. of time was plotted against the probit of cumulative emergence at each constant temperature. The days required for 50% emergence were calculated from the regression. Constant temperatures were estimated in each chamber by the arithmetic average of daily recorded temperatures (Lin *et al.* 1954). The developmental rate (1/days to 50% emergence) was plotted against its corresponding constant temperature and the developmental thresholds and degree-day requirements were calculated from the resulting regression (Arnold, 1959).

Adult emergence in the field was monitored to determine the accuracy of degree-day predictions. Yellow sticky traps were placed at the same sites where branches were sampled during the previous winter. Four, yellow Bristol boards (25 cm^2) were stapled to poles at 90 cm intervals. Three poles were located along the east face of the stand and four poles were placed at the cardinal points around each of the isolated trees. The boards were coated with Tanglefoot® and the trapped moths were counted and removed every two days. Maximum and minimum air temperatures were recorded with a thermograph located within a Stevenson screen. These data were used in a computer program approximating a sine wave to estimate degree-day accumulations (Allen 1976). In this program, daily heat unit accumulation was based on the maximum temperature relative to both the preceding and succeeding minimum temperatures.

The thermal requirements for all life stages of both species were determined by field sampling at weekly intervals throughout 1976 and 1977. Samples of cedar foliage were examined for the presence of leafminers and the species and growth

stage recorded. Daily temperatures recorded on three thermographs, located at various sites throughout the Arboretum, were averaged and used to calculate degree-days accumulated at the peak of each life stage. As pre-overwintering stages could not be reared, the developmental threshold of the post-overwintering stages was used to calculate thermal requirements for all stages.

Results and Discussion

The post-overwintering stages of *A. thuiella* had an estimated developmental threshold of 8.1°C (Fig. 1). Too few larvae of this species survived at 24.3 and at

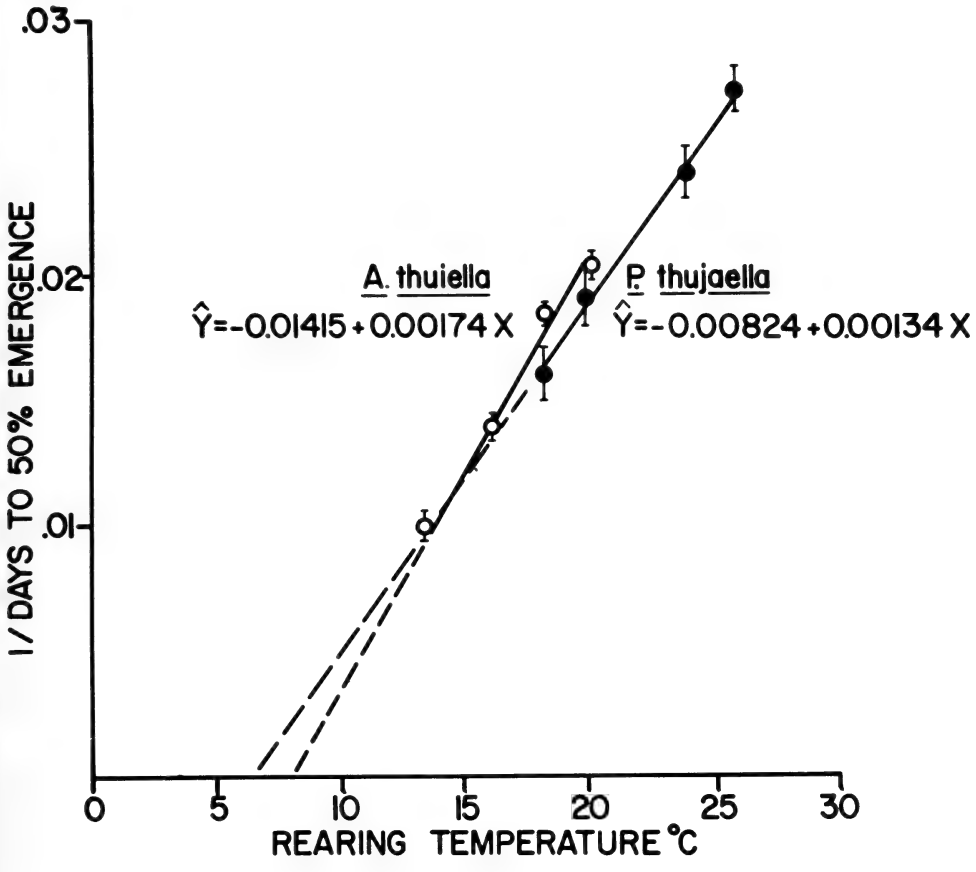

FIG. 1. Developmental rates at selected constant temperatures and 90% R.H. for post-overwintering stages of *Argyresthia thuiella* (Pack.) and *Pulicalvaria thujaella* (Kft.).

26.4°C for use in analysis. Overwintered larvae that were reared in the laboratory to adults required 575 heat units for 50% emergence. Under field conditions of spring and early summer, 575 degree-days were recorded on July 4, 1976 and on June 30, 1977. When monitored by sticky traps, 50% emergence of *A. thuiella* adults occurred on June 25, 1976 after an accumulation of 486 heat units, and on June 27, 1977 after an accumulation of 547 heat units (Table I). In 1976, 50% emergence occurred within 15.5% of the degree-day value predicted from

TABLE I. Date of 50% adult emergence and degree-days accumulated to 50% emergence of post-overwintering stages of *Argyresthia thuiella* and *Pulicalvaria thujaella,* Guelph, Ontario.

Species	Year	Date	Heat Units
A. thuiella	1976	June 25	486
	1977	June 27	547
P. thujaella	1976	July 7	745
	1977	July 1	718

laboratory rearings, while in 1977, 50% emergence occurred within 4.9% of the predicted value.

A developmental threshold of 6.2°C was calculated for the post-overwintering stages of *P. thujaella* (Fig. 1). Poor survival of larvae reared at 13.8 and 16.2°C prevented these results from being incorporated into the analysis. In the laboratory, 50% adult emergence occurred after 746 degree-days had been accumulated. This number of degree-days was recorded in the field on July 7, 1976 and on July 3, 1977. Fifty percent emergence of adults occurred on July 7, 1976 and on July 1, 1977 after an accumulation of 745 and 718 degree-days, respectively (Table I). Fifty percent emergence occurred within 0.1% of the predicted value in 1976 and within 3.8% of the predicted value in 1977.

These results are based on the assumption that temperatures within the mined leaf tissue were similar to those recorded in the surrounding air. Green (1965) found that temperatures recorded among needles of south-facing shoots of red pine trees were significantly greater than on other portions of the tree. Johnson (1975) recorded higher temperatures within the mines of the tentiform leafminer, *Lithocolletis blancardella* Fab., than on the surface of leaves located on east, west and south facing quadrants of apple trees. However, developmental times estimated for leafminers in each quadrant were not significantly different. In the present study, an increase in the temperature within the mines due to insolation apparently was sufficient to reduce the developmental period of the leafminers and cause the moths to emerge earlier than predicted. Cedar leafminers are well suited for predictions of developmental periods since all life stages occur within the leaf surface of an evergreen tree.

A comparison of emergence dates in 1976 and 1977 shows that 50% emergence in each year for *A. thuiella* varied by only two days (Table I). A difference of 51 degree-days for emergence was recorded between years, an apparent increase of 10.5% in degree-day requirements. Fifty percent emergence of *P. thujaella* adults occurred six days later in 1976 than in 1977, a difference of 27 degree-days, or an apparent decrease of 3.6% in degree-day requirements. The pattern of emergence of each species was slightly different (Fig. 2). In 1977, the more numerous moth, *A. thuiella,* emerged over a shorter period of time than *P. thujaella* and produced a distinct peak. *P. thujaella* moths continued to be caught in low numbers on the sticky traps for more than a week after the last *A. thuiella* moth was caught. The emergence period of cedar leafminers in Ontario occurred within the same periods as those recorded in New Brunswick (Silver 1957) and Quebec (Brillon 1971).

Thermal requirements, estimated from the field sampling for all stages except the egg (Table II), shows that *A. thuiella* required 1450 ± 19.4 degree-days for development from 50% egg hatch to 50% adult emergence. *P. thujaella* required 1657 ± 25.4 degree-days for development through the same period. Eggs of each

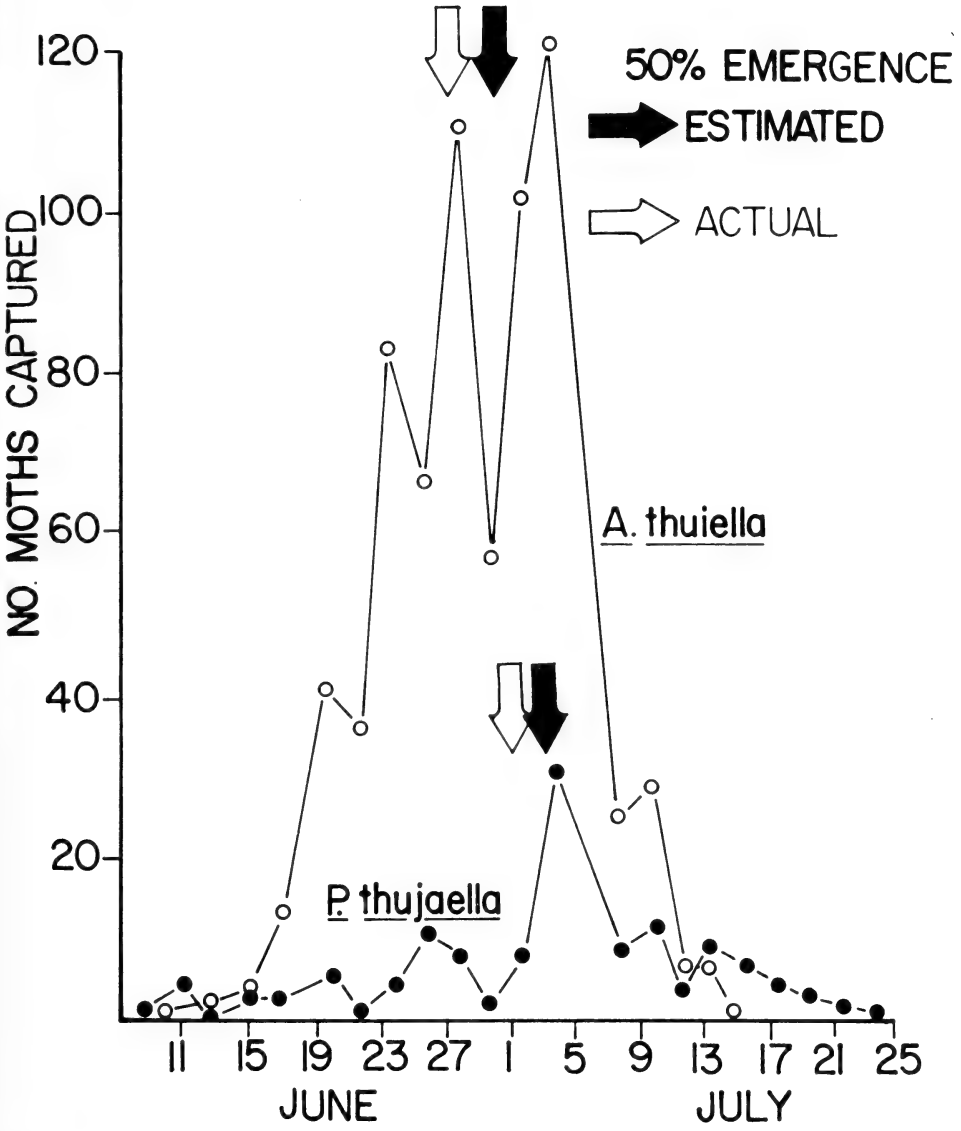

FIG. 2. *Argyresthia thuiella* (Pack.) and *Pulicalvaria thujaella* (Kft.) moths captured on yellow sticky traps during 1977 in the University of Guelph Arboretum, Guelph, Ontario.

species could not be readily distinguished so that the point at which 50% of the eggs of each species were hatched was selected as the beginning of stage I. The fifth instar of *A. thuiella* and the fifth and sixth instars of *P. thujaella* required the fewest degree-days for development. These instars are normally the overwintering stages of each species, and the small number of degree-days required for development may indicate an adaptation to conditions of slowly increasing temperatures in the spring. Degree-day requirements for the different developmental stages provide information which is useful for accurately assessing populations and for

timing insecticide applications or other control procedures.

TABLE II. Heat unit requirements for development of 50% of each stage of *Argyresthia thuiella* (Pack.) and *Pulicalvaria thujaella* (Kft.) in Guelph, Ontario, 1976-1977.

Life Stage[a]	*A. thuiella* (mean ± S.E.)	*P. thujaella* (mean ± S.E.)
I	391.3 ± 12.5	275.4 ± 9.4
II	81.5 ± 6.6	316.3 ± 10.9
III	130.4 ± 6.7	120.4 ± 4.3
IV	244.8 ± 11.0	120.5 ± 3.5
V	41.3 ± 4.9	69.0 ± 2.3
VI	134.2 ± 6.9	46.8 ± 3.0
VII	—	179.1 ± 7.2
Pupa	278.9 ± 9.1	360.1 ± 11.2
Adult (peak emergence)	147.4 ± 9.2	169.9 ± 4.0
Total	1449.7 ± 19.4	1657.6 ± 25.4

[a] I - VII = Instars

Acknowledgments

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THE EFFECTS OF TEMPERATURE ON DEVELOPMENT, ADULT LONGEVITY AND FECUNDITY OF *COLEOMEGILLA MACULATA LENGI*[1] AND ITS PARASITE, *PERILITUS COCCINELLAE*[2,3]

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Abstract

The developmental times were determined for each stage of the coccinellid, *Coleomegilla maculata lengi* Timberlake and its parasite, *Perilitus coccinellae* (Shrank) over a range of constant temperatures and these were used to calculate the thresholds and degree-days required for development. For total dvelopment of *C. m. lengi,* t = 13.8°C and K = 198.8 degree-days. The thermal requirements of *P. coccinellae* for the period of overwintering first-instar larva to pupa were t = 11.2°C, K = 180.5 degree-days. The thermal requirements determined in this study for *C. m. lengi* were applied to the field and accurately predicted the time-interval between the egg and pupal stage.

The fecundity and longevity of *C. m. lengi* collected from overwintering sites were studied over a range of temperatures. Fecundity was variable at each temperature and averaged 191.5 eggs per female overall but was greatest at 27°C. Longevity was similar for all temperatures and averaged 82.3 days. Longevity of *P. coccinellae* was greatest at 19°C, that was 17.1 days for isolated females and 5.0 days for females continuously exposed to hosts. The greatest average fecundity of *P. coccinellae* was 66.8 eggs per female at 25°C.

Introduction

Coleomegilla maculata lengi Timberlake is an abundant coccinellid in southern Ontario. It is a polyphagous species, feeding on many aphid species including the green peach aphid, the pea aphid, the cabbage aphid (Conrad 1959) and the corn leaf aphid. It also feeds on mites (Putman 1964), insect eggs (Conrad 1959, Bartholomai 1954, Warren and Tadic 1967) and pollen (Smith 1961, Putman 1964). *C. m. lengi* is found on most crops that support aphid populations. On corn, it was shown to be a beneficial predator of European corn borer eggs (Conrad 1959), although Foott (1973) concluded that coccinellids could not prevent damage by the corn leaf aphid.

C. m. lengi are parasitized by *Perilitus coccinellae* (Shrank) as adults and rarely as larvae (Smith 1960). *P. coccinellae* is thelytokous, has several genera-

[1] Coleoptera: Coccinellidae
[2] Hymenoptera: Braconidae
[3] Part of a thesis in partial fulfilment of an M.Sc. degree at the University of Guelph. Received for publication Jan. 30, 1979.

tions per year, and overwinters as first-instar larvae within the adult coccinellids. The incidence of parasitism of overwintering *C. m. lengi* has been shown to be as high as 60% (Richerson and DeLoach 1973).

A study was begun in 1976 to investigate the population dynamics of *C. m. lengi* on corn, with special reference to stage-specific mortality of the coccinellid and its relationships to the populations of its prey and its parasite. This paper presents the results of laboratory and complimentary field studies on the effect of temperature on rate of development, longevity and fecundity of *C. m. lengi* and *P. coccinellae*.

Materials and Methods

Coleogemilla maculata lengi

C. m. lengi was reared at six constant temperatures, 17, 19, 21, 23, 25 and 27.3°C under a 16:8 h LD regime in controlled-environment chambers, to determine the threshold temperatures and degree-days required for each developmental stage. Each beetle was reared individually in a 5.5 cm diameter plastic petri dish that contained a small moist piece of cellulose sponge to provide drinking water for the larvae and to raise the relative humidity inside the dish.

Tobacco leaves, infested with the aphid, *Myzus persicae* (Sulzer), were cut up and placed in the petri dishes with the beetle larvae. Surplus aphids were provided to prevent a food shortage that could retard beetle development. The small beetle larvae were provided predominantly with first- and second-instar aphids, whereas the beetles in later instars were provided with late-instar and adult aphids. The beetles were checked every 12 h to determine time of moulting and to replenish aphids and water as required. The percent mortality was determined for each stage at each temperature using various numbers of individuals. Adult beetles were weighed ½ day after emergence. Sex was determined by examining the genitalia under a dissecting microscope. Beetles reared at the different temperatures were checked for significant differences in weight using analysis of variance and Scheffé's test.

Except at very high and very low temperatures the relationship between developmental rate and temperature in insects is nearly linear. The developmental threshold, t, is the lowest temperature at which development occurs. The thermal constant, K, is the number of degree-days required for completion of the stage in question and is defined as $K = D\ (T\text{-}t)$ where D = days for development and T is the experimental temperature.

The developmental thresholds (t) and thermal constants (K) were determined for each immature stage and for total development by plotting the individual developmental rates against temperature. The regression equation of the form $y = a + bT$ was fitted to this curve. The point of interception of this line with the X-axis approximated the threshold temperature, t. The thermal constant, K, equalled 1/b. The standard errors of the estimates were determined following Campbell *et al.* (1974).

The accuracy of such thresholds was tested by accumulating degree-days observed in the field and comparing the predicted and actual occurrence of some life stage in the field. In 1977 and 1978, population studies were carried out in a corn field at Guelph, Ontario.

Temperatures within a corn field are significantly higher during the day and lower during the night than are those recorded within a Stevenson screen. Rahn and Brown (1971) showed that on bright, sunny days with low soil moisture, the

air temperatures within the canopy were as much as 2.2 to 3.3°C above those in shelters and the actual leaf temperatures were 5.6°C or more above those in shelters. With lower insolation (incoming solar radiation) and/or recent rainfall, these differences were smaller. At night, due to night-time cooling by radiation, the canopy air temperatures were as much as 1.1 to 1.7°C below those in shelters and the lowest leaf temperatures were 2.2 to 2.8°C lower.

The daily maximum and minimum temperatures recorded in a Stevenson screen located about 2 km from the population study site were corrected by the method of Rahn and Brown to give the daily maximum and minimum temperatures of the corn leaf and in the corn canopy. These were used to calculate the daily degree-day accumulations by two methods. Method I estimates the degree-day accumulation by $[(Tmax + Tmin)/2]$-t when $Tmin > t$ and $[(Tmax + t)/2]$-t when $Tmin < t$. This method tends to overestimate accumulations when $Tmin < t$. Method II (Baskerville and Emin 1969) is more accurate since it takes into account that the diurnal temperature curve is similar to the trigonometric sine curve.

The number of degree-days were accumulated from the date when 50% of the coccinellid eggs had been observed in the field to the date when 50% of the pupae had been observed in 1977 and 1978 on corn. These accumulations were made using the threshold for total development calculated in this study and by Obrycki and Tauber (1978) at Ithaca, New York.

Adults of *C. m. lengi* were collected from overwintering sites in May 1977, and held at 21°C for assessment of longevity and fecundity. Atallah (1966) showed that maximum egg production was achieved by females caged individually. Therefore, during oviposition, females were kept individually in plastic petri dishes, 5.5 cm in diameter, except for brief periods when a male was added to ensure continued fertility of the eggs. The beetles were fed powdered, freeze-dried, honey-bee larvae (Matsuka *et al.* 1972) and provided with water on a piece of cellulose sponge. Each day the eggs were counted and removed and food and water were supplied. Longevity was defined as the time between collection from the field and death.

In March 1978, beetles that had overwintered in cages were divided into groups and placed at six constant temperatures in controlled-environment chambers to determine their longevity and fecundity and the time to parasite emergence. The beetles were observed every 12 h. The date of first oviposition at each temperature was noted to determine the thermal requirements for initiation of oviposition. The beetles were held individually in petri dishes and fed freeze-dried honey-bee larvae as in 1977.

Perilitus coccinellae

The thermal requirements for development of the parasite in overwintering beetles were determined by collecting overwintered beetles from field cages in February and March and dividing them among six controlled-environment chambers held at 17, 19, 21, 23, 25 and 27°C. The beetles were kept in 5.5 cm plastic petri dishes, fed with powdered, freeze-dried, honey-bee larvae and provided with a moistened sponge. The beetles were checked every 12 h for emergence of the parasites and to provide food and water as required.

Total developmental time, i.e. the time from deposition of the egg of the parasite to the emergence of the mature parasite larva from the host, was determined by putting four or five laboratory-reared beetles into a petri dish with a parthenogenetic female parasite for one to two hours at room temperature. The

newly parasitized beetles were then distributed among five controlled-environment chambers held at 14, 17, 19, 25 and 27°C, with a 16:8 h LD period. These beetles were fed powdered, freeze-dried, honey-bee larvae and observed every 12 h. After 20 days, the beetles in the 14, 17 and 19°C chambers were transferred to 25°C. The developmental rates at these three temperatures were determined by comparing their developmental times at 25°C with those beetles held at 25°C for the whole developmental period.

The mature, parasite larvae emerging from the beetles in the above trials were held in the same chambers and the time for development of the pupa was determined. The threshold temperatures and thermal constants for development from the overwintering stage to late-instar larvae, from egg to late-instar larva and for the pupal stage were estimated by the regression method.

Newly emerged adult parasites were kept individually in 5.5 cm plastic petri dishes with screened lids. A moist sponge was placed in the dish and honey was spread on a small area of the lid screening. These isolated females were checked every 12 h to determine longevity and to provide more water or honey as required.

P. coccinellae will readily attack and oviposit into a single coccinellid more than once and apparently with little or no restraint. Therefore, newly emerged, parthenogenetic, female parasites were provided with two to five laboratory-reared beetles in which to oviposit for 24 h period. Water and honey were provided for the parasite and aphids were provided for the beetles. Each day these beetles were replaced with new ones. The parasitized beetles were kept for a few days at the higher temperatures or several weeks at the lower temperatures to ensure that all the eggs of the parasite had hatched and were at least first-instar larvae. These beetles were dissected and the number of parasite larvae counted. Trials were done at three temperatures (19, 25, 27°C). The effects of temperature on fecundity and longevity were determined by analysis of variance and Games and Howell's T modification (Keselman and Rogan 1978).

Results and Discussion

Coleomegilla maculata lengi

The development times for all immature stages, determined at six temperatures, are summarized in Table I. All of the eggs held at 14°C failed to hatch. Embryonic development did occur, however, since eggs became pigmented after 19 days and appeared to develop normally.

For many insects, there is a threshold temperature for hatching that is independent of the threshold for full embryonic development (Chapman 1969). Clearly, 14°C was above the threshold for embryonic development but below that for hatching.

Mortality was high at the low rearing temperatures but decreased at the high temperatures (Table II). Beetles reared over the mid-range of temperatures were heavier than those reared at the highest and lowest temperatures (Table II). The combination of rapid development, low mortality and normal weight indicates that the optimum rearing temperature for *C. m. lengi* is about 25°C.

The developmental thresholds and thermal constants calculated for *C. m. lengi* are shown in Table III. These thresholds are quite high, similar to those compiled by Neuenschwander (1975) for other species of coccinellids. These high thresholds allow the prey populations, which typically have lower thresholds, to continue to develop at temperatures below the threshold for the predator, thus ensuring a

TABLE I. The effect of temperature on the developmental times of all stages of *Coleomegilla maculata lengi*.

Stage		Temperature 17°C	19°C	21°C	23°C	25°C	27.3°C
Egg	N	96	90	63	122	70	100
	$\bar{x}$ (days)	8.6	6.9	5.1	3.8	3.0	2.5
	S.D.	0.4	0.5	0.5	0.4	0.1	0
	Range	7.5-9.5	6.0-9.0	4.0-6.5	2.5-4.0	3.0-3.5	0
First instar	N	28	39	39	74	64	89
	$\bar{x}$ (days)	10.3	7.4	4.6	3.4	2.7	2.5
	S.D.	2.1	1.0	1.0	0.6	0.5	0.4
	Range	6.5-15.5	05.5-9.0	2.5-7.0	2.5-5.0	1.5-3.5	2.0-3.5
Second instar	N	19	33	39	79	61	87
	$\bar{x}$ (days)	6.3	4.9	3.0	2.5	2.0	1.7
	S.D.	1.3	0.8	0.5	0.5	0.3	0.3
	Range	3.5-9.0	3.0-7.0	2.0-4.0	1.0-4.0	1.5-2.5	1.0-2.5
Third instar	N	6	33	42	82	60	88
	$\bar{x}$ (days)	7.1	5.7	3.5	2.8	2.2	1.9
	S.D.	1.5	0.9	0.6	0.4	0.3	0.3
	Range	6.0-10.0	5.0-9.0	2.5-5.0	2.0-4.5	1.5-2.5	1.5-2.5
Fourth instar	N	0	27	41	81	60	88
	$\bar{x}$ (days)		10.4	5.9	5.0	4.5	3.5
	S.D.		1.3	0.9	0.7	0.4	0.3
	Range		7.0-12.5	4.5-7.5	3.5-7.5	4.0-5.5	2.5-4.0
Pupa	N	2	26	42	82	61	85
	$\bar{x}$ (days)	9.5	7.7	5.1	4.3	3.4	2.9
	S.D.	0	0.5	0.4	0.4	0.2	0.3
	Range	0	6.5-9.0	4.0-6.0	3.0-5.0	3.0-3.5	2.5-3.5
Total development	N	0	26	42	79	62	84
	$\bar{x}$ (days)		42.4	27.3	21.3	17.9	14.9
	S.D.		1.9	1.5	1.7	0.8	0.5
	Range		38.5-47.0	25.0-32.0	18.5-26.0	16.5-20.5	14.0-16.5

TABLE II. The effect of temperature on % mortality and adult weight of *Coleomegilla maculata lengi*.

Stage	Temperature 17°C	19°C	21°C	23°C	25°C	27.3°C
% Mortality						
First instar	72.0	54.1	38.6	24.8	6.8	6.3
Second instar	29.0	14.0	2.3	3.3	2.9	0
Third instar	37.5	7.7	0	1.1	0	0
Fourth instar	—	24.3	0	1.1	3.0	4.5
Pupa	—	7.7	0	3.4	3.1	1.2
All stages	88.5	72.6	33.3	32.8	12.9	11.6
Weight						
N	0	23	39	59	61	40
$\bar{x}$ (mg)[a]	—	11.5[a]	12.7[b]	12.2[a,b]	11.6[a]	11.9[a]
S.E.	—	0.4	0.2	0.2	0.2	0.2

[a] Mean weights followed by the same letter are not significantly different ($P < 0.05$).

TABLE III. Thresholds and thermal constants for development of *Coleomegilla maculata lengi*.

Stage	Equation	t ± S.E.[a] (°C)	K ± S.E.[b]	r[c]
Egg	Y = —0.3837 + 0.0285X	13.5 ± 0.1	35.1 ± 0.3	0.98
First instar	Y = —0.4624 + 0.0330X	14.0 ± 0.3	30.4 ± 1.0	0.86
Second instar	Y = —0.6111 + 0.0448X	13.6 ± 0.4	22.3 ± 0.8	0.85
Third instar	Y = —0.6146 + 0.0428X	14.4 ± 0.2	23.4 ± 0.7	0.90
Fourth instar	Y = —0.2768 + 0.0207X	13.4 ± 0.3	48.4 ± 1.4	0.90
Pupa	Y = —0.3449 + 0.0254X	13.6 ± 0.2	39.4 ± 0.8	0.94
All stages	Y = —0.0696 + 0.0050X	13.8 ± 0.1	198.8 ± 2.4	0.98

[a] threshold temperature ± standard error (°C)
[b] thermal constant ± standard error
[c] correlation coefficient

more continuous food supply.

Obrycki and Tauber (1978) determined the developmental rates, thresholds, and thermal constants for all stages of *C. m. lengi* at Ithaca, New York. The rearing conditions were similar to ours and the aphid, *Myzus persicae,* was also used as prey. For the fourth instar, they stated that the relationship between developmental rate and temperature was linear over the range 18.3 to 26.7°C but not from 18.3 to 29.4°C. Therefore, the rate of development at 29.4°C was not included by them in the calculation of the threshold and thermal constant for the fourth instar. The calculated threshold was 9.4°C, much lower than those for the other stages. When Obrycki and Tauber's developmental rates for fourth instar are plotted adjacent to those developmental rates observed in this study, it is clear that the temperature reltaionships for both populations are similar (Fig. 1). In fact, the developmental rate at 29.4°C that was discarded by Obrycki and Tauber lies very close to the regression line determined for the population at Guelph. Therefore, a close comparison of the results of these two studies seemed warranted.

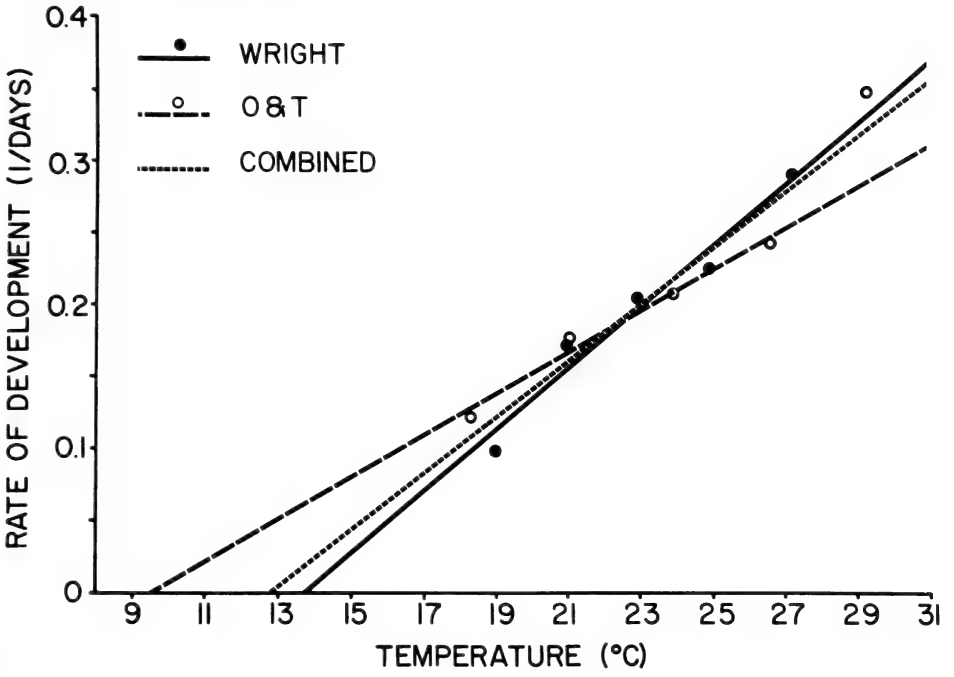

FIG. 1. The relationship between rearing temperature and rate of development of the fourth-instar larvae of *Coleomegilla maculata lengi* as determined in the present study, by Obrycki and Tauber (O & T) (1978), and by using the combined data of both studies.

The data presented by Obrycki and Tauber (1978) for the developmental times of each stage at each rearing temperature were used to recalculate thresholds and thermal constants by regression and for most of the stages the results were similar to those presented by them (Table IV). By including the developmental rates at 29.4°C for the fourth-instar larvae, the threshold value was increased from 9.4 to 12.1°C. The threshold for the pupal stage increased slightly from 10.2 to 10.9°C.

To compare the Ithaca and Guelph populations, the data had to be in similar form. Since the mean developmental times were available for the Ithaca population these were also used for the Guelph study. This equal weighting of developmental rates at each temperature resulted in some changes in the estimated thresholds and thermal constants (calculated for the data from the present study, Table IV). The mean developmental rates observed by Obrycki and Tauber and in the present study were used to determine the thresholds and thermal constants for the combined data (Table IV). Analysis of covariance showed no significant differences between the regression lines determined for the Ithaca and Guelph populations at $P < 0.05$. In general, thresholds for the combined data were closer to those determined for the Guelph population than to those of the Ithaca population.

There appears to be no difference between the thermal requirements for *C. m. lengi* in Guelph, Ontario and Ithaca, New York. The fact that different thresholds and thermal constants have been calculated for the same organism indicates the necessity of using many rearing temperatures and of using a consistent method of analyzing the data. Small differences in estimated thresholds will tend

TABLE IV. Thresholds and thermal constants determined for *Coleomegilla maculata lengi* using mean developmental rates observed in the present study, by Obrycki and Tauber (1978) and using the combined data.

	Wright & Laing			Obrycki and Tauber (Recalculated)			Combined data			
	t(°C)[a]	K[b]	r[c]	t(°C)[a]	K[b]	r[c]	Equation	t(°C)[a]	K[b]	r[c]
Egg	13.5	34.9	0.99	11.1	40.9	0.99	Y = —0.34518 + 0.02708X	12.7	36.9	0.99
First instar	14.2	29.6	0.99	10.2	40.1	0.98	Y = —0.38714 + 0.02997X	12.9	33.4	0.97
Second instar	13.1	22.3	0.93	12.6	21.9	0.99	Y = —0.63578 + 0.04701X	13.5	21.3	0.99
Third instar	14.0	24.2	0.99	10.8	31.1	0.99	Y = —0.47976 + 0.03725X	12.9	26.8	0.98
Fourth instar	13.7	47.0	0.98	12.1	53.9	0.97	Y = —0.25097 + 0.01959X	12.8	51.0	0.97
Pupa	13.1	47.1	0.99	10.9	48.7	0.99	Y = —0.27793 + 0.02263X	12.3	44.2	0.99
All stages	14.1	193.8	0.99	11.3	236.4	0.99	Y = —0.05872 + 0.00462X	12.7	216.5	0.99

[a] threshold temperature
[b] thermal constant
[c] correlation coefficient

to be compensated for by corresponding changes in the thermal constants, so the predictive value of these determinations is not likely to be affected adversely except when the temperature remains near the threshold for extended periods of time.

The observed date when 50% of the coccinellid eggs had occurred at Guelph in 1977 was July 19 and the date of 50% occurrence of coccinellid pupae was Aug. 4. In 1978, the dates of occurrence of 50% of the eggs and pupae of *C. m. lengi* were Aug. 8 and 25, respectively. Degree-day accumulations in corn were calculated for 1977 and 1978 using the shelter air temperatures, corn leaf and corn canopy air temperatures, and a threshold of 13.8°C as determined in the present study and of 11.3°C as determined by Obrycki and Tauber (1978). Table V shows the predicted dates of occurrence of 50% of the pupae using both thresholds with the three sets of microhabitat temperatures. The degree-day accumulations by Method I gave better predictions than those by Method II. For both thresholds, the predictions were poorest using air shelter temperatures and best using the corn leaf temperatures, indicating the importance of measuring the temperature of the microclimate when making such predictions. Both thresholds predicted the occurrence of 50% of the pupae accurately when the temperatures of the corn leaves were used. These temperatures are likely the closest to those that the beetles actually experience. Whereas the degree-day accumulations by Method I gave better predictions, the accumulations by Method II are more accurate. The error in predictions based on accumulations by Method II ranged between 2 and 9% but these errors are not due, necessarily, to errors in the estimated thresholds or thermal constants. In 1977, a set of 40 plants were checked daily for occurrence of coccinellid eggs and the rate of mortality and successful ecolosion. It was found that the date when 50% of the observed eggs had occurred was two days earlier than that when 50% of the eggs would have occurred had there been no mortality. High mortality also occurred in the early larval instars and it was likely that mortality of later-occurring individuals in an instar would be greater than that of earlier-occurring individuals, especially since coccinellids are cannibalistic. Later-instar larvae of coccinellids were commonly observed feeding on smaller larvae, particularly when they were inactive just before moulting. Such selective predation pressure on later-occurring individuals in an instar would skew the population curve to the left. Although the more accurate accumulations by Method II do not predict the date of 50% occurrence as accurately as those of Method I, it has been shown that this error could be due to selective predation of later-occurring individuals in a stage. Although the accumulations by Method I are overestimated, this method should be used when accurate predictions are desired.

The fecundity of 39 females of *C. m. lengi* collected in May 1977 and maintained at 21°C, was 200.6 eggs per female (Table VI). There was no significant difference between the mean fecundities at 21°C for 1977 and 1978. In 1978, fecundity and longevity were assessed over a range of temperatures for beetles collected from the overwintering cages in March (Table VI). No parasitized beetles laid eggs. Longevity was similar over the range of temperatures tested in 1978, although it was less at 25°C. Differences in fecundity were not significantly different because of the variability and small sample sizes. Nevertheless, the mean fecundity observed at 27°C was greater than that observed for the other temperatures. The greatest fecundity for an individual was 857 eggs at 27°C. When the estimates of fecundity were expressed as the number of eggs laid per day, the fecundity at 27°C was again the greatest, although not statistically different from those at 21 and 25°C. At 19°C, fewer beetles laid eggs and, in general, the rate of egg production was lower. Only two females laid eggs at 17°C, one laid 34 eggs

TABLE V. Predictions of the 50% occurrence of coccinellid pupae on corn using two methods for estimating degree-day accumulations with three sets of microhabitat temperatures and using the thermal thresholds determined in the present study and by Obrycki and Tuber (1978).

Microhabitat temperatures	Method of degree-day accumulations	Actual date	Thresholds determined by: Wright & Laing Predicted date	Wright & Laing % Error	Obrycki and Tauber Predicted date	Obrycki and Tauber % Error
Total coccinellid eggs and pupae 1977						
Shelter air temp.	I	August 4	August 11	30	August 9	23
	II	"	August 13	39	August 9	30
Corn canopy air temp.	I	"	August 18	17	August 7	14
	II	"	August 10	26	August 8	20
Corn leaf temp.	I	"	August 4	0	August 4	0
	II	"	August 6	9	August 5	1.5
Coleomegilla maculata lengi eggs and pupae 1978						
Shelter air temp.	I	August 25	August 31	20	August 30	20
	II	"	Sept. 4	27	August 30	17
Corn canopy air temp.	I	"	August 29	13	August 28	11
	II	"	Sept. 1	21	August 28	14
Corn leaf temp.	I	"	August 25	0	August 25	0
	II	"	August 27	8	August 26	4.5

TABLE VI. The effect of rearing temperature on longevity and fecundity of overwintered *Coleomegilla maculata lengi*.

		1977	1978[a]				
		21°C	19°C	21°C	23°C	25°C	27°C
Longevity	n	39	3	8	5	9	7
	$\bar{x}$ (days)	95.5	73.3[a]	73.8[a]	77.2[a]	44.8[b]	79.7[a,b]
	S.D.	41.1	0.6	9.6	14.3	17.6	37.6
	Range	47-161	73-74	60-85	60-96	24-76	52-133
Fecundity	n	39	3	8	3	7	8
	$\bar{x}$ (eggs)	200.6	74.7[a]	162.6[a]	93.7[a]	85.3[a]	349.5[a]
	S.D.	145.5	39.7	116.5	29.2	48.6	271.9
	Range	2-538	40-118	47-370	60-112	14-169	106-857
Eggs/day	n	39	3	8	3	7	7
	$\bar{x}$	2.01	1.01[b]	2.35[b,a]	1.38[b]	1.83[b,a]	3.88[a]
	S.D.	1.3	0.5	1.8	0.7	0.8	1.6
	Range	0.09-4.55	0.6-1.6	0.56-5.14	0.63-1.87	0.35-2.90	1.74-6.44

[a] Rows means in 1978 followed by the same letter are not significantly different at $P < 0.05$ (Games and Howell's T modification).

TABLE VII. The effect of rearing temperature on developmental times of *Perilitus coccinellae* larvae from overwintered adults of *Coleomegilla maculata lengi*.

	Temperature						
	14°C	17°C	19°C	21°C	23°C	25°C	27°C
n	10	21	21	21	32	20	13
Mean (days)	62.0	38.9	24.4	15.6	15.2	13.5	12.5
S.D.	7.5	4.1	3.3	1.6	1.4	1.3	1.7
Range	52.5-74.0 (91, 98)[a]	33.5-48.5 (61)	20.0-34.0	13.0-20.0 (29.5)	13.0-18.0 (27)	11.5-16.0	10.5-16.0

[a] Figures in brackets are the extremely long developmental times for a few overwintering parasites.

and the other only one. Considering all of the fecundity data collected in the present study, the overall mean fecundity was 191.5 eggs (S.E. = 19.9) and longevity was 82.3 days (S.E. = 4.4). These results are comparable to those determined by Smith and Williams (1976) at 23°C using a diet of live pea aphids, indicating that the freeze-dried honey-bee powder was a suitable food to promote maximum fecundity in this species.

The thermal requirement for first oviposition by overwintered female *C. m. lengi* was investigated in March 1978. The threshold temperature and thermal constant were calculated to be 15.4 ± 2.5°C and 82.2 ± 11.1 degree-days ($Y = -0.18745 + 0.01216X$, $r = 0.97$).

Perilitus coccinellae

There was no difference seen between the developmental times (to emergence of mature larvae) of *P. coccinellae* from overwintering beetles collected in February and those collected in March. Therefore, the data from these two trials were combined in Table VII. In the chambers held at 14, 17, 21 and 23°C, a few parasites took an abnormally long time to develop. These values are listed separately under the range for each temperature. The thresholds and thermal constants for the development of overwintering parasites were determined without these values and were 11.4°C and 179.2 degree-days. The threshold for development of overwintering larvae of *P. coccinellae* was lower than that for first oviposition by overwintered *C. m. lengi,* but at 19°C, the times to emergence of the parasite from the host and to first oviposition by the overwintered host were the same. At temperatures above 19°C, the time to first oviposition was shorter than to emergence of the parasite from the host. However, in no instance did a parasite emerge from a beetle that had oviposited. Thus any overwintering females that are parasitized are reproductively dead.

The thresholds and thermal constants for development from newly deposited egg to pupa were 13.1°C and 223.2 degree-days (Table VIII). Balduf (1926) stated that *P. coccinellae* overwintered as first-instar larvae and perhaps also as eggs within the coccinellid host. The few longer developmental times seen for the overwintering parasites match the predicted total developmental times from egg to pupa instead of first instar to pupa for the 17, 21, and 23°C individuals but not well for those reared at 14°C (Table IX). These predicted values, however, do indicate that a small proportion of the population of *P. coccinellae* overwinters as eggs instead of first-instar larvae.

The developmental times for the pupal stage of *P. coccinellae* were recorded for the parasites emerging from overwintered *C. m. lengi* and from the beetles parasitized in the laboratory. There was no difference in the developmental times for these two groups so the data were combined and are shown in Table X. The thresholds and thermal constants were 10.3°C and 116.3 degree-days (Table VIII). The thermal requirements for the pupal stage determined in this study were in close agreement with those determined by Obrycki and Tauber (1978) but the threshold for development from egg to pupa is higher for the Guelph population, t = 13.1°C, *vs* t = 9.9°C for the Ithaca population.

The longevity of isolated adults of *P. coccinellae* was greatest at 19°C (17.1 days) and decreased gradually with increasing temperature to a low of 3.6 days at 27°C (Table XI). In general, these longevities were greater than those observed by Obrycki and Tauber (1978) who provided their adult parasites with water, honey, a Wheast®-protein food mixture, and honeydew. Balduf (1926) estimated that the life span of this parasite in nature was probably two weeks. The results of this study support such an estimate.

TABLE VIII. Thermal requirements for development of *Perilitus coccinellae*.

	Linear Regression Equation	t ± S.E.[a]	K ± S.E.[b]	r[c]
Egg to pupa	Y = −0.05877 + 0.00448X	13.1 ± 0.5	223.2 ± 9.5	0.93
Overwintering first instar to pupa	Y = −0.06204 + 0.00554X	11.2 ± 0.1	180.5 ± 6.2	0.93
Pupa	Y = −0.08878 + 0.00860X	10.3 ± 0.4	116.3 ± 3.8	0.94

[a] threshold temperature ± standard error (°C)
[b] thermal constant ± standard error
[c] correlation coefficient

TABLE IX. Comparison of the long developmental times of some overwintering *Perilitus coccinellae* to the predicted developmental times from egg to pupa and overwintering first-instar larva to pupa at that temperature in the laboratory.

	Developmental time (days) Temperature 14°C	17°C	21°C	23°C
Observed—long times from overwintered beetles	91.0 98.0	61.0	29.5	27.0
Expected—egg to pupa	248	57.2	28.3	22.5
Expected—overwintered first instar to pupa	64.4	31.1	18.4	15.3

TABLE X. The effect of rearing temperature on the developmental times of *Perilitus coccinellae* pupae.

	Temperature 14°C	17°C	19°C	21°C	23°C	25°C	27°C
n	12	17	14	16	24	38	15
Mean (days)	24.0	20.1	13.8	10.3	9.2	8.1	7.2
S.D.	0	1.0	0.9	0.9	0.8	0.5	0.3
Range	—	17.5-22.0	12.5-15.0	8.5-12.0	7.0-10.5	7.0-10.0	6.5-7.5

TABLE XI. The effect of temperature on the longevity of isolated adults of *Perilitus coccinellae* fed with honey and water.

	Temperature 17°C	19°C	21°C	23°C	25°C	27°C
n	12	8	10	12	25	7
Mean (days)[a]	14.3[a,b]	17.1[a]	10.8[a,b,c]	8.0[b,c]	7.7[c]	3.6[d]
S.D.	6.4	4.8	4.6	3.0	2.9	0.8
Range	8.0-31.5	7.0-22.5	6.0-18.0	4.0-14.5	3.0-16.5	2.5-5.0

[a] Means followed by the same letter are not significantly different at $P < 0.05$ (Games and Howell's T modification).

Parasites that are exposed continuously to coccinellids have a shorter life span (Table XII). Only three temperatures were tested but even at 19°C, which gave the greatest longevity for isolated female parasites, longevity was very short. Longevity of parasites, exposed to beetles and held at 19°C, was significantly

TABLE XII. The effect of temperature on the longevity and fecundity of adults of *Perilitus coccinellae* exposed continuously to adults of *Coleomegilla maculata lengi.*

	Temperature		
	19°C	25°C	27°C
Longevity			
n	7	16	11
Mean number of days[a]	5.0	3.9[a]	3.5[a]
S.D.	1.8	0.6	0.6
Range	2.5-8.0	3.0-5.0	2.5-4.5
Fecundity			
n	7	16	11
Mean number of eggs[a]	62.1[a,b]	66.8[b]	23.4[a]
S.D.	40.7	37.6	17.2
Range	14-123	20-165	1-52

[a] Means followed by the same letter are not significantly different at $P < 0.05$ (Games and Howell's T modification).

greater than that at 25 or 27°C at $P < 0.05$.

The fecundity of *P. coccinellae* was tested at three temperatures and the results are summarized in Table XII. The sample size was small and the variability great, yet it is clear that a temperature of 27°C was detrimental to fecundity. This could be due to some physiological effect on the parasite or to increased activity of the host which makes successful oviposition more difficult and less frequent. Since high temperature shortens life span (Table XI), its effect is to decrease fecundity. Constant temperatures of 27°C seldom occur in the field, however, and the higher fecundity estimates seen at 19 and 25°C are more realistic.

Dissection of a few adults of *P. coccinellae* revealed large numbers of eggs in the ovaries, far more than the average estimated fecundity would indicate. Balduf (1926) dissected females, two days old, and found about 100 eggs/ovary and estimated a fecundity of 200 to 400 eggs/parasite. The maximum number of eggs laid by a female in this study was 165 at 25°C. It seems that fecundity is not limited by egg production but by the ability of the parasite to find suitable hosts. Even when provided with hosts continuously, the parasites generally failed to achieve the fecundity that dissections of the ovaries indicated was possible. Also, there could have been factors in this artificial rearing method that depressed oviposition and therefore reduced observed fecundity.

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DAMAGE TO GOLF COURSE FAIRWAYS BY *APHODIUS GRANARIUS* (L.) (COLEOPTERA: SCARABAEIDAE)

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Larvae of a dung beetle, *Aphodius granarius* (L.), were found on a golf course in Toronto, Ontario in 1976 and 1977. Sufficient larvae to cause damage were found on two fairways that consisted of annual and Kentucky bluegrasses. Although this species has been reported on pasture grasses in North America (Jerath and Ritcher 1959), this is the first report of this species from turfgrass in Canada. The Ohio Agriculture Research and Development Center has recently received reports of damage to golf courses in Michigan and Colorado in 1978 (Niemczyk, pers. comm.). In Toronto, larvae of *A. granarius* and those of a related and more common pest, *Ataenius spretulus* (Haldeman), were found on the same fairways. The larvae of these species were easily distinguished by the pattern of spines located on the raster (Ritcher 1966).

Damaged areas of a fairway were sampled once a week during August and September 1976 with a standard cup-changing tool, 11 cm in diameter. The turf and soil core were examined to a depth of 8 cm for the presence of larvae and pupae of *A. granarius* and *A. spretulus*. Ten cores constituted a sample (0.1 m^2) and 5 samples were taken each week. The number of larvae and pupae of *A. granarius* averaged 8.3 $\pm$ 2.8 per sample on August 3 but this declined to 0.8 $\pm$ 1.8 by September 7. Only 11 of the 128 larvae observed during this period were *A. spretulus*. Adults of both beetles were observed on fairways and greens during the entire period of investigation.

Beetles were observed again on greens in late May 1977 and two slightly damaged fairways were sampled in the same manner as in 1976. The average numbers of larvae and pupae from both fairways increased from 7.8 $\pm$ 2.1 per sample on June 1 to a peak of 18.8 $\pm$ 2.6 on July 6 and then declined to 2.2 $\pm$ 2.4 on July 27. At that time, both fairways were treated with insecticide and no further samples were taken. *A. spretulus* constituted $< 3\%$ of the larval population. Adults of *A. granarius* were observed the following spring but no subsequent larval population was detected in 1978.

It appears from these observations that *A. granarius* has two generations a year and a life cycle similar to that reported for *A. spretulus* by Niemczyk and Dunbar (1976). Damage has resulted but does not appear to be widespread at this time.

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AREA-METER MEASUREMENT OF LEAF DECOMPOSITION CAUSED BY SOIL FAUNA[1,2]

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Abstract

An optical, electronic area-meter was used to measure leaf-area reduction as an index of leaf decomposition rates in soil. Litterbags of 3 mesh sizes: 0.005, 0.70, and 9.0 mm, which excluded soil invertebrates of different size classes, containing a measured area of corn leaf, were buried in a cornfield. Bags were recovered at different time intervals and the remaining leaf-area measured. The rate of area reduction was greatest in large- and least in small-mesh bags, indicating the importance of soil fauna in the processes of leaf decomposition. The area-meter proved to be a rapid, precise tool for measuring the rates of leaf decomposition.

Introduction

Litter decomposition is a complex series of essential processes regulated by the soil biota (Crossley 1977), moisture, temperature and other factors. Any agricultural practice that reduces this breakdown could affect soil fertility. Rates of litter decomposition often are measured by the "litterbag" technique (Bocock and Gilbert 1957, Crossley and Hoglund 1962), in which a known weight of leaf litter is confined in mesh bags and buried in the soil. These bags are unearthed at various times and the loss in weight of the leaf litter determined. Bags of different mesh sizes exclude certain size-classes of soil invertebrates, thus allowing the relative importance of these classes to be assessed in the decomposition processes (Edwards and Heath 1963, Crossley and Witkamp 1964).

Heath *et al.* (1964, 1966) found that photometric measurement of leaf area changes, gave reliable and readily obtainable estimates of decomposition rates. Their method for measuring area made use of leaf discs (2.5 cm diam.) which were placed in nylon mesh (0.003, 0.5 and 7.0 mm) bags (10 X 7 cm), and buried 2.5 cm deep in woodland and fallow soil. The rate of litter disappearance was determined by measuring reduction in disc areas. The relative importance of soil microfauna and microflora in litter-breakdown was assessed by comparing results from the bags of different mesh size.

In this study we evaluated a modern optical, electronic area-meter for use in measuring reduction of leaf-area.

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[2] Part of a thesis submitted by the senior author in partial fulfilment of the requirements for a Doctor of Philosophy degree, University of Guelph.

Materials and Methods

The experimental site was a corn plot (120 X 30 m) in a 12.2 ha field of continuous corn under regular tillage and management at the Arkell Research Station, University of Guelph. The soil was a silt loam type (pH 6.9, organic matter content 4.4%).

Nylon mesh bags (11 X 11 cm) of 3 mesh sizes: 0.005 (S-small), 0.70 (M-medium), and 9.0 mm (L-large), were used to exclude soil invertebrates of different size-classes (S- and M- mesh fabric supplied by Tetko Inc., Scarborough, Ont.; L-mesh supplied by Restaurant Equipment and Supply Co., London, Ont.). The S-mesh bags were designed to exclude all soil animals, except protozoans; the M-mesh bags admitted only small arthropods (e.g. mites, springtails), potworms and nematodes; the L-mesh bags admitted "all" soil animals, including earthworms, isopods, millipedes and insects. All litterbags were filled with pieces of dried corn leaf of known area (ranging from 15.0 cm^2 to 27.0 cm^2). Corn leaves obtained from the tops of plants and of equal age and weathering history were selected.

The litterbags were buried in sets (1 each of S, M and L) in the row, between corn plants at depths of 3-5 cm. The stations in the plots for each set were assigned using randomly selected X- and Y- coordinates, where X was the number of meters along the row and Y was the row number. In 1977 and 1978, the litterbags were buried on June 9 (30 and 17 days respectively after seeding) when the corn seedlings were at least 15 cm high. Eight sets of bags were unearthed at 2, 8 and 16 weeks after burial. The bags were opened and the remaining leaf-area in each bag was measured using an optical, electronic area-meter (Model LI-3000, Lambda Instruments Corp., Lincoln, Nebraska). This device measured area with less than 1% error for areas 10 cm^2 or greater. Several leaf fragments per minute were processed using a conveyer belt fitted to the area-meter. The percentage of leaf-area disappearance was calculated and used as an index of rate of leaf decomposition. Difficulties were encountered in removing leaf tissue from the S-mesh bags in 1977. This was overcome in 1978, by placing the corn leaf fragment in a folded piece of L-mesh (14 X 8 cm) fabric which was then placed inside the S- and M-mesh bags. This prevented the leaf tissue from adhering to the sides of these bags, and reduced compression of the tissues from the weight of the overburden of soil. The rigidity of the L-mesh bags automatically reduced these effects.

Results and Discussion

Some per cent reductions in the mean area of corn leaves for the three mesh sizes unearthed from the cornfield are shown in Table I. These different rates of breakdown for the different mesh sizes (L>M>S) demonstrate the importance of soil fauna in mediating the decomposition processes of corn leaves. The slower rate of leaf-area reduction observed in the S-mesh bags in 1978, compared to 1977, may be accounted for by the improved efficiency of leaf removal from the bags which gave more reliable area measurements, and the lower soil moisture level in 1978.

The area-meter method is more rapid and precise than the tedious photometric (light box) method of Heath *et al.* (1964), which required that the leaf tissue first be punched into discs of standard area and up to 50 discs per bag were required. The area-meter measured directly irregular leaf areas, such as partially decomposed maple leaves (Fig. 1), with high precision.

TABLE I. Mean per cent reduction in corn leaf area for the three mesh sizes and three sampling intervals in an Arkell cornfield (1977 and 1978).

Weeks after leaf burial	Mesh Size	Mean Per Cent Leaf Area Reduction ± S.E. (n = 8) 1977	1978
2	S	9.3 ± 1.6	4.9 ± 2.9
	M	5.0 ± 1.4	8.6 ± 3.7
	L	40.5 ± 12.0	90.8 ± 3.7
8	S	33.5 ± 8.0	12.5 ± 3.1
	M	69.8 ± 9.9	61.2 ± 6.7
	L	98.4 ± 0.8	95.2 ± 3.9
16	S	53.8 ± 13.6	36.8 ± 8.8
	M	98.9 ± 1.1	71.9 ± 7.5
	L	100.0 ± 0	100.0 ± 0

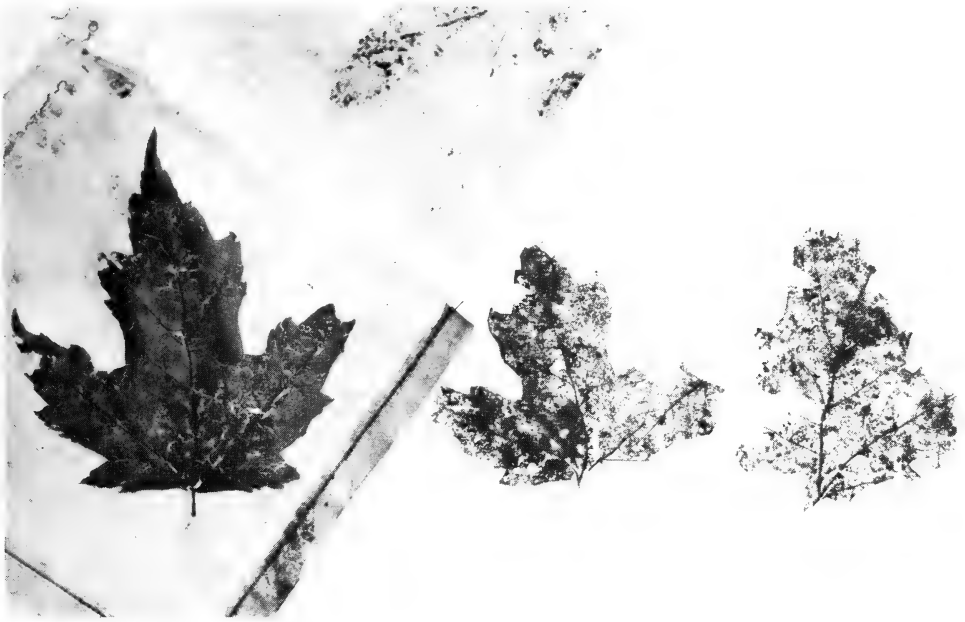

FIG. 1. Decomposition of maple leaves buried for 16 weeks in S- (left), M- (centre), and L-mesh bags in a Guelph pasture (1977).

The limitations of the area-meter technique include possible losses in leaf-weight due to leaching and microbial activity which may not be reflected by loss of leaf-area, or reduction in area due to shrinkage caused by moisture loss rather than decomposition. One limitation of the weighing technique is the presence of soil particles and microflora which may adhere to leaf tissue and cause over-estimation of the actual weight, a particular problem with the M- and L-mesh bags. Although various brushing and washing techniques have been used, soil particles cannot be completely removed from partially decomposed leaf material

without tissue loss (Way and Scopes 1968). We estimated that measurement of leaf-weight loss required five times as long as measuring loss of area by area-meter. A high correlation for per cent area loss versus per cent dry weight loss was reported by Heath *et al.* (1964) for decomposed oak and beech leaves in litter-bags. We found a high correlation ($r = 0.83$, $P < 0.05$) between per cent area loss and per cent weight loss of corn leaf tissue in the S-mesh bag (unpublished data).

Leaves of several species are currently being used in litterbag studies to measure changes in decomposition rates that might be caused by soil insecticide treatment.

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NEW RECORDS OF PARASITIC CHALCIDOIDS OF PEAR PSYLLA (HOMOPTERA: PSYLLIDAE) IN ONTARIO, WITH OBSERVATIONS ON THE CURRENT WORLD STATUS OF ITS PARASITOIDS AND PREDATORS[1]

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Abstract

Three chalcidoid parasitoids *(Trechnites psyllae* Rusch., *Pachyneuron* sp., and *Coccidencyrtus* sp.) were found for the first time parasitizing fifth-instar nymphs of *Psylla pyricola* Foerster, in 1975 and 1976, in the Niagara Peninsula of Ontario. The current status of parasitoids and predators of this pest of pears is also discussed.

Résumé

Trois parasites chalcidoides *(Trechnites psyllae* Rusch., *Pachyneuron* sp., et *Coccidencyrtus* sp.) ont été découverts pour la première fois parasitant des nymphes du cinquième âge de *Psylla pyricola* Foerster, en 1975 et 1976, dans la péninsule du Niagara, Ontario. L'état actuel des connaissances sur les parasites et prédateurs de ce déprédateur du poirier est également discuté.

Introduction

In the course of a study on the susceptibility of pear trees to the pear psylla, *Psylla pyricola* Foerster (Homoptera: Psyllidae) (Chang and Philogène 1976, 1978), we encountered parasitoids and predators of this pest in our rearings and field collections from the Niagara Peninsula of Ontario. Some of these were new to this area. These new records are reported here along with a review of the parasites and predators of pear psylla in North America.

Observations

a) *Parasitoids*

Psylla nymphs were collected in 1975 from a mature pear orchard on the Jordan Experimental Farm, Niagara Peninsula, Ontario and in 1976 from an uncultivated pear orchard southwest of this farm. Each year, 10 replicates of 20 fifth-instar nymphs per pear leaf were enclosed in petri dishes with moist filter paper and maintained at room temperature. From 30 to 45% of these nymphs became mummified both years. Five to seven days following mummification, chalcidoid wasps emerged from the psylla nymphs through a circular hole on the dorsal side of the abdomen.

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The wasps were identified as *Trechnites psyllae* Rusch. (Hymenoptera: Encyrtidae), *Pachyneuron* sp. (Hymenoptera: Pteromalidae) — both of which appeared in 1975 — and *Coccidencyrtus* sp. (Hymenoptera: Pteromalidae) (1 specimen found in 1976). The degree of parasitism of the 33 mummified psylla was as follows: *T. psyllae:* 58% (19 specimens); *Pachyneurons* 40% (13 specimens); *Coccidencyrtus:* 3% (1 specimen).

We did not obtain specific information on the mode and time of oviposition of the parasitoids or on their development. Parasitized psyllid nymphs were fairly active until mummification began.

The 13 species of pear psylla parasitoids found to date belong to two insect orders: Diptera and Hymenoptera (Table I). Of these, four species native to

TABLE I. Parasitoids of the pear psylla.

Order & Family	Species or Genus	Location	Reference
DIPTERA			
Itonididae	*Endopsylla* sp.	Scotland	Lal (1934)
	E. agilis de Meijere	British Columbia	McMullen (1971)
		England	Bagnall & Harrison (1924)
		Holland	Barnes (1930)
		Scotland	Barnes (1930), Lal (1934)
HYMENOPTERA			
Calliceratidae	*Lygocerus* sp.	England	Georgala (1957)
	L. semiramosuns Kieffer	Scotland	Lal (1934)
Encyrtidae	*Encyrtus* sp.	Russia	Yakhontov (1929)
	Prionomitus mitratus Dalman	British Columbia	McMullen (1964, 1966, 1971)
		California	Jensen (1957)
		Scotland	Lal (1934)
		Switzerland	Wilde (1950)
		Washington	Burts (1970)
	Psyllephagus sp.	California	Jensen (1957), Nickel *et al.* (1965)
		England	Georgala (1957)
		Italy	Golfari (1937), Grandi (1951)
	Trechnites insidiosus Crawford	British Columbia	McMullen (1966, 1971)
		California	Madsen *et al.* (1963), Madsen & Wong (1964), Nickel *et al.* (1965)
		Connecticut	Garman & Townsend (1941)
		New York	Crawford (1911)
		Nova Scotia	Rasmy & McPhee (1970)
		Oregon	Westigard *et al.* (1968) Westigard & Zwick (1972)
		Washington	Burts (1970)
	T. psyllae Ruschka	England	Georgala (1957)
		Germany	Ruschka (1923)
		Ontario	Present paper
Pteromalidae	[a]*Asaphes vulgaris* Walker	British Columbia	McMullen (1966, 1971)
		Scotland	Lal (1934)
	Coccidencyrtus sp.	Ontario	Present paper
	Pachyneuron sp.	Italy	Golfari (1937), Grandi (1951)
		Ontario	Present paper
		Scotland	Lal (1934)
	[a]*P. californicum* Grlt.	British Columbia	McMullen (1971)

[a] Also reported as a hyperparasitoid.

Canada, have been reared from the nymphal stages (McMullen 1971): *Trechnites insidiosus* Crawford, *Prionomitus mitratus* Dalm. (primary parasitoids) and *Pachyneuron californicum* Grlt., *Asaphes vulgaris* Walker (hyperparasitoids). It would then appear that *T. psyllae* is a primary parasitoid and that the *Pachyneuron* sp. collected at Jordan might be a hyperparasitoid.

It has been reported that parasitoids formerly present in the Niagara Peninsula — more specifically *Trechnites insidiosus* — did not survive insecticidal treatments (Wilde 1965). Our current report consequently is of considerable importance because organophosphates are still in use against *P. pyricola.* Moreover, *Trechnites insidiosus* has been recognized as the most effective of all parasitoids already present in most of the pear growing areas of North America.

The largest number of parasitoids in a single geographical area has been reported from British Columbia (Table I). Some of these were introduced from Europe but the exact status of origin of species like *Prionomitus mitratus* Dalman, is uncertain since it was actually reported from the North American continent prior to its introduction in 1963 (Jensen 1957, McMullen 1971). We have not been able to determine the significance of the parasitoid, *T. psyllae,* in North America, but we believe it will have to be carefully monitored in the future, particularly if integrated control programs are contemplated. It occurs in England and Germany (Georgala 1957, Jensen 1957) and to our knowledge it is reported for the first time in North America, although proper identification might not have been carried out prior to this report.

The status of *Pachyneuron* is different since it may be a hyperparasitoid and therefore, it could be a negative element in biological control. *Coccidencyrtus* is described for the first time as a parasitoid of *P. pyricola.* This may be a case of accidental parasitism.

b) *Predators*

Our studies of psyllid development were even more seriously affected by predators which regularly fed on various stages of the pest. This was particularly true of *Anthocoris* sp. The predators of pear psylla belong to the following orders: Coleoptera, Diptera, Hemiptera and Neuroptera and far outnumber parasitoids of the species (Table II). They are polyphagous and consequently not as dependent on *P. pyricola* as their parasitoid counterparts. Most predators reported seem to prefer the eggs and nymphs of the prey. This is something we have been able to observe in the present study, particularly predation of the eggs. *Anthocoris melanocerus* Reuter and *A. nemoralis* Fabricius are apparently more specific to pear psylla than the other predators, a characteristic our observations support (Burts 1971, McMullen 1971). Adult pear psylla are particularly preyed upon by *Platypalpus* sp. (Diptera: Empididae) (McMullen 1971, Mcmullen and Jong, 1967, Wilde 1962).

The effectiveness of these predators varies with the locality, climatic conditions, density of the prey, and presence of natural enemies. In Ontario, the green lacewings *(Chrysopa* spp.) were reported by Wilde (1965) to be the most abundant and efficient predators. However, in 1975-76, this was not the case in the Niagara Peninsula: *Anthocoris* spp. and assassin bugs (Reduviidae) were particularly active and numerous. It was usual to find the conspicuous reduviid nymphs feeding on psyllid nymphs and a variety of immature stages of other species such as aphids, anthocorids, chrysopids and coccinellids. This lack of specificity makes the assassin bugs particularly undesirable control agents for psylla, considering the number of beneficial species they are capable of destroying.

TABLE II. Predators of the pear psylla.

Order & Family	Species or Genus	Location	Reference
NEUROPTERA			
Chrysopidae	*Atractotomus mali* Meyer	Nova Scotia	Rasmy & McPhee (1970)
	Chrysopa sp.	Ontario	Wilde (1965)
	C. carnea Stephens	British Columbia	McMullen (1971), McMullen & Jong (1967), Wilde (1962)
		California	Nickel *et al.* (1965)
		Oregon	Westigard *et al.* (1968) Westigard & Zwick (1972)
		Washington	Burts (1963, 1970)
	C. oculata Say	British Columbia	McMullen (1964, 1971), McMullen & Jong (1967), Watson & Wilde (1963), Wilde (1962, 1963), Wilde & Watson (1963)
		New York	Slingerland (1896)
		Washington	Burts (1963)
	C. ploribunda Fitch	California	Madsen *et al.* (1963), Madsen & Yong (1964)
		Washington	Burts (1963)
Hemerobiidae	*Hemerobius* sp.	Oregon	Westigard *et al.* (1968)
	H. angustus Banks	California	Madsen & Way (1964), Madsen *et al.* (1963), McMullen (1971), Nickel *et al.* (1965)
	H. pacificus Banks	British Columbia	McMullen (1971), McMullen & Jong (1967)
Raphidiidae	*Agulla* Sp.	British Columbia	Wilde (1968)
		Washington	Burts (1970)
HEMIPTERA			
Anthocoridae	*Anthocoris antevolens* White	British Columbia	Anderson (1962), Anderson & Kelton (1963), Fields & Beirne (1973), Madsen (1961), Marshall (1950), McMullen (1964, 1971), McMullen & Jong (1967), Wilde & Watson (1963)
		California	Anderson & Kelton (1963) Madsen *et al.* (1963), Madsen & Wong (1964), Nickel *et al.* (1965)
		Oregon	Anderson (1972), Westigard *et al.* (1968)
		Washington	Anderson (1962), Burts (1970)
	A. melanocerus Reuter	British Columbia	Anderson (1962), Fields & Beirne (1973), Madsen (1961), McMullen (1964, 1971), McMullen & Jong (1967), Watson & Wilde (1963), Wilde (1963, 1965), Wilde & Watson (1963)
		Ontario	McMullen (1971), Wilde (1965)
		Oregon	Anderson (1962)
		Washington	Anderson (1962), Burts (1963)
	A. musculus Say	British Columbia	Anderson (1962)
		Nova Scotia	Rasmy & McPhee (1970)
	A. nemoralis Fabricius	British Columbia	Fields & Beirne (1973), McMullen (1971), McMullen & Jong (1967)

Order & Family	Species or Genus	Location	Reference
		Ontario	Anderson & Kelton (1963)
		Switzerland	Fields & Beirne (1973), McMullen (1971)
	A. nemorum Linnaeus	British Columbia	McMullen (1971)
		England	Georgala (1957)
Anthocoridae	*A. pilosus* Jakovliev	British Columbia	McMullen (1971)
	A. whitei Reuter	British Columbia	Anderson (1962)
		Oregon	Anderson (1962), Westigard *et al.* (1968), Westigard & Zwick (1972)
	Orius sp.	California	Madsen *et al.* (1963)
		Ontario	Nickel *et al.* (1965)
	O. tristicolor White	British Columbia	McMullen (1971), McMullen & Jong (1967), Wilde & Watson (1963)
		Oregon	Westigard *et al.* (1968), Westigard & Zwick (1972)
Miridae	*Campylomma verbasci* Meyer	British Columbia	McMullen (1971), McMullen & Jong (1967)
		Nova Scotia	Rasmy & McPhee (1970)
	Derseocoris brevis-piceatus Knight	British Columbia	Marshall (1959), McMullen & Jong (1967)
		Oregon	Westigard *et al.* (1968), Westigard & Zwick (1972)
		Washington	Burts (1970)
	D. fasciolus Knight	British Columbia	McMullen (1971), McMullen & Jong (1967)
	Diaphnocoris provancheri Burque	British Columbia	McMullen (1971), McMullen & Jong (1967)
COLEOPTERA			
Coccinellidae	*Adalia bipunctata* Linnaeus	New York	Slingerland (1896)
		Nova Scotia	Rasmy & McPhee (1970)
	A. frigida Schneider	British Columbia	McMullen (1971), McMullen & Jong (1967)
	Anisoclavia quatuor-decimguttata Linnaeus	Nova Scotia	Rasmy & McPhee (1970)
	Calvia duodecimmaculata Gebler	British Columbia	McMullen (1971), McMullen & Jong (1967)
	Ceratomegilla sp.	Ontario	Wilde (1965)
	Coccinella transverso-guttata Falderman	British Columbia	McMullen (1971), McMullen & Jong (1967)
		Nova Scotia	Rasmy & McPhee (1970)
		Oregon	Westigard *et al.* (1968), Westigard & Zwick (1972)
	Cycloneda polita Casey	Ontario	Wilde (1965)
		Oregon	Westigard *et al.* (1968)
	Hyppodamia convergens Guerin-Meneville	British Columbia	McMullen (1971), Wilde (1962), Wilde & Watson (1963)
		Ontario	Nickel *et al.* (1965), Wilde (1965)
		Oregon	Westigard *et al.* (1968), Westigard & Zwick (1972)
		Washington	Burts (1963)
	H. quinquesignata Kirby	British Columbia	McMullen (1971), McMullen & Jong (1967)
	H. tredecimpunctata tibialis Say	Nova Scotia	Rasmy & McPhee (1970)

Order & Family	Species or Genus	Location	Reference
	Magilla fuscilabris Mulsant	British Columbia	McMullen (1971), Wilde (1962), Wilde & Watson (1963)
	Olla abdominalis Say	Oregon	Westigard *et al.* (1968)
	Scymnus marginiccelis Mann	Oregon	Westigard *et al.* (1968)
	Stethocrus piciepes Casey	Oregon	Westigard *et al.* (1968)
DIPTERA			
Empididae	*Platypalpus* sp.	British Columbia	McMullen (1971), McMullen & Jong (1967)
Syrphidae	*Sphaerosphoria* sp.	British Columbia	McMullen (1971), Wilde (1962)
HYMENOPTERA			
Formicidae	*Lasius sitkaensis* Pergande	British Columbia	Wilde (1963)

Anthocorid nymphs were particularly efficient when feeding on psyllid nymphs hidden in the leaf axil. One should note that insecticide treatments have been particularly inefficient because of this trait of the pear psylla. Therefore, protection and augmentation of anthocorids is highly desirable. For several years the anthocorids have been claimed to be the most efficient predators in British Columbia, especially *Anthocoris nemoralis* (McMullen 1971). Moreover, *A. melanocerus* was imported from B.C. and released in Ontario and proved to be quite efficient (Wilde 1965). These Hemiptera are also recognized as valuable predators elsewhere (Burts 1970, Madsen *et al.* 1963).

Conclusions

Since its introduction from Europe in the 19th century, *P. pyricola* has become one of the most difficult pests of pear trees to control because of its feeding habits and honeydew excretions (Chang and Philogène 1976). Parasites and predators native to North America, were not reported until 1896 by Slingerland. The pest therefore went practically unchecked for 60 years. Insecticidal treatments have reduced the damages caused by pear psylla, but also have adversely affected the natural enemies, as reported by Wilde (1965) in Ontario. Pear trees not only suffer from direct insect damage but also from toxins and mycoplasmas injected by the insect that result in conditions known as "psylla shock" and "quick decline" (Chang and Philogène 1975, Hibino and Schneider 1970, Madsen *et al.* 1962, Wilde 1965).

The observations reported here, suggest that more attention should be given to the predator/parasitoid complex of *P. pyricola,* particularly in the pear growing areas of Ontario, and that more weight be given to biological and/or integrated control of psylla. We must put more emphasis on protection of the beneficial insect species which help maintain a low infestation level of psylla.

Acknowledgments

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TOXICITY OF INSECTICIDES TO LARVAE OF THE FALL ARMYWORM, *SPODOPTERA FRUGIPERDA*[1]

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Abstract

Fourteen insecticides were evaluated for toxicity to first-instar larvae of the fall armyworm, *Spodoptera frugiperda* (J. E. Smith), in laboratory spray tower tests. Cypermethrin, fenvalerate, permethrin, chlorpyrifos, sulprofos and profenofos were the most toxic, with LD_{95} values less than 17 mg a.i./liter. Parathion, methomyl, azinphos-methyl, methamidophos, acephate and endosulfan were all less toxic with LD_{95} values ranging from 30.2 to 567 mg a.i./liter. Larvae were tolerant to carbofuran and carbaryl.

Introduction

The fall armyworm, *Spodoptera frugiperda* (J. E. Smith) is a pest of various crops in southern Ontario in late summer and fall. The degree of damage depends on the population density of the migrating moths and on the stage of the crops when migration occurs. In 1976, moths from the south arrived in August when the crop of processing tomatoes was favourable for oviposition. In 1977 and 1978, with a later arrival from the south, larval damage was mainly to plantings of sweet corn and cover crops of rye. At the Harrow Research Station, plots of sweet corn used for evaluating insecticides for European corn borer have been occasionally attacked by the fall armyworm. This suggested that the usual controls for corn borer were not necessarily effective against the fall armyworm.

It is difficult to achieve commercially acceptable control of fall armyworm in late plantings of sweet corn in the southern United States (Janes 1975, Harrell *et al* 1977). The best treatment in those fields was methomyl alone or as a mixture with toxaphene. Control of a mixture of fall armyworm, which predominated, and corn earworm, on fresh market sweet corn in south Florida, was investigated in 1967 (Janes and Greene 1969). With eight applications on a twice-weekuy schedule, carbaryl at 1.5 lb a.i./acre gave 75% clean ears, while carbofuran at the same rate gave 92% clean ears, compared to 7% in the check plots.

Reported here is a laboratory study of the contact toxicity of various insecticides against first-instar fall armyworm larvae. It is important to control the small larvae on sweet corn before they move to protected sites within the ears.

Materials and Methods

Fall armyworm larvae were collected from unsprayed plots of late plantings of sweet corn in September 1978 and reared on an artificial diet (Shorey 1963) in cotton-stoppered vials at 25°C. Pupae were removed from these vials and placed in 2 cm of soil in a 6-liter plastic dish and adults emerged there. They were placed in an oviposition cage which consisted of a wire mesh cylinder 25 cm high and 18

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cm in diameter, lined with paper towelling and covered with a glass plate. A cotton wick in a vial of 5% sugar provided adult nourishment. This cage was kept at 25°C. with a 14 hr photoperiod (1350 lux). Egg masses that were laid on the paper were cut out and kept on moist filter paper in petri dishes until larvae emerged.

Insecticide dosages were made up from emulsifiable concentrates when available, or wettable powders, to produce a logarithmic series of concentrations (mg a.i./liter of water). First-instar larvae about one day old were placed on a thin smear of artificial diet on a filter paper in a petri dish. These dishes, each containing 10 larvae, were sprayed with a Potter tower delivering 1.8 μl/cm^2 and then covered and held in darkness at 24°C. Larvae not responding to probing after 48 hrs were counted as dead. Dosages were replicated five times and the data analyzed by probit analysis (Finney 1962).

Results and Discussion

The rearing method proved adequate, with production of large fertile egg masses and vigorous larvae. Three generations were reared. The test method was satisfactory, as indicated by an overall check mortality of 1.2%. There was very little cannibalism, but 5 to 10% of the larvae were lost from dishes treated with carbofuran, azinphos-methyl, chlorpyrifos, permethrin and profenofos, probably because of repellent action. In contrast to this, larval losses from the other treatments ranged from 0.5 to 2.8% and averaged only 1.7%.

The 14 materials listed in Table I are in order of effectiveness. The pyrethroids, permethrin, fenvalerate and cypermethrin, were not significantly different. Chlorpyrifos and sulprofos were slightly less toxic at the LD_{50} level, but due to the steeper slope of the probit mortality line, their LD_{95} values were comparable to those of the pyrethroids. Parathion and methomyl were not as toxic to first-instar larvae of the fall armyworm as they were to European corn borer (McClanahan and Founk 1972), but they would be good materials to consider for field tests. Azinphos-methyl, methamidophos, acephate and endosulfan were less toxic but still might be useful in the field.

The low toxicity of carbofuran and carbaryl indicated fall armyworm were tolerant to these materials. This explains why fall armyworm were present in carbofuran-treated plots at the Harrow Research Station. Carbaryl had not been tested in the plots since 1976. Data are not available to indicate whether this is a case of resistance, but the experiment of Janes and Greene (1969) suggests fall armyworms were more susceptible, especially to carbofuran, about 10 years ago.

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TABLE I. Toxicity of insecticides to first-instar fall armyworm larvae, evaluated 48 hr after spraying.

Insecticide	Product	Probit Line		Dosage mg a.i./liter			
		Intercept	Slope	LD_{50}	Confidence Limits	LD_{05}	Confidence Limits
permethrin	Ambush	4.24	2.00	2.40	1.61 - 3.07	15.9	10.3 - 39.2
cypermethrin	Ripcord	4.28	1.94	2.35	1.85 - 2.89	16.5	11.0 - 32.5
fenvalerate	Belmark	4.03	2.32	2.61	2.16 - 3.11	13.4	9.6 - 22.4
chlorpyrifos	Lorsban	2.27	4.14	4.57	4.03 - 5.19	11.4	9.2 - 15.6
profenofos	Selocron	Not linear [a]		6.23	-	14.6	-
sulprofos	Bolstar	0.22	5.58	7.20	6.49 - 7.99	14.2	12.2 - 17.9
parathion	Parathion	0.12	4.41	12.7	11.1 - 14.5	30.2	25.0 - 39.8
methomyl	Lannate	2.08	2.32	18.2	15.2 - 21.8	93.2	65.5 - 161
azinphos-methyl	Guthion	0.29	2.85	44.9	38.2 - 53.5	169	125 - 269
methamidophos	Monitor	—2.25	3.73	87.8	77.1 - 101	242	191 - 350
endosulfan	Thiodan	Not linear [a]		115	-	567	-
acephate	Orthene	—2.70	3.70	121	106 - 139	338	271 - 473
carbofuran	Furadan	—4.62	2.76	3060	2570 -3610	12080	9090 - 18650
carbaryl	Sevin	Not linear [a]		5000	-		

[a] Due to significant heterogeneity of the data for these materials the intercept, slope, and confidence limits can not be used for comparisons. The LD_{50} and LD_{05} are computed estimates.

THE POTENTIAL OF A LOCAL PLANARIAN, *DUGESIA TIGRINA* (TRICLADIDA, TURBELLARIA), FOR THE CONTROL OF MOSQUITOES IN ONTARIO[1]

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Abstract

The planarian flatworm, *Dugesia tigrina* (Girard), (Tricladida, Turbellaria) was collected from the Thames River in London, Ontario, reared in the laboratory and found to feed on both larvae and pupae of the mosquito, *Culex pipiens* L., a vector of St. Louis encephalitis. Each planarian consumed an average of 1.2 mosquito larvae per day. Moreover, *D. tigrina* fed on field-collected black-fly larvae. The laboratory population of *D. tigrina* doubled every 10 to 14 days when fed *Daphnia* and fragments of earthworms.

In field tests, placement of *ca.* 150 laboratory-reared *D. tigrina* in each of four catch basins infested with *Culex restuans* Theobold and *C. pipiens* was followed after four weeks by a reduction of larvae and pupae to an average of 4/dip in three basins compared to 69/dip in two control basins. *D. tigrina* did not survive in the fourth catch basin which contained black, stagnant, foul-smelling water.

Introduction

Mosquitoes are an annual threat to both the comfort and health of residents of southwestern Ontario. Many municipalities find it necessary to conduct monitoring and abatement campaigns each summer. Abatement is based almost entirely on a reduction of breeding areas and the use of insecticides.

The planarian flatworm, *Dugesia tigrina* (Girard), = *(Planaria maculata* Girard), has been known to be a predator of mosquitoes since Lischetti (1919) and Stage and Yates (1939) reported it to consume *Culex* and *Aedes* larvae (Jenkins 1964). A larger species, *Dugesia dorotocephala* (Woodworth), has recently been shown to also act as an effective predator of mosquito eggs, larvae and pupae in California (Legner and Medved 1972, 1974; Medved and Legner 1974; Yu and Legner 1976).

Because the weekly use of insecticides is time-consuming, planaria appear to offer advantages over insecticides in some situations, such as in catch basins of urban areas. If planaria survive in catch basins they may provide lasting control. Moreover, if the planarian used is indigenous, extensive tests to establish its safety to vertebrates will not be required. It is adapted to local climatological conditions and it is already commercially available through biological supply houses.

Hence, a series of tests were conducted at London, Ontario to determine: 1) if local planaria can be reared in quantity in the laboratory; 2) if and how

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local planaria feed on *Culex pipiens* larvae and pupae; 3) how many mosquito larvae planaria will consume; and 4) whether laboratory reared planaria, after introduction, can control mosquito larvae in urban catch basins.

Materials and Methods

Dugesia tigrina were collected from the under surfaces of stones in the Thames River on the University of Western Ontario campus and placed in wash basins with two liters of aerated water and three pieces of 5 x 5 x 1 cm clay tile. Various foods were tested including beef liver, boiled eggs, live brine shrimp, live *Daphnia* and one cm fragments of live earthworms.

To determine if the planaria were multiplying, five mature individuals were placed in each of five wash basins and counted at 2-week intervals. They were provided with an excess of live *Daphnia* and fragments of earthworms as food on alternate days when surplus food was removed.

To determine if planaria fed on mosquito larvae, *C. pipiens* larvae were collected from the Byron Bog and reared (de Meillon and Vijayamma 1966) with Japanese Quail, *Coturnix coturnix* L., as a blood source for adult females. Activities of larvae placed in water in petri plates with planaria were observed under a microscope. Similarly, black fly larvae collected from the Thames River were also observed with planaria.

The average number of mosquito larvae that each planarian destroyed per day was determined by placing 5 planaria in each of 5 basins with 10 mosquito larvae (third instar). An additional three basins with mosquitoes but without planaria served as controls. The live and dead larvae were removed and counted daily and then replaced with 10 new larvae.

Finally, on 28 July, 1978 four groups of 150 reared-planaria were placed in four of six catch basins (storm sewers designed to drain excess surface water) in Ailsa Craig, Middlesex County, Ontario, which were known to contain both water and mosquito larvae during summer months. The remaining two catch basins served as controls. Mosquito populations were monitored by counting the total larvae and pupae in each of three 300 ml dips, taken simultaneously to introduction of planaria and subsequently at one week intervals (28 July, 4, 11, 17 and 28 August). In addition, observations for planaria were conducted by an examination of the walls of each catch basin near the water surface as well as by inspection of the undersurfaces of stones at the bottoms.

Results and Discussion

Planaria were easily reared from an original stock of 50 to *ca.* 1,000 in the laboratory during the spring of 1978 using live *Daphnia* and fragments of earthworms as food. Records taken over a 30-day period revealed that the population doubled every 10 to 14 days at 23 $\pm$ 1°C. Reproduction occurred only by transverse fission, posterior to the pharynx. The tapered caudal third of large specimens constricted and eventually separated into an anterior individual with a transverse posterior end, and a smaller posterior inactive individual. The latter individuals remained inactive for several days during which heads and pharynges developed.

When planaria were placed in petri plates with mosquito larvae or pupae they rapidly immobilized and consumed all but the exoskeletons of both larvae and pupae. Disabled larvae, or pupae rapidly attracted planaria which coiled over one another to extract the contents of the exoskeletons with their feeding tubes

(Fig. 1). Larvae crushed with forceps also proved highly attractive as did whole black fly larvae.

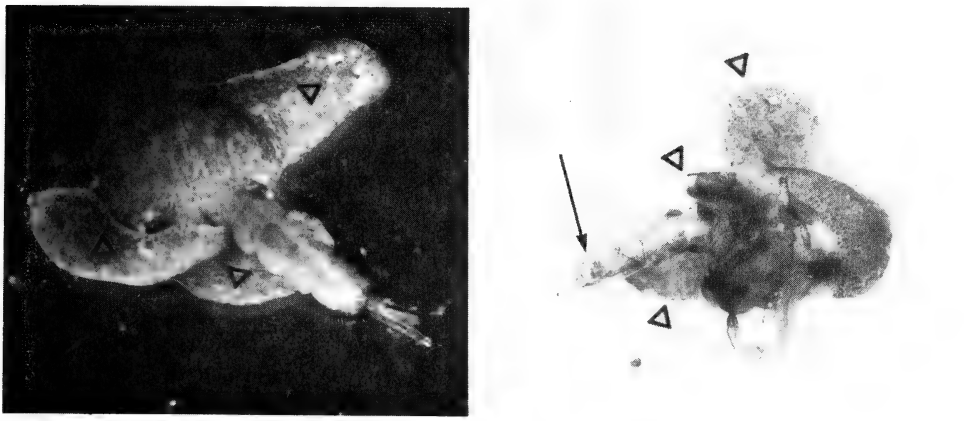

FIG. 1. Several *Dugesia tigrina* feeding on a mosquito larva (left) and pupa (right). Feeding tubes (pharynges) have been inserted into the abdomens of the hosts. The tip of a feeding tube is indicated within pupa by an arrow while triangles indicate individual planaria.

The capture of larvae occurred in one of three ways. Most frequently, the planarian simply glided up to a larva and contacted it with the most anterior tip of the head. This firmly attached the flatworm and allowed it to glide over and envelop larvae regardless of any evasive actions of the latter. In a few seconds, the tip of the pharynx penetrated the cuticle and active sucking had commenced (Fig. 1). Frequently the eye-pigments of larvae were observed being drawn into the digestive tract of the planarian. A second means of capture occurred when swimming larvae became entangled in the gelatinous mucus that invariable accumulated around feeding planaria. The more such larvae attempted to escape the more entangled they became until they eventually succumbed. Since the exoskeletons of the larvae remaining after feeding were always surrounded by mucus, more larvae were often trapped than actually served as food. Finally, mosquito larvae in the vicinity of feeding planaria became immobilized without antanglement. This might be attributed to either toxic materials and/or enzymes secreted by feeding planaria.

An average of 26, with a range of 22-30, third instar *C. pipiens,* larvae were destroyed by each of 25 mature planaria over a 21-day period. This is an average of 1.2 larvae per planarian per day. There was no mortality in the controls. Though young planaria appeared and disappeared during the tests there was no increase in the numbers of planaria over 1 cm long.

When a population of over 600 planaria had been reared in the laboratory, 150 were released in 4 of 6 mosquito-infested catch basins in Ailsa Craig, Ontario. Four weeks later planaria were present in three of the four catch basins but there was no satisfactory way of estimating their numbers. None was seen in the fourth catch basin which contained black, stagnant, foul-smelling water and contained an average of 30 mosquito larvae and pupae per dip. Hence, it has not been included in the results. This catch basin obviously received some unknown materials in addition to surface water.

There was a significant reduction ($P < 0.01$) in numbers of mosquito larvae

and pupae in catch basins receiving planaria compared to control basins by the fourth week after introduction (28 August, Fig. 2). The total larvae estimated to be in one of the control basins was over 18,000 with an overall average of 69 ± 34 larvae and pupae per dip in the controls. Of the planaria-treated catch basins however, one had no larvae and the remaining two had fewer than 10 per dip with an overall average of 4 ± 2.8.

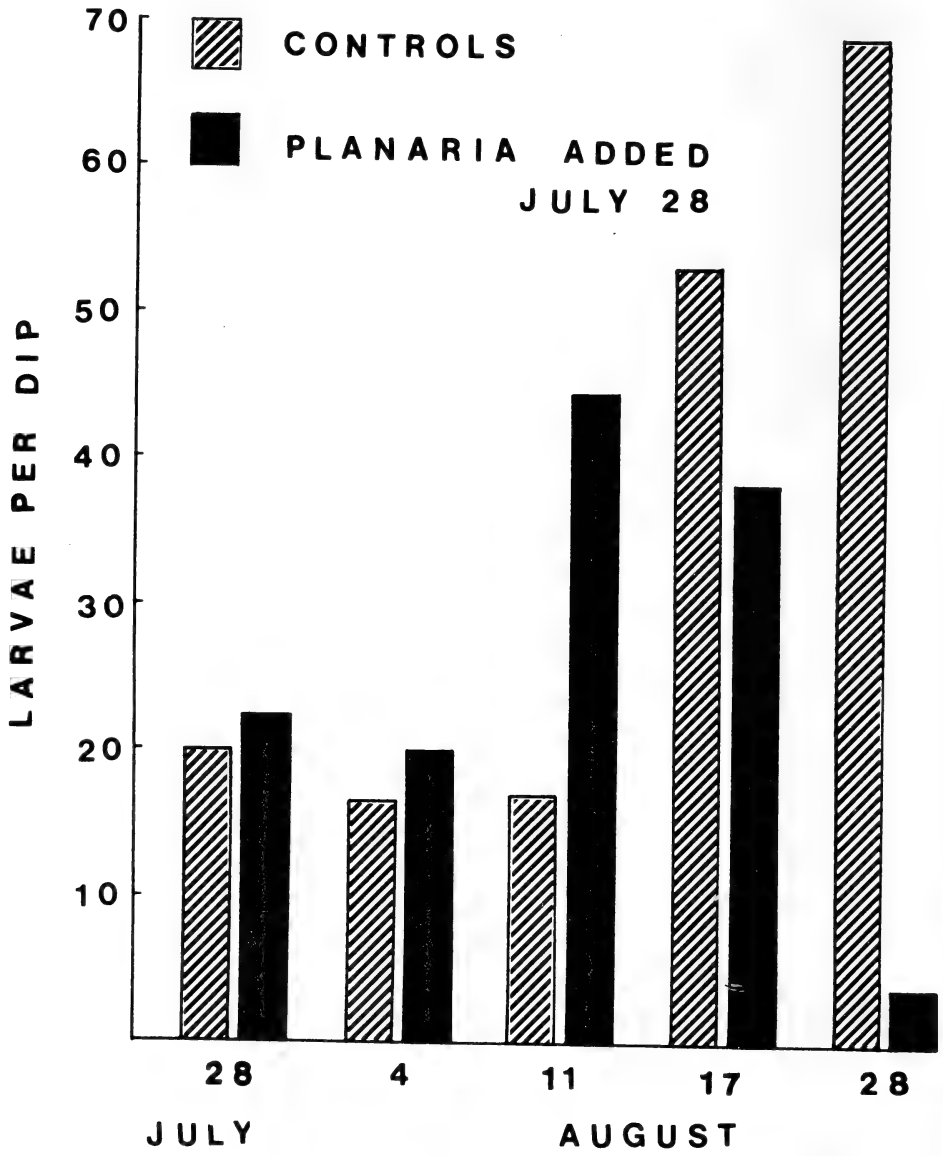

FIG. 2. The average numbers of mosquito larvae per dip taken from catch basins containing *D. tigrina* and from untreated controls; Ailsa Craig, Ontario.

Beginning on July 28, when the planaria were introduced, there was a close

relationship between the number of larvae per dip in both treated and untreated catch basins except on 11 August and the already mentioned week of 28 August. On 11 August there were more mosquito larvae in the dips from the treated basins (44 ± 31) than in those from the controls (17 ± 10). Although this difference was not significant, it does indicate a need to determine whether planaria attract mosquitoes to oviposit in their proximity. A more likely explanation however is that the difference is due to random variations in mosquito numbers between catch basins. After 11 August, the mosquitoes in the treated basins appeared to decrease while in the control basins they increased. The upward trend in the controls corresponded to an increase in rainfall and occurred at almost the usual time for a rise in *C. pipiens* populations (Judd 1954).

Samples of larvae revealed that the populations included only *C. pipiens* and *C. restuans*. The *C. restuans* represented 15% of the mosquito populations on 28 July, 5% on 4 August and had disappeared by 11 August.

Acknowledgments

The co-operation, assistance and travel provided by the Middlesex Health Unit in the persons of Mr. Shean Ryan and Dr. Bruce Hutchinson is most gratefully acknowledged.

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FIRST REPORT OF JAPYGIDAE (INSECTA: DIPLURA) FOR ONTARIO[1]

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Abstract

Specimens of Japygidae (Insecta: Diplura) have only once previously been reported for Canada (British Columbia) and that by hearsay. Herein several specimens from two widely separated Ontario counties, Niagara and Essex are reported, along with general specimen and site description.

Introduction

Very few North American insects are as poorly known as the order Diplura which contains four families, Japygidae, Anajapygidae, Projapygidae, and Campodeidae (Tomlin 1979). All species are usually small, pale animals found in damp situations in soil, under stones and in rotting wood and debris. The mouth parts are of the chewing type, partly withdrawn into the head, and their feeding habits, though probably predatory, are unknown. As of 1941, the family Japygidae was represented by less than a dozen species from the United States and *none* for Canada (Fox 1941). Spencer (1945) reported that a reliable colleague (L. G. Saunders) had found two specimens of *"Japyx"* in 1944 under a rosette of leaves of an autumn dandelion at Brentwood, Vancouver Island. As far as can be ascertained, this was the first record of Japygidae for Canada but no trace of these specimens has been found. Although the senior author has received oral reports from several workers that Canadian (including Vancouver Island) specimens of Japygidae have been found, usually from arthropod extractions of soil, there has been no other published report.

Swenk (1903) listed six well-marked species that had been described from the United States and Mexico. In 1947, Silvestri published an analysis of Japygidae held by the Harvard College Museum of Comparative Zoology collected up until 1936 (only 4 species of which were from continental U.S.A.). Young (1951) and Chandler (1957) both published reports on the occurrence of japygids in Indiana, one species of which, *Metajapyx subterraneus* (Packard), was evidently quite common in soils over wide areas of Indiana.

Although japygids are almost never found in entomological collections, they are not nearly so rare in nature as one might suppose; more probably it is the general lack of interest by entomologists in the "Apterygota" which gives rise to this situation.

Materials and Methods

Soil samples were collected from Windsor Airport (Essex Co.) and Jordan Farm (an apple orchard, 0.5 km south of the south shore of Lake Ontario in the Regional Municipality of Niagara) at approximately monthly intervals during the summer of 1976. The samples from Jordan Farm were from soil cores 9.5 cm dia. x 15 cm deep. Soil cores from Windsor Airport were 5 cm dia. x 15 cm deep. The

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soil cores were transported to London, Ontario for extraction by modified Tullgren funnels in a method described by Tomlin (1978). Jordan Farm soil type was a sandy loam, and that of Windsor Airport a clay loam. The Windsor cores were taken from the turf within 30 m of the tarmacadam runways.

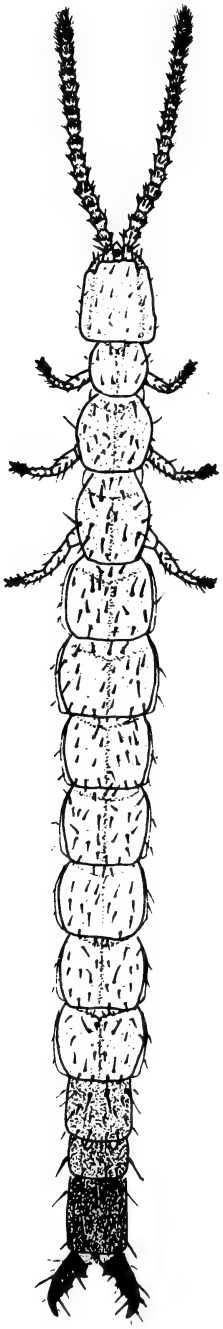

FIG. 1. General dorsal view.

Results and Discussion

Occurrence of Japygids in Ontario

Since our gross sorting method did not separate Japygidae from Campodeidae (both were scored under a single title), we do not have an accurate frequency of occurrence or density records for Japygidae. However, we did obtain about eight specimens from each site: from Jordan Farm on Feb. 25 and Mar. 3, and from Windsor Airport, April 15 and Aug. 3, 1976.

General Description of Japygid Specimens

Overall length is approximately 3 mm and the general colour is creamy white to light yellow. The antennae are filiform and 18-segmented and the thorax has two pairs of stigmata; the abdomen has 10 visible segments (Fig. 1). The distinctive posterior cercal forceps (Fig. 2) are strongly sclerotized with two large teeth. So far we have been unable to determine the species, but it appears to be close to

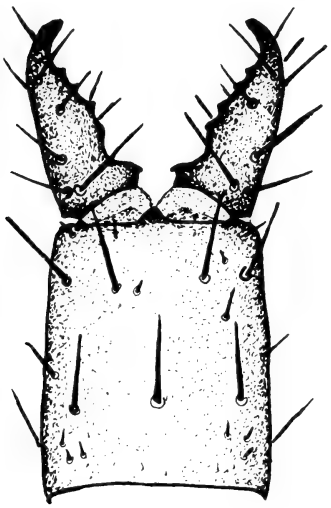

FIG. 2. Dorsal view of forceps.

the genus *Parajpyx*. A more comprehensive description of this insect's morphology and taxonomic position is in preparation. Specimens from both sites are apparently similar to each other.

Acknowledgments

The authors acknowledge the technical and collecting assistance of Mr. J. Miller, Dr. N. Holliday, and Ms. P. Vander Deen.

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AN IMPROVED RAPID METHOD THAT DEMONSTRATES CUTICULAR TOPOGRAPHY, INCLUDING SENSILLA, IN ARTHROPODS[1]

BELA A. L. NAGY[2]

Abstract

Arthropod cuticular topography, such as sensilla, ridges, spines, pits, sutures, and setae, can be quickly and easily demonstrated with a .01% solution of crystal violet applied after treatment with hot KOH and bleach. Crystal violet proved superior to Grenacher's borax carmine, chlorazol black E, and unstained, cleared and/or bleached whole mount when each was observed under any one of bright field, phase-contrast or Normanski light microscopy. Excellent results were obtained on representatives of the following taxa: Gammarus (crustacean), Dermacentor (tick), Lycosa (spider), Centruroides (scorpion), Megostigmata (mite) and Spirobolus (millipede); as well as representatives of the following insect orders: Diplura, Orthoptera, Hemiptera, Homoptera, Coleoptera, Lepidoptera, Diptera, and Hymenoptera.

Complete scale removal from lepidopteran antennae was achieved without affecting sensillar structure or size, with a combination of hot KOH and the mechanical action of boiling.

This method promises to be very advantageous in studies of arthropod sensilla, mite chaetotaxy and in the identification of small arthropods.

Introduction

A technique was developed to enable observation of the types and abundance of sensilla on antennae of the Oriental fruit moth, *Grapholitha molesta* (Busk). The technique selectively removed scales and differentially stained sensilla with such rewarding results that it was tested on other arthropods. It soon became obvious that this technique had general applicability in morphological and taxonomic studies on a wide range of arthropod taxa.

This paper describes the procedure, its modifications, potential uses, and the results on the representatives of the taxa on which it was tested.

Materials and Methods

Biological material for external morphological studies was stored in 80% ethyl alcohol. Material initially fixed for light microscopy, electron microscopy or even storage was also used after it was washed in 80% alcohol.

The 0.5% stock solution of crystal violet was prepared according to Galigher & Kozloff (1971).

A) *General Procedure*

1. Boil in 10% KOH until only cuticle remains.
2. To wash, soak several minutes in distilled water.

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3. If pigment removal is desired: bleach in a 3% solution of sodium hypochlorite (1:1 aqueous dilution of "Javex"®) until cuticle is a very light brown or yellow.
4. To wash, soak for 1 to 2 minutes in distilled water.
5. Stain to desired intensity in .01% solution of crystal violet.
6. To wash, soak for 1 to 2 minutes in distilled water.
7. Mount in "Uvak"® or other water-miscible mounting media.

NOTE: i) Duration of KOH treatment depends on size of specimen.

ii) Over-bleaching or KOH treatments results in poor or no stain uptake.

iii) Over-stained specimens can be destained by long washes in water or quick dips in alcohol.

iv) "Javex"® is a commercially available liquid bleach.

v) To facilitate transfer of small specimens a wire loop or pipet may be used.

B) *Modification for Antennal Scale Removal*

1. KOH treatment: Pour 20 ml of 10% KOH into a 50 ml beaker, which has a roughened inner surface, and add several 3 mm. glass boiling beads.
2. Cover with an inverted petri dish and bring to a boil. Adjust heat to insure constant bubbling such that the antennae are carried up and down the beaker walls.
3. Wash several minutes and proceed with bleach step (3) above.

NOTE: i) Size of beaker and volume of KOH solution is critical.

ii) Inner surface of beaker may be roughened with emery cloth.

iii) If antennae become stranded on beaker wall, wash down with KOH solution in a pipet.

To test the effect of treatments on the antennae, measurements were made with an adjustable hair ocular micrometer of the sensillum trichodea length, basal width and tip width of *Grapholitha molesta* (Busck). Measurements made on 10 untreated antennae were compared with those of 20 antennae treated with hot KOH.

The crystal violet staining technique was applied to representatives of the following taxa: Gammarus (crustacean), Dermacentor (tick), Lycosa (spider), Centruroides (scorpion), Mesostigmata (mite) and Spirobolus (millipede); as well as representatives of the following insect orders: Diplura, Orthoptera, Hemiptera, Homoptera, Coleoptera, Lepidoptera, Diptera, and Hymenoptera. The results were compared with: unstained, cleared and/or bleached whole mounts with bright field, phase-contast, and differential interference contrast optic (Normarski) microscopy. Finally comparisons were made with Grenacher's borax carmine and chlorazol black E.

Results and Discussion

The crystal violet procedure, reported here, is quick, reliable, and yields fine detail; it also stains topographical features such as sensilla, ridges, spines, pits and

setae darker than their background (Fig. 1 A - F and 2 C & D). This technique, for most specimens is a superior alternative to presently available light level microtechniques used to observe arthropods and their structures. A summary of

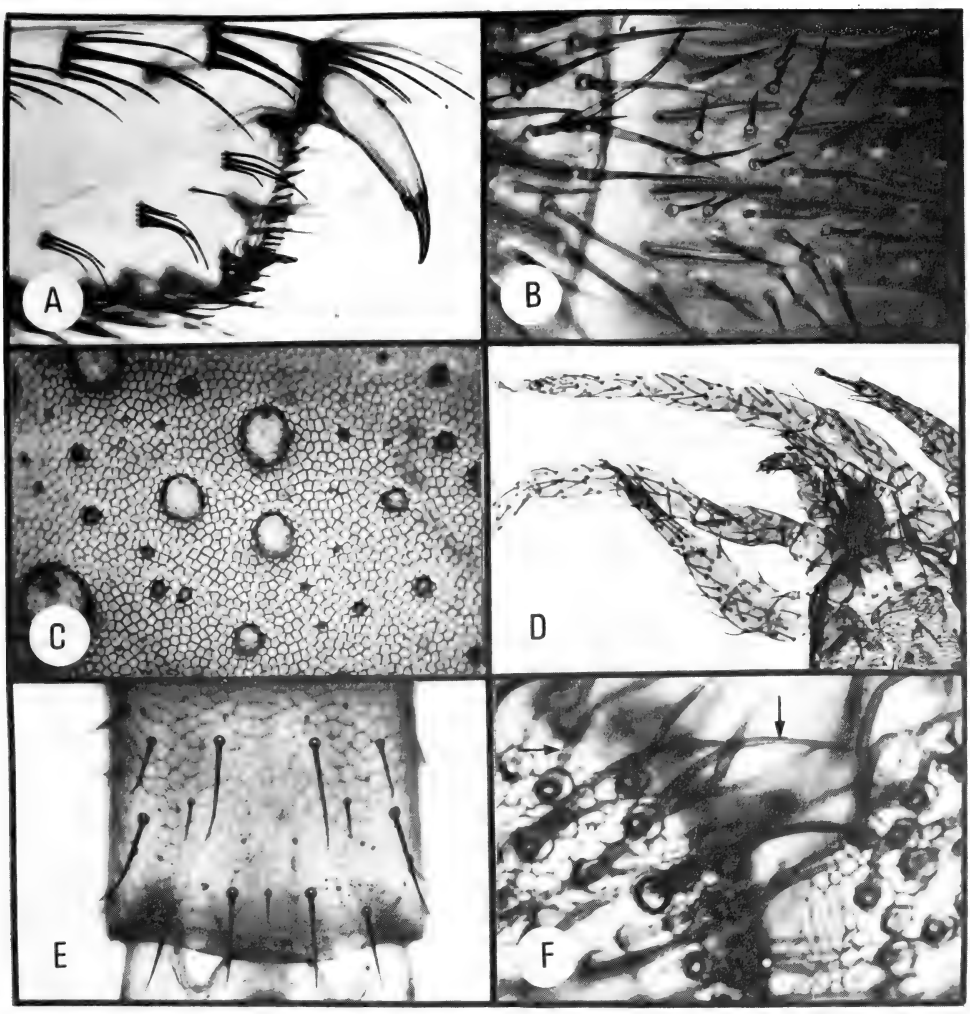

FIG. 1. Examples demonstrating cuticular topography on various arthropods using the hot KOH, bleach and chrystal violet stain technique. A, *Gammarus* sp. (Amphipoda: Crustacea) gnathopod (x 69). B, Ichneumonid wasp (Hymenoptera) antennal sensilla (x 192). C, *Centruroides* sp. (Scorpionida) leg (x 109). D, mesostigmatic mite (Acari) legs (x 67). E, Japygid (Diplura) 8th abdominal tergite (x 206). F, *Grapholitha molesta* (Lepidoptera) antennal sensilla trichodea (arrows), (x 950).

presently used microtechniques for arthropods is provided by Barbosa (1974), Gray (1973), Humason (1979), Galigher & Kozloff (1971), and Pantin (1964).

Due to the wide variation in cuticular thickness, sclerotization and pigmentation among arthropods, exceptions can be found to the procedural advantages and disadvantages pointed out in the following discussions. However, the statements

apply to the representatives of the taxa tested and in all likelihood to similar arthropods.

Commonly used whole mounts (unstained, cleared or bleached and stained) when compared with the crystal violet procedure had several disadvantages. Unstained whole mounts were generally visible on the objective side only, tended to be blurred and revealed only limited surface detail (Fig. 2 A). Although clearing in KOH increased transmitted light, it did not remove pigments and thus produced

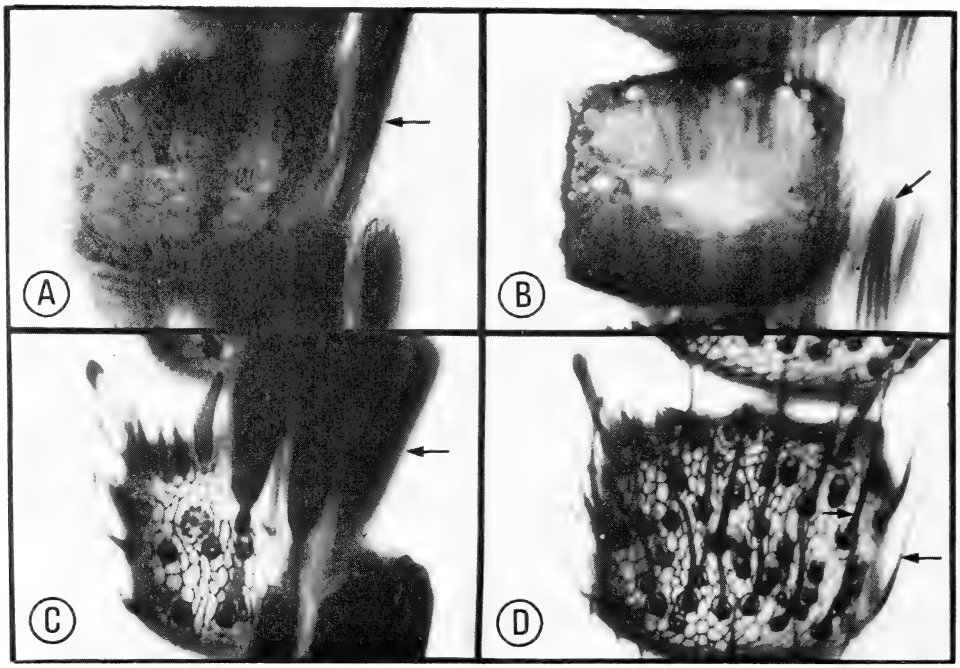

FIG. 2. Examples demonstrating cuticular topography on the antennal flagellum of *Grapholitha molesta* employing different techniques. A, untreated whole mount with scales (arrow) attached (x 740). B, KOH treated, unbleached and unstained with scales (arrow) attached (x 740). C, KOH treated, bleached and stained with scales (arrow) attached (x 740). D, KOH treated, bleached and stained with scales removed. Note the sensilla trichodea (arrows) previously covered by scales are clearly visible (x 740).

hazy results (Fig. 2 B). Furthermore, as can be seen in Fig. 2 B, the sensilla tended to become transparent and indistinct. The use of bleaches to remove pigments, cleared specimens optically, but reduced fine surface detail. By combining clearing, bleaching and the use of crystal violet the disadvantages were reduced or eliminated while stain-related advantages were introduced (Fig. 2 D).

Crystal violet staining is only successful after cuticular chitin is converted to chitosan through hot alkali (KOH) treatment. Unlike chitin, chitosan bonds crystal violet in a reaction similar to Wisselingh's iodine test for chitin (Campbell 1929). The KOH treatment should be monitored and stopped when all internal proteins and fats are hydrolyzed and saponized. Considerable care must be taken to protect skin and eyes from hot KOH. Over-boiling in KOH will result in specimen break-up and/or no stain uptake. Over-treatment with KOH may be a problem with small, weakly tanned insects (e.g. diplurans). To avoid over-treatment, rupture large specimens. For small specimens, make a tiny hole with a

minuten pin, in a non-crucial area, to promote KOH access and reduce treatment time.

Dark pigmented specimens require bleaching prior to staining for clear observation of cuticular topography. Bleaches such as sodium hypochlorite and hydrogen peroxide remove pigments (Barbosa (1974), Galigher & Kozloff (1971), and Gray (1973). As with KOH, over-bleaching results in from poor to no stain uptake. For most insects, and especially for counting sensilla, bleaching was essential. Bleaching reduced stain uptake in the flagellar body and increased stain intensity in the sensilla of most insects (Fig. 1 B, E & F and 2 D) which greatly facilitated counting. When bleaching was omitted, the flagellum stained darker than the sensilla and this made counting them difficult.

Theoretically, the use of crystal violet as a cuticular stain would appear to be questionable since it was commonly used to stain bacteria (Galigher & Kozloff (1971) and Gray (1973) and with insects to indicate the permeability of sensilla (Slifer 1960). However, arthropod structures treated with hot KOH, such as a crustacean gnathopod (Fig. 1 A), insects antennae (Fig. 1 B & F and 2 C & D), scorpion leg (Fig. 1 C), entire mesostigmatic mites (Fig. 1 D) and dipluran tergal plates (Fig. 1 E) stained exceptionally well with crystal violet. The advantage of the crystal violet procedure was further enhanced by the relative lack of other cuticular stains. Of the thousands of available histological stains only a few reliably stain cuticle. These are borax carmine, particularly Grenacher's alcoholic, chlorazyl black E, and in some special cases acid fuchsin.

Grenacher's borax carmine, as described by Galigher & Kozloff (1971), when compared with crystal violet has the disadvantage of being a long procedure requiring several days. Moreover, it stained weakly and revealed little fine detail. Chlorazyl black E, although a rapid method, failed to stain thin cuticular projections such as sensilla, ridges, and setae, thus making it of little use.

Optimal results were obtained using a .01% solution of crystal violet. The use of higher concentrations resulted in stain precipitation, which gave specimens a dirty appearance and reduced visual observation, while low concentrations failed to stain. To prevent over-staining of small specimens, the staining process had to be observed under a dissecting microscope. To ensure visibility, a small petri dish was filled with stain to a height not exceeding 2 mm. Extremely small specimens (e.g. mites) were stained within a drop on a glass slide.

Taxonomists and morphologists often require accurate and reliable dimensions of various structures. To ensure that the vigorous treatment of specimens during KOH treatment had no effect on structures or size, treated material was compared with untreated. Small delicate sensilla were chosen due to their potential succeptibility to deformation and/or shrinkage as compared to larger and thicker cuticular structures. Multivariate analysis of measurements along with a Hotelling T square test showed no significant differences (Table I).

Most lepidopteran antennae are covered with scales which often hide important structures such as sensilla (Fig. 2 A, B, & C). Scale removal by sonification as suggested by Percy (Pers. Comm.) resulted in incomplete scale removal or damage. The use of adhesives also proved inadequate, especially for small insects. The procedure described here removed all scales completly without removal of sensilla (Fig. 2 D). It was important to monitor boiling to ensure that the antennae tumbled up and down the beaker wall by the bubbling. Varying beaker sizes and KOH volumes failed to give consistent results. Use of larger beakers resulted in failure to the antennae to be thrown up the beaker wall while smaller beakers tended to boil over.

TABLE. I. Comparison of sensillum trichodea length, basal width and tip width measurements of untreated and treated antennae of *Grapholitha molesta* (Busck).

Sensillum trichodea dimensions	Means untreated[a] (n = 10)	Means treated[b] (n = 20)	Multivariate analysis α Value	Significance
Length	31.98 μm	32.28 μm	.60	N.S.
Basal width	1.62 μm	1.55 μm	.33	N.S.
Tip width	.41 μm	.45 μm	.15	N.S.
Hotelling T square			$\alpha =$ .50	N.S.

[a] Whole mount.
[b] Hot KOH using modification for antennal scale removal, bleach and crystal violet stain.

As demonstrated in Fig. 1, this technique is ideally suited to show cuticular surface structures. The most promising applications appear to be 1) the study of sensilla, and 2) mite chaetotaxy.

The study of sensilla is often made difficult by small size, sensillar transparency and/or obstruction by scales (Fig. 2 A, B & C). The procedure reported here eliminated or reduced these problems (Fig. 2 D). Furthermore, the ease with which similar sensilla could be distinguished and counted greatly increased the reliability of results and speeded up the identification process.

The technique reported here has already been adopted by Dr. A. D. Tomlin, Canada Agriculture Pesticide Ecology Group, due to the superior quality of preparations for mite chaetotaxy. The treatment of various difficult to key mites has simplified identification and enabled the observation of surface structures and details previously unnoticed with Normarsky optics (Tomlin, pers. comm.). Excellent contrast and resolution, even at 1,000 X, may in certain cases permit the use of this technique as a cheap alternative to scanning electron microscopy.

A disadvantage of this crystal violet procedure is that it is not suitable for permanent slides since it fades with time. In the case of valuable specimens, the cover slip can be lifted after observation, the specimen washed and stored in 80% alcohol. When further observations are required it can quickly and easily be restained and mounted.

The advantages are 1) speed and ease of use, 2) clear observability with only brightfield LM, 3) through focusing with minimum distortion, 4) adjustability to suit a wide range of specimens, 5) does not alter structure and size 6) requirement of only a few chemicals, 7) highlights cuticular projections, 8) gives reliable results, and 9) stains a wide range of arthropods.

Hence, the technique reported here clearly reveals cuticular topography better and easier than methods previously employed on the members of the taxa listed. Furthermore, the technique appears ideally suited for 1) identification of very small arthropods, 2) mite chaetotaxy, and 3) the survey, measurement and counting of sensilla.

Acknowledgments

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III. SCIENTIFIC NOTES

FIRST RECORD OF THE CEREAL STEM MOTH, *OCHSENHEIMERIA VACCULELLA*, (LEPIDOPTERA: OCHSENHEIMERIIDAE) IN CANADA

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Ochsenheimeria vacculella F. Von Roesslerstamm was collected for the first time in Canada in 1978. The species was collected as larvae at Cayuga, Ontario in early June, reared to the adult stage (Fig. 1) and identified by Dr. A. Matuura,

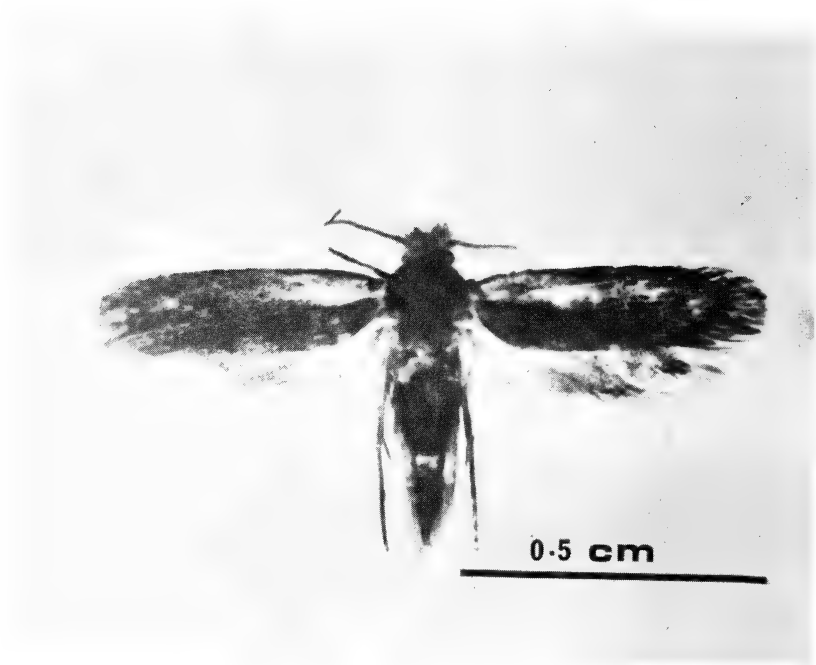

Fig. 1. Adult of *Ochsenheimeria vacculella*.

Biosystematics Research Institute, Ottawa. *O. vacculella* is a Eurasian species that became established in Ohio State some time before 1964 and has also been reported from Pennsylvania and New York States (Davis 1975).

The pest was first seen at Cayuga by extension personnel as part of a pest problem in a field of bluegrass being grown for seed production. The larvae were

present in the stems in low numbers and, along with thrips, contributed to a moderate incidence of 'silver-top' in one field of bluegrass. On 12 June, the larvae were nearly mature and were collected by sweeping the grass with a 38 cm net *(ca.* 0.5 larvae/sweep). None was found in the stems at this time but larvae were collected 8 km away in a hay field indicating that the species was well established.

As the common name indicates, the cereal stem moth, as well as attacking a number of species of grasses, is a potential threat to cereals. However, the only North American reference is by Davis (1975) who reports the early collections, describes the species and outlines the known biology. Recent personal communications (Drs. J. K. Flessel of Ohio, A. A. Hower, Jr. of Pennsylvania and R. G. Helgesen of New York State) have located no report of economic injury.

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MICROSPORIDIAN PARASITES OF *ARCHIPS CERASIVORANUS* (FITCH) IN THE DISTRICT OF ALGOMA, ONTARIO

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Abstract

Examination of specimens of the ugly-nest caterpillar, *Archips cerasivoranus* (Fitch) revealed the presence of three species of microsporidia, *Nosema cerasivoranae* Thomson, *Pleistophora* and *Thelohania* sp. Incidence, spores sizes of these species, and possible relationships to microsporidia in the spruce budworm, *Choristoneura fumiferana* (Clem.) are reported.

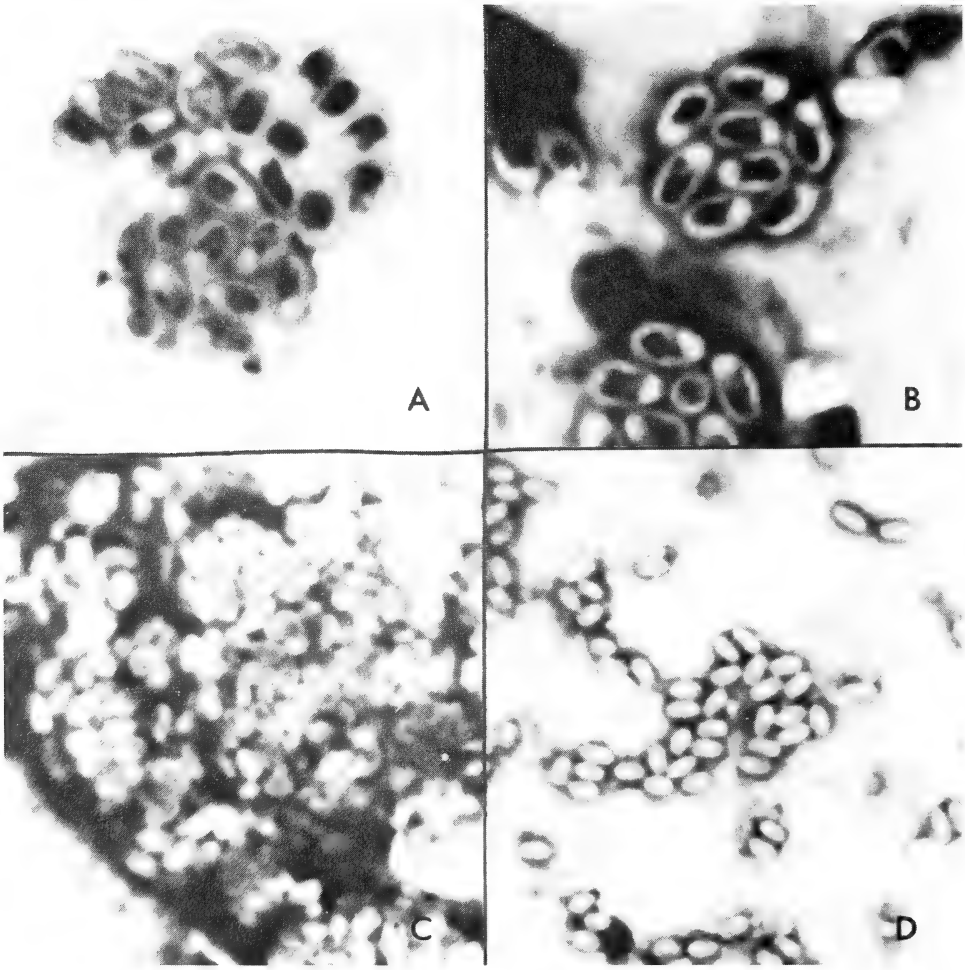

FIG. 1. Stages of a *Pleistophora* sp. and *Thelohania* sp. from *Archips cerasivoranus*. X2300. Fixed in methanol, stained with Giemsa solution. A, Spores and sporoblast of *Thelohania* sp.; B, Spore of *Thelohania* sp. in groups of eight; C, Pansporoblast of *Pleistophora* sp.; D, Spores of *Pleistophora* sp.

A microsporidian parasite in the ugly-nest caterpillar, *Archips cerasivoranus* (Fitch) was first described in detail by Thomson (1960). Based on the observation that only one spore was formed from each sporont he placed the parasite in the genus *Nosema* and proposed the name *N. cerasivoranae.* Smirnoff (1965) reported the occurrence of a *Pleistophora* sp. of microsporidia occurring in the same insect.

Collections of A. *cerasivoranus* from various locations in the District of Algoma, Ontario during the summers of 1978-79 revealed the presence of three species of microsporidia, each usually occurring individually in the larvae. Tissue smears from the infected larvae were air-dried, fixed in absolute methanol, and stained with Giemsa. The dimension of the spores was measured using an ocular micrometer. Examination of the stained smears revealed the presence of *N. cerasivoranae, Thelohania* sp. (Fig. 1, A, B) and a *Pleistophora* sp. (Fig. 1, C. D). All infections had advanced to a late state and few vegetative stages were present. Furthermore, identification of the infected tissues was difficult.

Sporonts of the *Thelohania* sp. contained eight nuclei and eventually produced eight sporoblasts (Fig. 1, A). Measurements of 50 fixed and stained spores of this species averaged 2.5 x 4.3μ with ranges of 2.1-3.4 x 3.8-5.1μ. Sporonts of the *Pleistophora* sp. resulted in a large and variable number of spores (Fig. 1, C). Measurements of 50 fixed and stained spores of the *Pleistophora* sp. averaged 1.6 x 2.2μ with ranges of 1.2-1.7 x 1.7-2.9μ.

Examination of 128 specimens of *A. cerasivoranus* in 1978 indicated that 35.9% were infected with *Pleistophora* and 2.3% with *Thelohania.* In 1979 28% were infected with *N. cerasivoranae,* 3% with *Pleistophora* and 22% were infected with both. No *Thelohania* was detected in 1979.

Smirnoff (1965) reported that larvae of the spruce budworm, *Choristoneura fumiferana,* were highly susceptible to the *Pleistophora* sp. Wilson (1975) reported the occurrence of a *Thelohania* and *Pleistophora* sp. in the spruce budworm, with mean spore dimensions of 2.4 x 4.3μ (range 1.9-3.0 x 3.8-4.8μ) and 1.4 x 2.4μ (range 1.2-1.7 x 1.9-2.7μ) respectively. Although there is a slight difference in mean spore sizes it is probable that the *Thelohania* and *Pleistophora* sp. occurring in *A. cerasivoranus* are the same as those in the spruce budworm. The *Pleistophora* sp. in the spruce budworm has subsequently been determined to be *P. schubergi* (Weiser 1961 and pers. comm.).

References

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IV. INDEX

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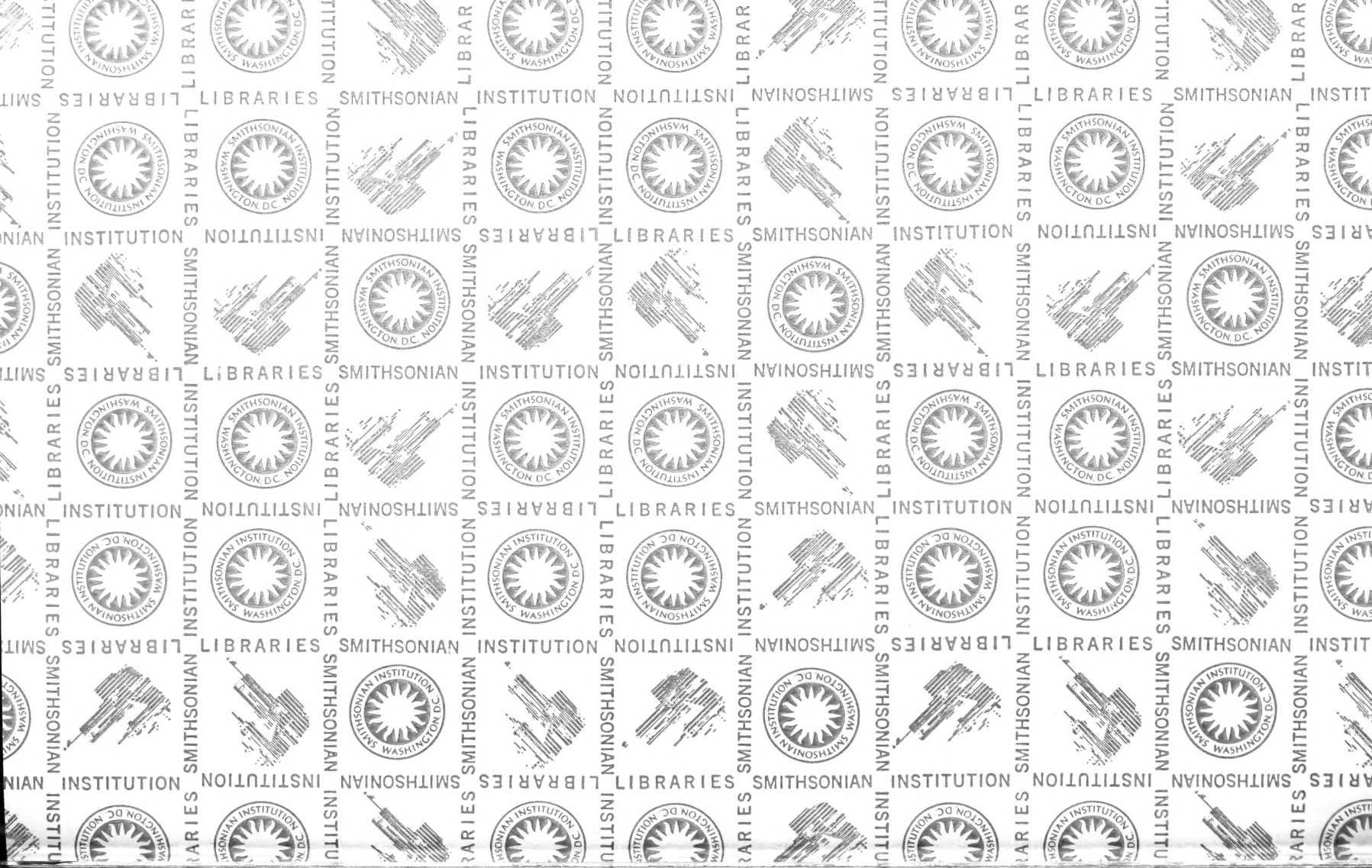
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