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ALBANY, N. Y.

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NEW YORK STATE MUSEUM

CHARLES C. ADAMS, *Director*

1 MOSQUITOES AND WILD LIFE AS INTER-RELATED PROBLEMS IN HUMAN ECOLOGY

BY ROBERT D. GLASGOW Ph.D., *State Entomologist*
New York State Museum

2 A PRELIMINARY REPORT ON THE SALT MARSH VEGETATION OF LONG ISLAND, NEW YORK

BY NORMAN TAYLOR, *Temporary Botanist*
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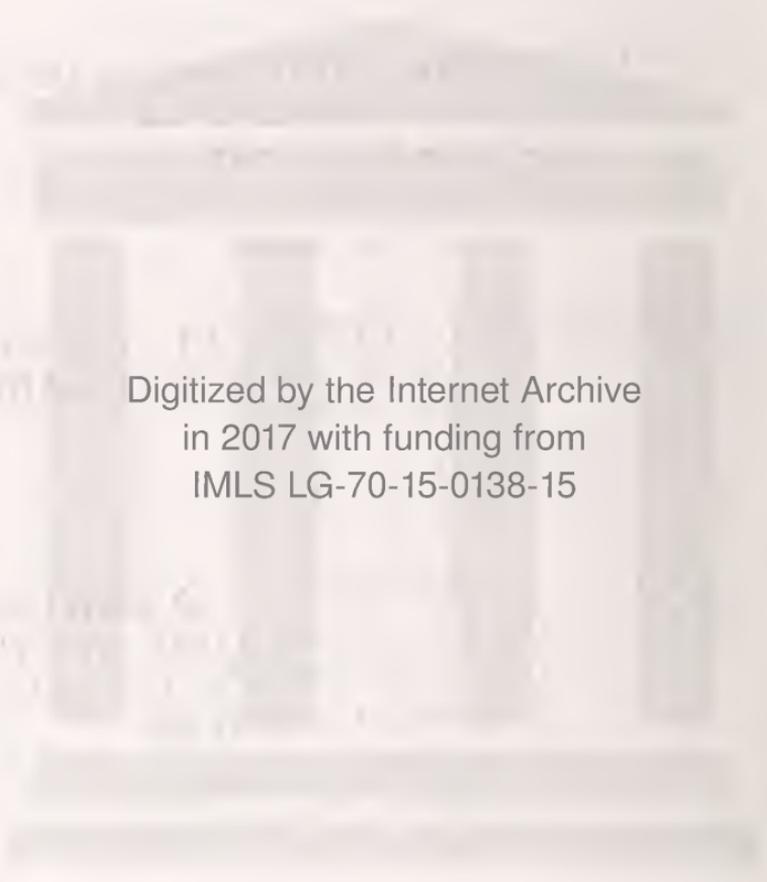
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INTRODUCTION

Mosquito control and wild life conservation, with the interactions of which the series of studies here introduced will be concerned, are two among many new activities developed by the present generation of modern man. Most of these new activities, including both mosquito control and wild life conservation, have not yet become fully adjusted to each other nor to the general pattern of human

affairs; and the rectification of such maladjustments is a prolific source of human problems.

But who shall decide, and how, when important public interests appear to conflict one with another, or with arrogant opinion or long-established custom? This ever-recurring question, as old as man himself and always fraught with discord, has attended every turn of history and confronted every forward move that man has made.

From the standpoint of human benefit the suppression of mosquitoes is an object of manifest importance, as is also the conservation of our sadly depleted wild life; but the contention that these two individually desirable ends may be in part mutually exclusive—that the suppression of mosquitoes must necessarily destroy or dispossess associated forms of wild life, or that functionally adequate wild life preserves with mosquitoes suppressed would be quite impracticable—has been a source of much unprofitable controversy. This controversy has delayed important public improvements in New York and elsewhere; and our age-old question has assumed another of its protean forms.

The problem here, as usual, has been complicated by blind partisanship and selfish interest, where a sound solution may be found only through ordered scientific study.

But this particular problem is not a simple one. It concerns other special fields of human activity which, like mosquito control and wild life conservation, are also recent products of the complex and rapidly changing intraspecies ecology of modern man. Here, as often happens with conflicting objectives in overlapping fields of human interest, each objective has merit not only from the standpoint of the group supporting it, but also from that of public benefit as well. The best solution, therefore, is likely to be not one that is enforced by the strongest group, but rather one that is arrived at by agreement, through a mutual examination of the general background, of the problem itself, of the special interests concerned and of the relation of all these to the ever-shifting pattern of human activities.

Still, who shall decide, and how? Will the procedure follow the usual course of human behavior and lead to a stalemate that is merely a resultant of partisan strength, or can the disciplined intelligence of the groups concerned find and have accepted a really sound solution in harmony with the ecologic forces that will inevitably shape the final course, however men might wish to plan it otherwise.

EMERGENCE OF THE PROBLEM

When it was decided that the unemployment situation of the early 1930's should be met in part by a work relief program, mosquito control work was immediately approved as a particularly suitable form of work relief activity. For mosquito control work would contribute to human comfort and to the protection of human health and human life, and in so doing would tend at the same time to increase property values; thus, the work would be useful beyond question. It could be done very largely by common labor with hand tools, and in such a manner that 95 per cent or more of the total cost would go into actual relief pay rolls. It would not displace nor compete with any existing or immediately prospective normal employment.

ANTECEDENT MOSQUITO CONTROL WORK

Earlier mosquito control work had usually been local; but such work had been organized and maintained for many years in several states, more commonly as county or municipal units, and both with and without state aid. In the North Atlantic states mosquito control work had been supported by generous appropriations as sound public policy, in a considerable number of the more populous counties in northern and central New Jersey; on Long Island, New York; and in Connecticut. Many of these counties, as a part of their depression-budget economies, had reduced their appropriations for mosquito control work. Some had reduced this item as much as 50 per cent, and a few had provided only for holding together a skeleton staff of their most experienced workers.

RELIEF FUNDS FOR MOSQUITO CONTROL WORK

Many counties with their mosquito control budgets reduced accepted the work relief program as a windfall, and promptly set up mosquito control work relief projects. These projects usually were designed not only to provide for the completion of current work schedules, but also to provide for doing at once work that might have been spread over several years if dependent even upon normal county appropriations. Other, less populous counties in which mosquito control work had never been provided for, also set up mosquito control work relief projects in the hope that they could afford to provide annually for maintenance if the (for them) prohibitive first cost could be met from relief funds.

While the earlier trend under the local emergency work bureaus of the Temporary Emergency Relief Administration had been principally toward doing with relief labor the contemplated future work of local projects, there came late in 1933 what may in some quarters have seemed an almost explosive expansion of such work. This phase of mosquito control work relief came as a part of the Civil Works Administration which ran its brief course between December 1, 1933, and February 14, 1934. Included in the general Civil Works Administration program were a nationwide malaria control program sponsored by the United States Public Health Service, and a nationwide pest mosquito control program sponsored by the United States Department of Agriculture through its Bureau of Entomology.

To provide for the first ten weeks of the nationwide C. W. A. pest mosquito control program, an allotment of approximately \$4,000,000 was made, of which the sum of \$400,000 was reallocated for work to be done in the State of New York outside the New York City Metropolitan Area. In this State the United States Bureau of Entomology worked in collaboration with the Division of Science and State Museum of the New York State Education Department, the federal program being directed by Dr F. C. Bishopp, Principal Entomologist in Charge, Division of Insects Affecting Man and Animals, who appointed the writer director of the work in New York.

When the Civil Works Administration concluded its activities, most of its mosquito control projects, including those started before December 1933, were continued under the Temporary Emergency Relief Administration until they were taken over in some states, notably in Delaware and New Jersey, by the Civilian Conservation Corps, and in other states by the Works Progress Administration.

CONTROL PROGRAM QUESTIONED

The amounts provided for the mosquito control program of the Civil Works Administration were not large in comparison with subsequent allotments for this and related work, and the Civil Works Administration itself was discontinued at the conclusion of the ten weeks provided for in its first appropriation; yet it was made the occasion for launching in the name of wild life conservation, an organized protest against the continued extension of mosquito control work. This protest was prompted by fear that unnecessary harm to the wild life habitats might result from hastily organized or inadequately supervised mosquito control work.

The issues thus joined present a highly complex problem, the ramifications of which touch many fields of human interest. In this problem mosquito control and wild life conservation are fundamental objectives, each of a specific and independently organized activity of the human community, and are relatively incidental to the other human interests concerned.

THE MOSQUITO PROBLEM

Mosquitoes are universally known and detested because of the annoyance they cause. The female (only) has mouth parts adapted for piercing the skin of animals and sucking blood; and a female mosquito apparently must have a meal of blood before she can mature and deposit a batch of eggs.

PEST MOSQUITOES

The females of all species of mosquitoes feed on the blood of terrestrial vertebrates. A few of the rarer forms take only the blood of cold-blooded vertebrates (reptiles and amphibians); but most mosquitoes feed on the blood of birds and mammals including man. These last are appropriately called pest mosquitoes.

SOME PEST MOSQUITOES CARRIERS OF DISEASE

Associated with the specialized type of host-parasite relation that exists between vertebrates and mosquitoes, a few disease-producing organisms have come each to require both a mosquito host and a vertebrate host to complete its life cycle. Usually a particular mosquito species appears to be required by, or best suited to, the causative agent of each such mosquito-borne disease.

Many mosquito-borne diseases can not in nature pass directly from mosquito to mosquito nor from man to man or vertebrate host to vertebrate host; for in this group of diseases the causative agents, though belonging to unrelated groups, appear usually to have in their complete life cycle two developmental stages, one of which can be passed only in a mosquito host and the other only in a vertebrate host. With this obligate alternation of hosts in the developmental cycle of a mosquito-borne disease, the causative agent can pass only from vertebrate host to mosquito host, and from mosquito host to vertebrate host; and only after an interval characteristic of its development in either host can the causative agent pass from that host to the next.

Notable among the mosquito-borne diseases are: (1) the human malarías, (2) yellow fever of man, (3) dengue or "breakbone fever" of man, (4) filariasis of man, (5) "heartworm" of dogs and other Canidae; (6) the bird malarías; (7) filariases of birds. A general discussion of mosquito-borne diseases and their place in the biological complex with which our immediate problem is concerned will be deferred until another time; here it is enough to point out the fact that so far as known, mosquito-borne diseases would vanish in the absence of appropriate mosquito carriers.

The carriers of mosquito-borne diseases of man and of other animals are, according to the disease concerned, some one or another of the ordinary pest mosquitoes; so control measures that will effectually suppress pest mosquitoes will at the same time arrest or prevent the dissemination of mosquito-borne diseases.

PERTINENT MOSQUITO HABITS

All mosquitoes develop in quiet water, usually in some sheltered place where the larval food of the species concerned is likely to occur. The egg-laying habits of the major groups differ widely. (1) In the genus *Culex*, to which the common house mosquito belongs, the eggs are deposited on the surface of the water in boat-shaped masses. (2) In the genus *Anopheles*, which includes the carriers of human malaria, the eggs are buoyant, and are deposited singly on the surface of the water. (3) In the genus *Aedes*, which includes the carrier of yellow fever, the eggs are deposited singly, and usually upon moist earth in depressions that have held water, and which if undisturbed will be filled again with the water required for larval development. The eggs of some species may hatch promptly, or within 48 hours in warm weather. The eggs of other species, as of some *Aedes*, may lie unhatched over winter, and even then may not all hatch when first submerged or may persist unhatched for more than a year. Although aquatic in all of the life stages but the adult, the larvae and pupae of most mosquito species must have atmospheric air which they secure at the surface of the water. The exceptions to these very general statements do not materially concern our immediate problem.

Different mosquito species differ widely in their habitat preferences. Some of these differences are suggested by their common names, such as those of the common "house" or "rain barrel" mosquito, the "tree hole" mosquito, the "woodland pool" mosquito, the "swamp" mosquito, the "salt marsh" mosquito and others.

MOSQUITO CONTROL

Mosquito control procedures may differ widely, not only in relation to the habits of different mosquito species, but also according to the special requirements of individual problems. These problems themselves fall into two general groups: (1) upland problems, or problems concerned with the control of mosquitoes that develop in fresh water; (2) salt marsh problems, or problems concerned chiefly with the control of mosquitoes that develop in the brackish water of tidal marshes and the like.

CONTROL PROCEDURES

When even the informed layman thinks of mosquito control work, he is likely to visualize the draining of swamps or the application of oil to the surface of mosquito-breeding waters. Such measures have their place in the armament of mosquito control workers; but they may be wholly unsuited to many situations.

DRAINING AND FILLING

Draining and filling are alternative procedures equally effective for the suppression of mosquitoes, because either will permanently remove the environmental conditions necessary for the developmental stages of these insects; but this will be accomplished at the cost of destroying or dispossessing associated plant and animal life, and this cost should be taken into account in choosing the control measures to be used.

The term "draining," however, must not be confused with the very different purpose and effect of the specialized ditching procedure employed for the suppression of salt marsh mosquitoes.

OIL AND LARVICIDE

The application of a suitable oil to the surface of mosquito-breeding water is a thoroughly effective control measure if properly carried out; but it is a temporary measure to be repeated at frequent intervals and is relatively expensive on this account, and it is objectionable also because it may be harmful to vegetation, to fish, to birds and to other forms of animal life that share the mosquito habitat. For these reasons, oil is now employed only in special cases, or as a supplementary, emergency procedure; and even then a special pyrethrum larvicide recently developed by Ginsberg in New Jersey that is apparently harmless to vegetation, to fish or to birds is preferable to oil.

BIOLOGICAL CONTROL

Where preservation of the aquatic habitat is desired, minor modifications may be employed that will shift the biological balance sufficiently to exclude mosquitoes. Mosquitoes develop in sheltered, vegetation-clogged, shallow water at the margins of streams, ponds and swamps. In open water the larvae or "wigglers" are quickly destroyed by top feeding minnows and other natural enemies. The development of these insects, therefore, may be prevented by suitable modification of mosquito-breeding shallow margins, and by building up the population of mosquito-eating fish by stocking or otherwise.

With favorable topography, a mosquito breeding swamp may sometimes be converted into open water by a dam; but here again, the habitat will not be the same, and the community of animals and plants will be changed in some degree.

SALT MARSH DITCHING

Another form of biological, or, better, of ecological control is presented by the specialized type of ditching employed for the control of salt marsh mosquitoes. Drainage in the usual sense is neither intended, nor even possible; unless in the special cases where (and it must be for some very good reason on account of the cost) the procedure is supplemented by the addition of dikes and tide-gates. The ebb and flow of the tides is naturally unchanged; but development of mosquitoes on the salt marsh is discouraged both by providing readier access to the marsh for the "wiggler" eating killifish, and by hastening the outflow of tidal waters from the marsh sufficiently to prevent any fish-free water standing long enough for the mosquito larvae to reach the pupal stage.

On the high salt marsh, however, the situation is more complicated; and many special problems there may require careful study.

ECONOMIC LIMITATIONS

In general, the control of mosquitoes is subject to definite economic limitations. Such work is necessarily a community problem, because the flight range of the insects would usually make individual action largely futile. To keep a given area free from mosquitoes, it is necessary to prevent development of the insects not only within the area itself, but also within a surrounding protective zone of sufficient extent to exclude any but the most exceptional migrations of the insects. The nature and extent of such protective zones will be governed by a combination of factors grouped about the mosquito

species to be excluded; and will usually balance somewhere between the rapidly mounting cost of a wider zone and local ability and willingness to pay for still more complete protection from this type of annoyance. In any case, extensive mosquito control operations are economically practicable only where populations and property values can support the cost.

UPLAND CONTROL AN URBAN PROBLEM

In rural districts much improvement may often be accomplished with moderate effort, by mosquito control work about individual farmsteads; but, except where malaria is endemic, upland mosquito control operations of sufficient magnitude to be of interest from the standpoint of wild life conservation will usually be limited to urban areas where human welfare will inevitably take precedence over any other consideration. Even here, however, mosquito control work and any special wild life problems may be mutually adjusted by sympathetic study and cooperation.

SALT MARSH CONTROL INEVITABLE

The control of salt marsh mosquitoes is perhaps the most urgent among pest mosquito control problems in the North Atlantic states, and is a source of great anxiety to those concerned with the conservation of wild life. The salt marsh mosquitoes include the malaria-carrying *Anopheles crucians*, and the notorious, so-called "Jersey" mosquito, *Aedes sollicitans*, which is said by Headlee to migrate as far as 40 miles from the nearest breeding place.

Commerce and industry have brought huge masses of humanity together in seaport towns and cities with popular seaside residential and recreational developments interspersed, so that few great salt marsh areas are not within troublesome flight range of considerable human populations. As a consequence, popular demand for the general suppression of salt marsh mosquitoes over large areas is rapidly becoming irresistible, and its early accomplishment was probably assured, even if work relief funds had not been used to hasten it.

WILD LIFE CONSERVATION

The virgin forests of America were unsurpassed, and early American writers describe an almost unbelievable abundance of game birds and other forms of wild life; but conservation is born of scarcity, not of abundance.

HAMPERING PIONEER CONCEPTIONS

The American pioneer was hampered by the immeasurable abundance of many things about him. To the pioneer farmer the forest was an encumbrance on the land, to be removed at heavy cost in physical exertion; and many game animals destroyed crops. Such men could have no comprehension of conservation; and opinions and customs shaped by their experience still persist. Until a few years ago, the ruling idea in both popular opinion and public policy in America, an inheritance from pioneer days, was that our natural resources were inexhaustible and that their exploitation by anyone would contribute to the general welfare. The natural consequence of this fallacy has been shameful public indifference to waste that now seems criminal.

DIMINISHED HABITATS LIMIT WILD LIFE

Wild life has been ravaged by wholesale slaughter; but even more decisively harmful has been the destruction of wild life habitats. With forests felled, swamps drained and prairies plowed, vast areas once possessed by wild life have been lost beyond recovery as wild life habitats. In a favorable environment a decimated population can easily restore its numbers; but with its former imperial domain reduced to scattered fragments, even without the toll that has been taken by predatory man, wild life's once teeming myriads must still have shrunk to near present-day proportions for lack of habitats for larger numbers.

SELECTIVITY OF INDUCED ENVIRONMENTAL CHANGE

Those now charged with responsibility for the conservation and restoration of our wild life resources are keenly aware of the critical importance for these objectives of preserving the already meager wild life habitats from unnecessary further shrinkage. It is quite natural and fit, therefore, that they should question whether a procedure like mosquito control that depends for its effectiveness upon rendering a special environment no longer suited to one of its normal inhabitants, may not at the same time render the environment in some degree less well suited to associated forms.

NEED OF PLANNED COORDINATION

Mosquito control and wild life conservation have largely been developed, each without reference to the other, as if they were wholly unrelated interests. Beyond occasional unprofitable contro-

versy, little serious thought seems to have been given to their general interactions, or to their better adjustment to each other and to other human interests. This situation, however, is equally characteristic of many other recently developed activities of man, and is a logical consequence of the unsettled state of current human ecology.

With increasing knowledge, growing populations and multiplying interests and activities, modern man has undergone a rapid differentiation of social and economic groups and group functions that parallels in some degree the vastly slower differentiation of species through organic evolution. Just as plant and animal species of diverse origin may when brought together be ecologically ill adjusted, so human groups and their specialized activities that have arisen in response to uncoordinated demands, may likewise be mutually ill adjusted. The nearing saturation point in the development of many special fields of human interest has begun to bring group interests into conflict. The interactions and readjustments among these groups now constitute an important phase of the increasingly complex intra-species interactions of modern man, and it is of these readjusting interactions that our major problem is a part.

OBJECTIVES OF MOSQUITO CONTROL WORK

Perhaps nothing can illustrate better than the control of mosquitoes, both man's conquest of ancient terrors and how recent have been some of his advances in knowledge and in related power to control formerly unknown factors in his own environment. Until twoscore years ago, even medical men still thought malaria was caused by a "miasma" of infectious particles floating in the air exhaled from swamps; and that yellow fever was transmitted by "fomites," or by clothing, bedding and other articles that had been used by or had been otherwise in contact with a yellow-fever patient. It was not until 1898 that Ross found a mosquito to be the alternate host and thus the carrier of a malaria of birds; a discovery that was quickly extended to demonstrate that *Anophele* mosquitoes likewise are carriers of human malaria. It was not until 1901 that Ross and his associates Carroll, Lazear and Agramonte found yellow fever apparently to be carried only by a single species of mosquito.

Following these discoveries, measures for the control of mosquitoes were developed which quickly brought about the suppression of yellow fever in Havana, Cuba, in New Orleans and elsewhere, and made it possible for America to build the Panama Canal after the French had failed for lack of just such knowledge. Effective

measures for the control of salt marsh, and other pest mosquitoes were also developed; but prior to the past four or five years at the earliest, the areas upon which practical use of these measures had been made were relatively so insignificant both in total size and in distribution that, in the judgment of most biologists, legitimate mosquito control operations could not possibly have been a factor of any consequence in bringing about the present continent-wide depletion of so many of our wild life species.

There does remain, however, a legitimate question whether and in what degree present or future mosquito control procedures of any kind may prove harmful, indifferent or helpful in their relation to measures employed for the conservation and restoration of our critically depleted wild life species. And in our rapidly increasing series of wild life preserves, even if mosquito-borne diseases of wild life are disregarded, at least those near urban and residential areas, or within flight range of important mountain or seaside recreation areas must provide for the control of mosquitoes as a protection to human health and human comfort, and possibly also to human life; and means of doing this must be found that will be least harmful to their primary purpose.

This is not a matter of choice, either with mosquito control workers or with wild life protectors. It is simply one of the trends in human ecology that neither group could turn aside if it would.

Mosquito control work was employed first for the protection of human health and human life through the suppression of disease-carrying mosquitoes. Later, this objective was extended to include the general suppression of pest mosquitoes, which serves the double purpose of promoting human comfort and checking mosquito-borne disease if present or preventing its introduction. Developed before man had become conservation conscious, the relation of mosquito control to wild life was largely overlooked.

RELATED OBJECTIVES OF WILD LIFE CONSERVATION

As it relates to the control of mosquitoes, wild life conservation is interested chiefly with the preservation of the special habitats concerned.

Swamp and tidal salt marsh are such special habitats, each of relatively small area in the aggregate, and each the home of many animals and plants that can live nowhere else.

Drainage of a swamp will merge it with the surrounding upland, and make a now much-needed special type of habitat that is already

small, still smaller; while the addition to the general upland habitat is relatively insignificant. Such drainage is usually for agricultural purposes, even though it may sometimes masquerade as mosquito control. Legitimate upland mosquito control work of any consequence, however, will usually be confined to urban and immediately adjacent areas, where wild life will be a secondary consideration and the work of minor concern to wild life conservation.

The tidal salt marsh areas are of special significance as resting and feeding, and sometimes also as breeding places for migratory waterfowl. This limited special habitat is already being rapidly and extensively destroyed by hydraulic fill and otherwise for urban, residential, recreational and industrial use. Preservation unimpaired of adequate salt marsh areas suitably placed is important for the welfare of the characteristic animals and particularly the birds of the salt marsh environment.

It is important, therefore, to know whether the various mosquito control procedures employed on the salt marsh are the best that can be found, and in any case, to find as speedily as possible just what their effect may be.

Here is a group of problems that can be solved only by careful scientific study; not by partisan dispute.

COMPREHENSIVE PLANNING NEEDED

Many still remaining wild life habitats and particularly many salt marsh areas, will shortly be obliterated by human interests that are advancing as blindly and relentlessly as the tides. It is useless to oppose this advance directly. Anything that can be done must be done through carefully considered long-time planning, and through studies of probable future trends in the extension of man's activities. Instead of spending energy and resources in fighting a futile rear-guard action in defense of obviously doomed habitats, more of permanent value can be accomplished by striving to bring about provision for an adequate series of permanent wild life preserves and for their proper administration and supervision.

Sound planning must be based not on theory, but only on knowledge gained from scientific study of the problems to be solved.

COORDINATED STUDIES

In New York City are located the national headquarters of many organizations of naturalists, of sportsmen and of other groups interested in conservation. As a consequence, New York is a focal point

for conservation activities of many kinds; and it is not surprising that opposition to the extension of mosquito control work should have taken form in this State, either first, or very early in the course of its development.

COOPERATION OF INTERESTED GROUPS

When this growing opposition became apparent, representatives of federal, state, local and private groups concerned with mosquito control work or with wild life conservation were asked to collaborate in a study of the problem. Through a series of conferences and field inspection trips in New York City and on Long Island, a tentative understanding was arranged concerning mosquito control work in this State.

Further provision was made for a coordinated series of investigations to be planned jointly and from time to time to be reviewed by representatives of all the interested groups. These investigations will be carried on as resources and opportunity permit, by participating federal, state and private agencies. Studies in this series are now being carried on, notably by the United States Biological Survey, by the United States Bureau of Entomology and by various public and private agencies in several states.

THE GENERAL PROGRAM

The two reports that follow in this bulletin are based upon a part of the contribution that is being made by the New York State Museum to the general program. Other studies are in progress, and a comprehensive survey of the entire field as far as it is represented in New York is planned.

Practical difficulties relating to the expenditure of public funds, to publication and the like have made it seem best for each participant to work independently on his part of the program, and for each to publish as he may and be individually responsible for his own results and conclusions. Then from time to time as published reports accumulate, representatives of interested groups may meet to review, digest and summarize such additions to our knowledge of the problem, and in collaboration to plan further work and any necessary readjustments of wild life conservation and mosquito control procedures.

A PRELIMINARY REPORT ON THE SALT MARSH VEGETATION OF LONG ISLAND, NEW YORK

BY NORMAN TAYLOR

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CHARACTER AND DISTRIBUTION OF LONG ISLAND SALT MARSHES

HISTORICAL AND DESCRIPTIVE

Ever since the Dutch landed at Gravesend the salt marshes have been objects of interest, fear, cupidity, and recently, of much con-

trovery. Quite naturally, the Hollanders cast nostalgic eyes at them and soon began thinking of schemes for diking what they supposed were the fertile flat acres which then and still fringe the shores of Jamaica bay. As one old chronicle has it, the marshes "appealed to the Dutch eye with fonder association than the hills and dales of Manhattan. Nieuw Amersfoodt included the salt marshes along Jamaica bay, where efforts at dyking were already made, on Y'Beeren Eylandt (Barren Island), then much larger than now, and overgrown with cedars."

That effort came to nothing as have all similar ones. In a country with boundless opportunity and every variety of soils, there was little use in rescuing these vast tracts from the clutches of the sea. Three hundred years later immense areas of them have been reclaimed, not for agriculture, but to provide summer homes, and often permanent ones, for the ever-increasing population that is forced from New York to the country.

This successful colonization along the edges of the marshes has been made possible only because modern engineering and the entomologists have found a way to control, if not entirely eliminate the curse of these watery flats—the salt marsh mosquito.

Long before this utilization of the upper edges of the marshes, others had cast practical eyes at their utilization in a very different way. In 1848 there was organized, with an impressive list of directors, and a charter from Albany, the "Long Island Canal and Navigation Company." They submitted to the Legislature a "Report on the project of uniting the Great Bays of Long Island by canals, from Coney Island to Bridgehampton." This document, issued at Brooklyn in 1848, makes interesting reading in view of the present traffic of pleasure boats from New York to Canoe place and thence to Peconic bay. The modern channels, cut through miles of salt marshes, have accomplished what the old company could not, and the boating public now passes free through what would have been a toll canal.

Quite different has been the appeal of the marshes to those who see in them a place where land and sea meet, and Nature spreads a thin sheet of vegetation that is unique. There is the brilliant emerald green of the salt meadow grass, the grayish sheen of spike grass, and the much darker patches of black grass. Each holds sway over huge tracts, and nearer to the sea all give way to the sturdy and much coarser salt marsh grass. While, as we shall see presently, these

STATIONS FOR LONG ISLAND SALT MARSH STUDIES

By Norman Taylor - 1936

- Stations where test pits were dug and records kept in them and in mosquito ditches.
- Salt marshes visited and notes on vegetation made, but no pits dug or regular records kept.

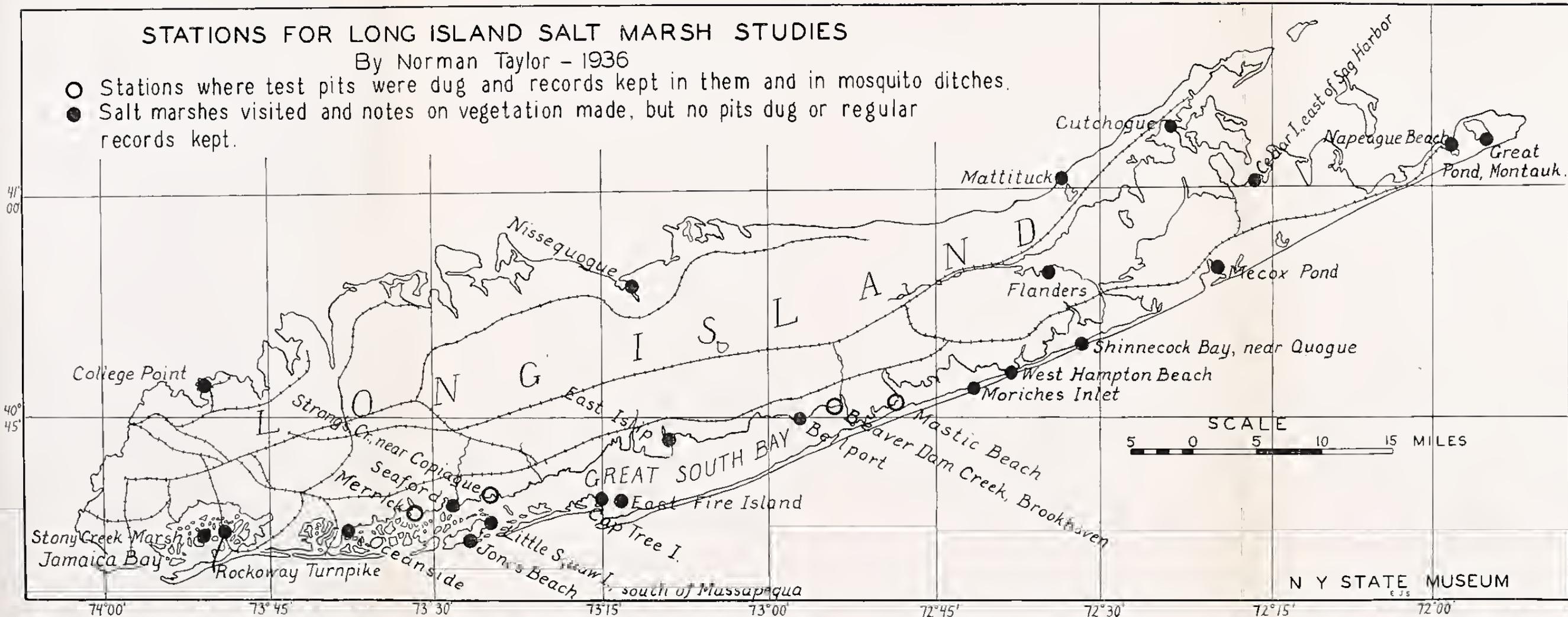


FIGURE 1 Stations for Long Island salt marsh studies

plants make the marshes, there are other and much more showy denizens of these tidal flats.

Cut by innumerable creeks, this panorama of greenery has caught the fancy of some and the fear of others. Sidney Lanier saw them for what they are when he wrote:

"Ye marshes, how candid and simple and nothing-withholding and free,
Ye publish yourselves to the sky and offer yourselves to the sea.
Tolerant plains, that suffer the sea and the rains and the sun. . .

Less poetic and sometimes quite superstitious persons think they are dangerous, full of quagmires, and harbor all sorts of nocturnal terrors. But poets and botanists know better, each having tramped miles over the marshes, often in water half way to one's knees. Only the "rotten spots," to be discussed later, will let one through the stiff, well-nigh impenetrable turf. And at high tide, in sunshine, the marshes have a beauty which Lanier knew how to express better than the botanist:

The creeks overflow; a thousand rivulets run
Twixt the roots and the sod; the blades of the marsh-grass stir;
Passeth a hurrying sound of wings that westward whirr:
Passeth, and all is still; and the currents cease to run;
And the sea and the marsh are one.

EXTENT OF LONG ISLAND MARSHES

There are thousands of acres of salt marshes on Long Island, but by far the greatest area of them fringe the southern shore of Nassau county. The latter claims more than 19,000 acres of marsh, while Suffolk county has far less. There is, in fact, a progressive reduction of the marshes as one goes eastward, and for the sake of the record and for the bearing which this reduction has on their origin, it is well to relate here the chief facts regarding the extent and location of the salt marshes of the island.

The marshes behind Coney island have been so much disturbed by filling and building operations that they scarcely present a problem of any interest to the ecologist. In Jamaica bay, however, there is still a very large area, fringing the mainland, covered with undisturbed marshes. In addition there are several large islands, notably Ruffle bar, Duck point and especially Stony Creek marsh. The latter, according to local tradition, has remained in an essentially undisturbed state for many years, perhaps since the advent of the Dutch. At the present time it is covered almost exclusively with salt marsh grass (*Spartina alterniflora glabra*), which here grows luxuriantly, although the whole island is covered by six to eight inches of water at every

high tide. Scarcely a single other plant is found on this island except an occasional and very rare glasswort (*Salicornia europaea*). There is practically no salt meadow grass (*Spartina patens*), which seems unable to stand daily submergence. There are many other marshes like it (see figure 2).

By far the greatest concentration of marshes on the island occurs immediately west of the neck of upland which extends from Hewlett to Far Rockaway. The western fringe of this upland carries the same salt marsh vegetation as that of Jamaica bay, but eastward the conditions are very different. While there is much open water in Jamaica bay, in the region between the mainland and the barrier beaches, stretching from the Rockaway peninsula to a line approximately south of Massapequa, the amount of open water is negligible. On the ground the place appears like an impenetrable mass of marshes, but actually, as the map discloses, it is a series of innumerable salt marsh creeks which extend up into the edge of the mainland and also divide the innumerable large and small salt marsh islands which congest the bay. The navigable channels in this area are so intricate and the rest of the bay is so shallow that long familiarity is necessary to make a safe passage through this area.

From Massapequa to a line stretching from Bay Shore to the end of Oak Island beach the marshes decrease greatly in size and there is correspondingly much more open, although still shallow water. More marshes are found on the inner side of the barrier beach than abutting the mainland, there being a considerable number of salt marsh islands, like Cedar island, which either touch the barrier beach or are near it.

From Fire Island inlet to the eastern extremity of Shinnecock bay the marshes become less and less extensive, being confined on the mainland to the areas around the discharge of the larger streams. Two of the largest areas of this character are found at the mouth of the Connetquot river near Great river, and near the mouth of Carmans river. There are scattered and much smaller marshes eastward, notably at Mastic, East Moriches and near Westhampton Beach. The inner side of the barrier beach from Fire Island inlet to Southampton has only occasional and rather small areas of salt marsh, although a considerable amount of marsh was destroyed at the site of what is now the new inlet at Moriches which broke through in March 1931.

Continuing eastward, the salt marsh areas become still less, although there are some at Montauk and along the shores of Gardiners bay



FIGURE 2 Salt marshes at Fleetwood, Cutchogue. These are flooded twice daily and mostly covered with salt marsh grass (*Spartina alterniflora glabra*).



FIGURE 3 Field equipment for salinity records. Leaning against the rucksack a 500-cc beaker, the hydrometer inside it; and at the left the thermometer. In the background the marsh elder (*Iva oraria*).

and Peconic bay, but in the latter, even at the mouth of such a large stream as the Peconic river, the areas of marsh are not very extensive, nor are they at New Suffolk, Cutchogue or Orient (figure 2).

The marshes facing Long Island sound along the north shore are still smaller than any so far noted and have not, generally speaking, come within the range of this study; this partly because of the fact of the excellent work of Johnson and York upon the marshes at Cold Spring Harbor, and also because of the very different tidal conditions which exist along the sound as compared to the tides of the south shore. For the completion of the record, however, it is well to note that small and, in some cases, extremely interesting marshes occur at Mattituck, Wading River, Mount Sinai, Stony Brook, Nissequogue, Sunken Meadow, Cold Spring Harbor, at the head of Hempstead harbor, at the head of Little Neck bay, and at the head of Flushing bay, an area now filled in for the World's Fair site. These marshes throughout the north shore are nearly always at the mouth of streams and they are subject to tides of very considerable magnitude, especially those toward the western end of the island.

Returning to the marshes on which most of this effort has been expended, namely those along the south shore of Nassau and Suffolk counties, there naturally arises the question as to why the nearly continuous marsh area in the bay should stop close to the Suffolk county line, becoming relatively scattered eastward. This brings us to the question of how the marshes originated. Most competent observers are convinced that the marshes have grown upon material deposited at the mouth of the innumerable streams and rivers which flow into the bay from the northward. The discharge from these rivers at the present time, and possibly in the past, varies of course with the depth of the water and the amount of it. The studies made many years ago upon the Underground Water Resources of Long Island by A. C. Veatch and others contain what may be an explanation of this distribution of the marshes.

All of the streams which flow into Jamaica bay and into the area from the Rockaway peninsula to about Massapequa originate in small ponds or fresh-water marshes, none of which are more than three or four miles from tidewater. They are sluggish; their discharge, even in freshets, is not very extensive, and it may well be that these relatively weak streams have deposited the material upon which the marshes now grow. The figures, too long to quote here, show that all the streams in the area under discussion, except possibly East Meadowbrook, Wantagh and Massapequa creeks, are in the category of streams that discharge very little water. Compared to 20 or 30

small streams, these three are the only ones of any considerable discharge.

Quite a different state of affairs occurs in Suffolk county beginning with Carll's river at Babylon, the Connetquot river near Great river, Carmans river, and, of course, the Peconic river, the largest stream on Long Island. All of these streams carry vastly more water than most of those in Nassau county and while marshes are found near the mouth of all of them, neither they nor the other streams in their area appear to have created the conditions favorable for the extensive development of salt marsh vegetation.

The difference in the extent of the marshes as between Nassau and Suffolk counties may also, however, be due to the very different conditions that obtain in the tidewater impinging on these shores. This feature of the study will be considered in detail under the section about Tidewater and Fresh Water.

THE UNDERLYING MINERAL SOIL

Most of the marshes immediately adjacent to the upland show from the many pits dug in them that the salt marsh turf varies from two to three feet in depth and is underlain by the mineral soil. According to the Soil Survey of Long Island by Jay A. Bonsteel, this mineral soil is, generally speaking, that which has been mapped as Galveston sandy loam. The material dug up from the test pits made during this study, while not identified as this, consists of approximately 90 per cent sand and 10 per cent coarse sand and fine gravel.

The marshes contiguous to the barrier beaches usually have turf about half the depth of those along the mainland and in all the places so far observed appear to be underlain by dune sand.

ECONOMIC STATUS

Except for the cutting of salt hay the marshes have little or no agricultural value. Nearly all the harvest is made up of salt meadow grass (*Spartina patens*) and black grass (*Juncus gerardi*), the former species being much the more common. Most of the salt hay is used for packing china, and for mulching gardens and cold frames; but in the past there are records of the use of salt meadow grass (*Spartina patens*) as a minor cattle food.

The marshes today have far greater value as residential sites than as a source of salt hay. Their use as sites for houses has come within the past 20 years and is based upon two things.

The first of these is the modern dredging and pumping machinery which permits the construction of reasonably deep water channels,

some of which start at the bay and end at the upland. The sand and gravel pumped from such sites, commonly and in this report, called hydraulic fill, is forced out over the area adjoining such dug channels and ultimately forms home sites. Thousands of acres of what was once marsh is now covered with hydraulic fill, which is almost at once captured by ditch reed (*Phragmites communis*), of which much will be said later (see figure 12).

Such areas would be nearly useless for home sites if the salt marsh mosquito were as common today as it was 20 years ago. But this very ancient curse of Long Island is now well under control due to the millions of feet of mosquito control ditches dug by the Nassau County Mosquito Extermination Commission, and more recently by a similar commission in Suffolk county.

Such ditching does not absolutely destroy all mosquitoes, but it has so reduced their numbers that in many miles of walking over the marshes during the past summer mosquito bites were so rare as to cause comment.

This combination of the utilization of hydraulic fill as home sites and the reduction to livable conditions of the mosquito nuisance has added more economic value to the marshes in the past 25 years than all the crops of salt hay cut since the settlement of the island early in the seventeenth century. It is this greatly increased economic value which has, of course, dictated the extensive ditching of the marshes. And upon any reasonable appraisal of human needs the work of mosquito control far outweighs any of the reported injury to the marshes which some assume has come as the result of that ditching. This will be dealt with in greater detail in its proper place.

The economic value of the marshes can be summarized, then, as primarily their utilization as home sites when the pressure of population becomes acute as it already is in Nassau county; secondarily, as a source of salt hay; and if there is still another category of usefulness, it is their utilization by various forms of wild life.

It is commonly said of the latter that this phase of the salt marshes is purely an ecological problem to be settled only by the experts. But broadly considered, the marshes may best be viewed as the site of two phases of ecology. On the one hand is the purely human ecology of the people living along their edges or upon hydraulic fill, as exemplified on any summer day by thousands of families enjoying boating, bathing, fishing, or even gardening upon what was mosquito-infested and essentially uninhabitable land only a few years ago. On the other hand, the greatest area of the marshes is still untouched and presents problems of great interest both to the animal and plant

ecologist. This report will hereafter deal with the latter phase of the salt marshes, but it is to be understood that it is of academic rather than practical interest and for this reason the results of this study should always be weighed against human rather than strictly scientific needs.

FACTORS LIMITING THE SALT MARSH VEGETATION

THE TIDES

The salt marsh vegetation being predicated upon the presence of salt water, a study of the incidence and range of the tides on Long Island became necessary not only for this work, but because they apparently explain some of the factors which control the distribution of the marshes. For all the region from Southampton to Coney island the government tide records at Sandy Hook were used as a basis. For the extreme eastern end of the island, including Peconic bay, Montauk and Gardiners bay, the reference station for the tides is the one which the Government maintains at New London, Conn. Unfortunately, scarcely any of the area occupied by the marshes has exactly the same tidal range as Sandy Hook, but the Coast and Geodetic Survey has provided a table with corrections for all of the stations within the area of this study.

The accompanying tables show that during June, July, August and September the night tides vary from a low of 3.6 to 6 feet above mean low water, while the day tides are, generally speaking, considerably lower than this, especially in June and July. The extreme range between dead low water and flood tide in the open ocean at Sandy Hook may thus be nearly six feet at spring tides and only about three feet at neap tides. Inside the barrier beaches the volume of the tides is greatly influenced by the number and effectiveness of the inlets to the open ocean. In the western part of the island extremely active inlets occur at the western end of Rockaway beach, at Long beach, Jones inlet at Jones beach, and the largest of all of them, the Fire Island inlet. From Fire Island inlet eastward there is no break in the barrier beach except the new one opposite Moriches. The effect of this relatively continuous barrier beach is to reduce greatly the height of the tides within the bays, and this is especially significant as one goes eastward through the Great South bay and its continuations.

Throughout the area of the greatest salt marsh concentration the daily tidal range, even granting the reduction that comes from the barrier beach, varies from 2 to 3.4 feet at ordinary tides and from

4.2 to 5.4 feet at spring tides. In other words, the amount of water moved twice daily throughout the tidal creeks of Nassau county, especially toward the western end of it, is very large. From about Bay Shore or Babylon eastward throughout the range of the Great South bay and its continuations the daily tidal range varies only from .6 to .7 of a foot at ordinary tides to .7 to 1.0 foot at spring tides.

As we shall see later, this comparatively minor fluctuation of the tides at the eastern end of the island has a marked effect on the salinity of the water in the Great South bay and its continuations eastward. While this has no doubt been affected in recent years by the breaking through of the Moriches inlet, it is still true that the amount of tidewater entering the eastern end of Great South bay and its continuations is much less than that entering the bays of Nassau county where the concentration of the marshes is the greatest.

Contrary to usual statements, the tides do not normally rise so high in the winter months as they do in the growing season. The Coast and Geodetic Survey's Tide Tables, Atlantic Ocean, 1936 show that during January to May 31st there were only 12 days when the high tides reached a height of 5.7 feet above mean low water. And in the fall months of October, November and December there were also 11 days when it reached that height or above. October is the month of the highest tides during 1936, when for seven days of the month the high tide did not fall below 5.8 feet above mean low water. The record for the months outside the growing season is as follows:

TABLE I

Critical or high tides (that is, 5.6 feet above mean low water or higher) during the winter or nongrowing season

DATE	FEET ABOVE MEAN LOW WATER	DATE	FEET ABOVE MEAN LOW WATER
January.....	None	October 1.....	6.1
February.....	None	2.....	6.2
March 23.....	5.8	3.....	6.0
24.....	5.8	4.....	5.8
April 19.....	5.7	29.....	5.9
20.....	6.0	30.....	6.1
21.....	6.1	31.....	6.1
22.....	6.0	November 1.....	5.9
23.....	5.8	27.....	5.7
May 18.....	5.8	28.....	5.8
19.....	6.1	29.....	5.8
20.....	6.1	December.....	None
21.....	6.0		
22.....	5.8		

Thus during eight months there were only 23 days when the tide was 5.7 feet above mean low water, or more, and coming during the period of complete or partial dormancy they are doubtless of less significance than they would be when vegetation is active.

During the active growing season (June 1st to October 1st) there were also 23 days when high tides rose to 5.7 feet above mean low water or more. Unlike the winter tides, all of these summer highs come at night or at least in late afternoon.

The record:

TABLE 2

The high tides, growing season, June 1—October 1, 1936, night tides only (only those rising to 5.7 feet or more)

DATE	FEET ABOVE MEAN LOW WATER
June 16.....	5.8
17.....	5.9
18.....	6.0
19.....	5.9
20.....	5.7
July 4.....	5.7
5.....	5.7
6.....	5.7
16.....	5.7
17.....	5.8
18.....	5.7
August 1.....	5.7
2.....	5.9
3.....	6.0
4.....	5.9
5.....	5.7
30.....	5.7
31.....	5.9
September 1.....	6.0
2.....	5.9
3.....	5.7
29.....	5.7
30.....	5.8

While it is true that during 23 days which came in the growing season of 1936 these spring tides rose far above the normal level, they never touched any of the marsh surface except that covered by salt marsh grass (*Spartina alterniflora glabra*) and by mixtures of salt marsh grass (*Spartina alterniflora glabra*) and salt meadow grass (*Spartina patens*).

As the figures show, the same condition applies during the winter months, but tidal trash found far up on the marshes and even up to the edge of the upland shows that when winter storms happen to coincide with spring tides the whole marsh must be covered by many inches of water. Rather constant observations of the marshes, both during the night and day, reveal the fact that that never happened during the growing season of 1936, not even during the peak tides which came during the first few days of September.

SEA WATER

The source of all salt water affecting the marshes is, of course, the sea, and a series of readings were made upon the degree of salinity and temperature of the sea water during the summer.

The readings show that the water of the Atlantic near the shore is slightly lower in salt content than in the open ocean. All the records in the table below were taken just outside the surf and at various stages of the tide.

TABLE 3

Specific gravity and temperature of ocean water, Long Island, 1936

DATE	PLACE	STATE OF TIDE	TEMPERATURE	SPECIFIC GRAVITY
July 3.....	Jones beach.....	High.....	69° F.	1.0220
July 8.....	Jones beach.....	Half low.....	67° F.	1.0225
July 20.....	Jones beach.....	Half high.....	69° F.	1.0220
July 28.....	Montauk.....	Low.....	66° F.	1.0215
Aug. 2.....	Bridgehampton.....	High.....	69° F.	1.0225
Aug. 4.....	Moriches inlet.....	High.....	74° F.	1.0210
Aug. 20.....	Jones beach.....	Low.....	75° F.	1.0220
Aug. 31.....	Moriches inlet.....	Half high.....	72° F.	1.0210
Sept. 1.....	Jones beach.....	High.....	71° F.	1.0225
Sept. 5.....	Jones beach.....	High.....	68° F.	1.0225
Sept. 10.....	Jones beach.....	High.....	72° F.	1.0225
Sept. 13.....	Moriches inlet.....	Low.....	73° F.	1.0220
Sept. 14.....	Jones beach.....	Half low.....	66° F.	1.0220

The highest record of specific gravity is 1.0225, which is considerably below the average for the open Atlantic. Whether this is due to seepage of fresh water into the sea is not certainly known but appears likely as there are fresh water wells all along the barrier beaches of Long Island.

At every one of the numerous breaks in these barrier beaches the sea is carried twice daily directly into the bays and often far up the

tidal creeks. But as we shall see presently, the loss of specific gravity is very considerable and differs greatly in various parts of the island.

Before considering this dilution of sea water as it enters the marshes, it is perhaps necessary to record the methods used in making the tests.

SALINITY

There are several methods of testing the salt content of sea water. Before explaining the methods used here, it is well to record the fact that while sodium chloride (common salt) is the chief ingredient, there are others. A fairly typical analysis of sea water shows the following:

Sodium chloride	78%
Magnesium salts	15-16%
Calcium salts	4%
Others	1-2%

It is usually assumed, and has been in this report, that the proportion of common salt (sodium chloride) in sea water is the determining factor in the distribution of salt tolerant plants such as those in the marshes. And a quick and easy method of determining this salt content was necessary in view of the hundreds of tests to be made under all sorts of field conditions.

All chemical methods were discarded because of the difficulty of carrying the necessary apparatus, and also because they often disclose minor differences in salt content that are without significance to the plants, and greatly complicate the keeping of records.

Much the simplest and most direct method of determining the salinity of sea water is to test it with a hydrometer, and this method was adopted for this study (figure 3). All readings throughout the report have been reduced to 15° C., which is almost exactly 60° F.

For those who choose to translate the hydrometer readings of specific gravity into actual sodium chloride percentages, the following table is appended. It was supplied by the Massachusetts Institute of Technology with the specifications for the hydrometer used in these studies.

TABLE 4
Specific gravity and sodium chloride concentration

SPECIFIC GRAVITY	PER CENT OF SODIUM CHLORIDE
I.000.....	.000
I.002.....	.269
I.004.....	.532
I.005.....	.800
I.007.....	1.056
I.009.....	1.320
I.011.....	1.584
I.013.....	1.848
I.015.....	2.112
I.017.....	2.376
I.019.....	2.640
I.021.....	2.908
I.023.....	3.168

These figures for specific gravity cover the whole range from fresh water to the highest salt content found along the ocean shore of Long Island during the summer of 1936. Many upland fresh water streams were found to be at or near the first figure, while sea water came just under the last figure. Between them lie all the records taken of salt marsh channels, of the occasional sheet water that floods the marshes, of the water under the marshes, and of many of the open bays towards the eastern end of Great South bay.

Because so many other workers have used specific gravity as a criterion of the salt content of brackish waters it has been adopted in this report. The objections to it are only technical and minor ones, except possibly for waters that have become turbid or muddy.

In order to eliminate this as a factor and make all readings comparable a series of tests was conducted to determine exactly how much correction should be made in readings of turbid waters, both fresh and salty.

The method used was to take a 500-cc beaker of distilled water and another with a solution of salt water testing 1.020, both at 60°. To both of them an equal amount of muck or slime was added as follows:

A solution of as much muck as could be made into a pourable liquid was made from the muck pumped up on one of the marshes.

This muddy solution was then poured into the beakers with the following result:

<i>Distilled water</i>.....I.000 (clear)	<i>Salty water</i>.....I.020 (clear)
Faintly cloudy.....I.001	Faintly cloudy.....I.020
.5 cc muck solution added	.5 cc muck solution added
More cloudy.....I.0015	More cloudy.....I.020
1.0 cc muck solution added	1.0 cc muck solution added
Muddy water.....I.002	Muddy water.....I.021
1.5 cc muck solution added	1.5 cc muck solution added

As the table shows, the amount of difference is slight, far less than the plants growing in such water appear to mind. But to eliminate even this slight error in readings all those from turbid waters have been corrected as though they were from clear. Such readings, in any case, only apply to a few tests; never, of course, coming in question where active tide water is in evidence.

THE BAY

While the records show relatively stable salt content for sea water, the conditions behind the barrier beaches make the salt content of bay water far from uniform. The differences in the figures that follow are no doubt due to the much greater tidal range in western Long Island than is found at the eastern end. The details of this tidal range are shown elsewhere.

To the vegetation of the marshes the significant fact is that its supply of salt water varies widely in the degree of salinity. In other words, the same species of plant may tolerate high salt content near western Long Island, but also grow with even greater luxuriance in far less salty waters toward the eastern end of the island.

This basic difference between the bay waters should be understood before there can be any true understanding of the various tests made in the mosquito ditch waters, those under the marsh, or the sheet water that rarely floods part of the surface of the marshes.

Salinity records kept through most of the summer are separated into two groups, namely, western Long Island and eastern Long Island.

TABLE 5

Salt content of Long Island bay waters, 1936; records of open water along outer edges of the marshes or at lower end of tidal creeks

Western Long Island

	SPECIFIC GRAVITY	
	Average at low water	Average at high water
Merrick.....	1.019	1.021
Strong's creek (near Copiague).....	1.019	1.020
Seaford.....	1.021	1.021
Biltmore shores.....	1.019	1.020
Oceanside.....	1.018	1.020
Jones Beach causeway.....	1.021	1.021

The average salt content of these bay waters is about 1.020 at high tide and a little lower at low tide. But the conditions in the bay waters of eastern Long Island are very different.

TABLE 5—(continued)

Eastern Long Island

	SPECIFIC GRAVITY	
	Average at low water	Average at high water
Bellport.....	1.013	1.015
Beaver Dam creek (Brookhaven).....	1.012	1.016
Mastic beach.....	1.008	1.015
Head of Shinnecock bay.....	1.013	1.016
Mecox bay.....	1.008	1.010
Cutchogue (Peconic bay).....	1.018	1.018
Napeague (Gardiners bay).....	1.019	1.021

The last two localities are nearer the open sea, so far as the origin of their water is concerned, than the first three. The latter are all inside the barrier beach and they show both for high and low tides a large reduction of salt as compared with the waters of western Long Island. What this means to the salt marsh vegetation will be dealt with in that section of this report.

SUMMARY OF WATERS THAT AFFECT THE SALT MARSHES

The basic conditions of the waters affecting the salt marshes of Long Island may well be summarized thus:

1 There is a greater volume of tide water at the western end of the island than at the eastern end, and the amount of salt is considerably greater at the western end than at the eastern.

2 The figures for these differences are:

	<i>Average specific gravity</i>
Ocean water of Long Island.....	1.022
Bay waters of western Long Island.....	1.020
Bay waters of eastern Long Island.....	1.015

The figures for bay waters are based on averages taken at many high tides. Those taken at or near ebb tide show considerably less salt in the water due to dilution from fresh water streams and seepage from fresh water springs which are found all over the area both under the marshes and in the bays. This feature of the problem will be treated in the detailed studies of the marsh vegetation in another section of the report.

THE SALT MARSH VEGETATION

SALT MARSH PLANTS

We can safely leave to the textbooks the old question of whether salt marsh plants grow in such places because they like them or because they must. As we find it today, the vegetation of the marshes may be looked upon as a highly specialized plant society, far more salt tolerant than ordinary plants. Their roots are in direct touch with waters of varying degrees of saltiness, and some salt marsh plants are far more tolerant of salt than others.

On Long Island there are perhaps 50 to 60 species of salt marsh plants, but as many of them are rare and local or of little significance in creating the all but impenetrable turf which makes up the bulk of the marshes, only the significant plants in this process will be considered here.

Of the latter there are about 25 species, but four of them are far more important than the others. For it is these four species which make up nine-tenths of the area of all Long Island marshes. Their way of life, and especially their tolerance of salt are thus of prime importance in any right understanding of the problems of salt marsh vegetation.



FIGURE 4 Salt marsh grass (*Spartina alterniflora glabra*) at Mastic, showing its failure to invade mud banks and deep water of tidal creek. Tide about half in



FIGURE 5 The same grass at Great pond, Montauk, becoming established on a shingle beach, and far more luxuriant than when growing in the closed association of the marshes

In order of salt tolerance these four plants are as follows:

1 **Salt marsh grass** (*Spartina alterniflora glabra*). This is the tallest, coarsest and most salt tolerant of all salt marsh plants found on Long Island. It grows normally along the outer, seaward edges of the marsh, usually in places that are flooded twice daily at all spring high tides, and often at every high tide except the lowest ones occurring at periods of neap tides.

The vegetative fitness of salt marsh grass for such an environment is very obvious. Its coarse, thick and leathery leaves are admirably suited to a deficiency of assimilable water, for it must not be forgotten that it lives in a physiologically dry habitat and thus exhibits all the common characteristics of plants with a deficient water supply. This in spite of the fact that it is twice daily bathed in salt water, most of which it tolerates rather than uses.

Its salt tolerance appears to be just great enough so that it excludes the encroachment of other plants of the marshes that are less tolerant of salt than salt marsh grass. Furthermore, it makes such an impenetrable turf that digging in it is next to impossible. Its mass of coarse, wiry and extremely tough roots must be chopped rather than dug, especially the upper ten inches of it.

Competition between individual plants of salt marsh grass within the area occupied by it well illustrates one feature of its response to the highly specialized conditions under which it grows. Wherever salt marsh grass makes an exclusive growth of turf it rarely reaches a height of two feet and scarcely ever flowers, but along the edges of ditches and creeks, where crowding is less severe, the plant often reaches a height of four to five feet and always flowers.

In its ordinary environment it is subjected to water with a specific gravity varying from 1.018 to 1.022, the usual figure being about 1.019. The danger of assuming that it "likes" such salt concentration as this is well illustrated by what the plant occasionally does in areas far less salty than this.

After nearly a whole summer's observation of its habit of growth in its usual environment, it came as a surprise to find salt marsh grass growing far more luxuriantly at Mecox (near Bridgehampton), at Montauk (see figure 5) and at the upper end of Seaford creek at Seaford, the water at both places testing, respectively, 1.010 and 1.003. At both places the plant made no turf but large isolated and dense clumps of it were five to seven feet high and flowered profusely. Again, along the shores at the upper end of Great pond at Montauk it was equally profuse. The water here tested 1.020 and the luxur-

iance of the plant was undoubtedly due to lack of competition, that is, dense crowding.

Such facts point clearly to the danger of assuming that this most salt tolerant of all land plants on the marshes really prefers such sites. It is probably more nearly the truth to say that better than any other plant on the marshes it will *stand* such conditions, and stand them so well that practically no other plant ever permanently invades its domain. But if luxuriance and flowering are any criterion of success, the plant shows very clearly what it "prefers" by its behavior in relatively much less salty water than its usual environment.

It is impossible, without detailed mapping of salt marsh grass (*Spartina alterniflora glabra*) in many places, to state definitely how much of the total area of the marsh is occupied by this grass. Wide observation of it on many marshes, and the fact that it is usually confined to areas that are covered by water at most high tides, indicate that it covers only a negligible fraction of the whole area of any marsh—perhaps scarcely one-tenth of 1 per cent of the whole. Its chief interest, then, is not the amount of it, but the fact that, more than any other plant of the marshes, it occupies the areas nearest the influence of sea water. On some salt marsh islands, notably at Stony Creek marsh in Jamaica bay, and at Cutchogue (figure 2) it is practically exclusive. It is also exclusive on many other islands and in other places that are covered with salty water at most high tides.

2 **Salt meadow grass** (*Spartina patens*). This is next in salt tolerance to, and far more important than salt marsh grass. In a perfectly arranged marsh this plant would lie behind the salt marsh grass (*Spartina alterniflora glabra*), because its salt tolerance is less than that plant's. Actually, drainage or trifling differences in grade may permit salt meadow grass to occupy land nearer the bay than salt marsh grass.

Because salt meadow grass is by far the most common grass on the marshes, covering, often exclusively, thousands of acres, its habit of growth and salt tolerance are of prime importance. It is a far finer-textured grass than salt marsh grass, usually grows from 15 to 28 inches high, and flowers profusely, however densely it may be crowded. Its spikelets, which first appear early in July, are very striking with their coppery-red sheen, which soon changes to yellow-green or even straw color. Its root system is much finer than that of salt marsh grass, but just as tough, and it makes an impenetrable turf that is very difficult to cut.

Another feature of salt meadow grass is the peculiar habit of forming "cow-licks." These wind-matted patches of flattened grass vary



FIGURE 6 Salt marsh grass (*Spartina alterniflora glabra*) at Merrick, showing the sharp edge of turf along a small creek, and the holes of fiddler crabs which provide aeration



FIGURE 7 Dense growth of salt meadow grass (*Spartina patens*) at Cedar point, near Sag Harbor, along edges of a salt marsh pool

from a few yards in width to several acres. Some of them are more densely matted than others, and a few play a part in the development of "rotten spots" to be noted presently. Just how these "cow-licks" are started is unknown, but once beaten down, the grass never becomes erect during the current growing season, although it often keeps green and growing, often sending up flowering spikes from the tangled, flattened mass of leaves.

"Cow-licks," at least on Long Island, are practically confined to salt meadow grass (*Spartina patens*), more rarely found in black grass (*Juncus gerardi*), and almost never in spike grass (*Distichlis spicata*). Their comparative frequency in salt meadow grass undoubtedly accounts for the occurrence of other plants throughout the area generally occupied by salt meadow grass.

3 **Black grass** (*Juncus gerardi*). This is undoubtedly the next most prominent plant in making the salt marshes what they are. While occupying many thousands of acres, it is not so extensive as salt meadow grass (*Spartina patens*). The black grass (*Juncus gerardi*) is in reality not a grass at all, but a low, wiry rush with very dark green foliage and tiny fruits that become blackish at maturity. It is apparently next to salt meadow grass in its salt tolerance and is hence usually found toward the upper, that is, landward, stretches of the marshes. It is one of the chief plants cut for salt hay.

4 **Spike grass** (*Distichlis spicata*). This plant is of much less significance, but still of considerable importance. It is a true grass, about half the height of salt meadow grass (*Spartina patens*), and its foliage generally has a whitish color as have the short dense flowering spikes. Its salt tolerance is decidedly varied, often ranging from places that are flooded twice daily to places far up on the marshes that are scarcely ever flooded. The area occupied by spike grass is far less than that covered by salt meadow grass or black grass, its usual habitat being the upper reaches of the marshes, where it occurs in scattered patches from a few square yards to an acre or two. It scarcely ever covers large areas, and of the four chief plants on the marshes it is the least important.

An interesting feature of its occurrence on the marshes is the wide use of this plant in arid areas of the West as an indicator of fresh ground water. It is supposed to be one of the surest indications of available water in these arid plains where little or no question of salt tolerance is involved.

On the salt marshes of Long Island its usual habitat is in that part of the marsh most distant from sea water, and probably most subject

to seepage of fresh waters under the marsh, or to actual contact of fresh or only slightly brackish stream water.

FOUR DOMINANT SPECIES

The four species mentioned above are by far the most important in creating the plant society we know as the salt marshes. Their dense turf, especially of salt marsh grass (*Spartina alterniflora glabra*), the salt meadow grass (*Spartina patens*), and black grass (*Juncus gerardi*), makes encroachment by other species very difficult, and *en masse*, almost impossible, except for a few ephemeral plants to be considered later.

In the case of salt marsh grass, its twice daily flooding results in its tolerating water with a specific gravity of about 1.019, which is certainly its usual habitat.

But the other three plants are in a somewhat peculiar position so far as being flooded with salt water.

Prolonged observation, both during the summer of 1936 and in years past, confirms the fact that the area occupied by salt meadow grass (*Spartina patens*), black grass (*Juncus gerardi*), and spike grass (*Distichlis spicata*) is scarcely ever subject to surface flooding during the growing season, except for brief periods as outlined below.

The area thoroughly in contact with tide water twice daily is overwhelmingly that occupied only by salt marsh grass, very rarely by salt meadow grass, and still more rarely by black grass.

In other words, nine-tenths, and perhaps nineteen-twentieths of the marsh is never touched by tide water unless surface flooding should bring it far above the usual channels.

Detailed observations stretching from June 17 to September 15, 1936, show, however, that the great areas of the marsh occupied by plants other than salt marsh grass were not once flooded by high tides. No surface water flooded these areas, either from day or night tides, although the latter average six to eight inches higher than the day tides, and sometimes more. During this period spring tides occurred four times: June 17th-19th, July 16th-17th, August 7th-8th, and September 3d-4th. The latter was higher than any other, but even these high tides did not succeed in flooding any sizeable area of the marsh not occupied by salt marsh grass. A little salt meadow grass along the edges of some ditches was flooded on the extreme high tide of September 4, 1936, which was by far the highest tide during the growing season of 1936. There was also some flooding of salt meadow grass near creeks during this tide. But at several



FIGURE 8 Cow-lick in salt meadow grass (*Spartina patens*) at Strongs creek, near Copiague



FIGURE 9 Cow-lick in black grass (*Juncus gerardi*) at Strongs creek near Copiague

stations observed during this spring tide only a fraction of the area occupied by salt meadow grass was flooded.

During the growing season, then, we are faced with a "saline" environment which gives no surface indication of salinity, except the plants growing upon it, and tidal trash far up on the marshes. The latter, brought up during winter storms, indicates complete coverage of the surface by salt water, but this may be only once or twice a season, and local baymen report that it does not by any means happen every winter.

Even when winter flooding does come, it occurs when the plants have passed into winter dormancy, and the effects of sea water at such a time can hardly be what they would during the growing season.

THE REAL ENVIRONMENT

We are faced, then, with a profusion of salt marsh vegetation, nine-tenths of which seems to be subjected to a paucity of surface salt water during the growing season. This apparent anomaly, noticed first at Merrick ten years ago, suggested then that we should seek under the marsh for the controlling factors.

With this in mind, 11 pits were dug under significant species, usually down to the mineral soil at the bottom of the marsh, at Merrick, Strongs creek (near Copiague), Beaver Dam creek (Brookhaven) and Mastic. Frequent readings in these pits indicate that the water table under the marsh fluctuates only slightly and that the salinity of these undersurface waters fluctuates scarcely at all.

This undersurface water table does not rise and fall with the daily tides, nor with rainfall or the lack of it (except for a day or two after heavy rains), nor with proximity to creeks, ditches or the bay, except in some pits dug under salt marsh grass (*Spartina alterniflora glabra*), which were flooded at some moderately high tides and by all spring tides. In between such flooding the water quickly assumed its normal level.

RECORDS FROM TEST PITS UNDER DOMINANT PLANTS

The places selected for the test pits were mostly under the four significant species, as found growing in widely separated localities. As the section on tides and salinity shows very plainly, both these vary between eastern and western Long Island. Two of the stations established were in the western third of the island, at Merrick and Strongs creek near Copiague, while Beaver Dam creek near Brookhaven and Mastic beach were chosen to represent the conditions toward the eastern end of the island.

The first set of records shows only the *level* of the underground water beneath the marsh, determined by measuring down from a fixed point on the edge of the pit. No readings were taken until two days after digging the holes so as to allow the water to resume its normal level and to settle the sediment caused by digging.

The water level under the different plants at the four localities is shown in the four tables.

TABLE 6
Level of underground water beneath the marsh at Merrick
DEPTH TO WATER TABLE BELOW THE SURFACE; IN INCHES

	<i>Spartina patens</i>	<i>Spartina alterniflora glabra</i>	<i>Iva oraria</i>
June 21.....	9	6	8½
June 23.....	7	0	8½
June 23 ^a	5½	6¾	7
July 2.....	9½	flooded	10¼
July 23.....	3¾	flooded	5¼
July 25.....	5½	5	6¼
July 25.....	7¾	16¼	6¼
July 25.....	6	10¼	6½
July 27.....	7	6¾	8
July 30.....	6¼	6	7
Aug. 6.....	5½	flooded	5½
Aug. 14.....	7	5¼	7
Aug. 22.....	8½	6¼	4
Aug. 30.....	6¼	3½	5½
Sept. 3.....	8¼	flooded	7½
Sept. 11.....	7½	7	8

^a Bold face indicates high tide. Other records at low or half tide.

TABLE 7
Level of underground water beneath the marsh at Strongs creek
DEPTH TO WATER TABLE BELOW THE SURFACE; IN INCHES

	<i>Spartina patens</i>	<i>Juncus gerardi</i>	<i>Distichlis spicata</i>
July 27.....	9	10	27
July 30.....	3¾	2¾	5½
Aug. 6 ^a	6	4¾	11½
Aug. 14.....	11½	10½	17½
Aug. 22.....	11½	11	15
Aug. 30.....	5¼	4½	11½
Sept. 3.....	8½	7¾	14
Sept. 10.....	13	12½	17

^a Bold face indicates high tide. Other records at low or half tide.



FIGURE 10 Sample of test pits dug in the marshes. This one is at Merrick, through salt meadow grass. The others were dug at various places in the marshes, mostly about 8 inches wide and to the bottom of the marsh.



FIGURE 11 Salt reed grass (*Spartina cynosuroides*) at Strong's creek, near Copiague

TABLE 8

Level of underground water beneath the marsh at Beaver Dam creek
DEPTH TO WATER TABLE BELOW THE SURFACE; IN INCHES

	<i>Spartina patens</i>	<i>Spartina alterniflora glabra</i>
Aug. 11.....	2 $\frac{1}{4}$	3 $\frac{1}{2}$
Aug. 15.....	2 $\frac{3}{4}$	4 $\frac{1}{4}$
Aug. 23.....	4 $\frac{3}{4}$	5 $\frac{1}{2}$
Aug. 31 ^a	1 $\frac{1}{4}$	2
Sept. 10.....	4 $\frac{1}{2}$	5

^a Bold face indicates high tide. Other records at low or half tide.

TABLE 9

Level of underground water beneath the marsh at Mastic
DEPTH TO WATER TABLE BELOW THE SURFACE; IN INCHES

	<i>Spartina patens</i>	<i>Spartina alterniflora glabra</i>	<i>Scirpus robustus</i>
Aug. 4 ^a	6 $\frac{3}{4}$	flooded	6 $\frac{3}{4}$
Aug. 11.....	7	2	6
Aug. 15.....	7 $\frac{3}{4}$	2 $\frac{1}{2}$	7 $\frac{1}{4}$
Aug. 23.....	9 $\frac{1}{2}$	5 $\frac{1}{2}$	8 $\frac{1}{2}$
Aug. 31.....	flooded	flooded	2 $\frac{1}{4}$
Sept. 10.....	9	5	9

^a Bold face indicates high tide. Other records at low or half tide.

NOTE. This marsh was not ditched at the time of taking these records. All other records are from ditched marshes.

It seems difficult to escape the conclusion that this relatively stable underground water is the chief factor in the vegetative stability of the marshes. The variations that do occur are not great and the nature of the spongelike turf is such that capillarity more than overcomes these minor fluctuations of water level.

Under the marsh, therefore, is this fixed, constant supply of water, always available no matter what surface flooding may or may not be in evidence, what the rainfall may be or what the conditions of wind or heat. All the latter are shifting and ephemeral, while the water table stays rather constant.

That the origin of such water is the tides is obvious. But mixed with this underground tidal water there is a variety of other waters from springs, and the seepage from drainage channels or from fresh water streams that are so often "drowned" at all high tides.

In other words, it became apparent that while the *level* of this undersurface water may well be the explanation of the continuity of the marshes as a plant society, it could not of itself explain the distribution of the various dominant species.

It may well be that no *one* factor will explain the segregation of this huge marsh vegetation into its easily recognizable types. The interaction of several factors may possibly be the real answer. But if the *level* of the water seems to be the explanation of the continuity of the vegetation as a whole, the diversity of its component parts may perhaps be due to the varying *degrees of salinity* found in these undersurface waters.

The conditions of surface flooding being essentially nil during the growing season, the question naturally arises: What sort of water is it that appears to be such an effective control of the distribution and extent of the four dominant salt marsh plants? Because salt marsh grass (*Spartina alterniflora glabra*) is in more or less continuously flooded areas, the undersurface salinity of its waters can perhaps be eliminated, particularly as the records of water level show that test pits dug in salt marsh grass are often flooded at high tide.

But for salt meadow grass (*Spartina patens*), black grass (*Juncus gerardi*) and spike grass (*Distichlis spicata*) there is no such flooding. With this in mind, readings of the salinity in all the 11 pits in the foregoing tables were made at the same time as the measurements for water level. Also, because they are often of special interest, similar records were kept for pits dug under salt marsh bulrush (*Scirpus robustus*) and marsh elder (*Iva oraria*).

The records of salinity of these pits were as follows:

TABLE 10
Specific gravity of water in test holes at Merrick

	<i>Spartina patens</i>	<i>Spartina alterni- flora glabra</i>	<i>Iva oraria</i>
July 27.....	1.018	1.021	1.0215
July 30.....	1.017	1.021	1.021
Aug. 6 ^a	1.018	flooded	1.0205
Aug. 14.....	1.017	1.017	1.0205
Aug. 22.....	1.018	1.020	1.020
Aug. 30.....	1.017	1.020	1.020
Sept. 3.....	1.018	1.022	1.022
Sept. 11.....	1.021	1.023	1.022

^a Bold face indicates high tide. All other records at low or half tide.

TABLE II
Specific gravity of water in test holes at Strongs creek

	<i>Spartina patens</i>	<i>Juncus gerardi</i>	<i>Distichlis spicata</i>
July 27.....	1.008	1.0105	1.0105
July 30.....	1.0055	1.0065	1.006
Aug. 6 ^a	1.006	1.008	1.007
Aug. 14.....	1.007	1.010	1.010
Aug. 22.....	1.008	1.010	1.010
Aug. 30.....	1.007	1.010	1.008
Sept. 3.....	1.007	1.010	1.009
Sept. 10.....	1.008	1.011	1.010

^a Bold face indicates high tide. All other records at low or half tide.

TABLE I2
Specific gravity of water in test holes at Beaver Dam creek

	<i>Spartina patens</i>	<i>Spartina alterniflora glabra</i>
Aug. 11.....	1.006	1.005
Aug. 15.....	1.005	1.006
Aug. 23.....	1.005	1.005
Aug. 31 ^a	1.006	1.005
Sept. 10.....	1.004	1.005

^a Bold face indicates high tide. All other records at low or half tide.

TABLE I3
Specific gravity of water in test holes at Mastic

	<i>Spartina patens</i>	<i>Spartina alterniflora glabra</i>	<i>Scirpus robustus</i>
Aug. 4 ^a	1.010	1.016	1.003
Aug. 11.....	1.012	1.019	1.002
Aug. 15.....	1.011	1.017	1.001
Aug. 23.....	1.011	1.017	1.002
Aug. 31.....	1.017	1.017	1.010
Sept. 10.....	1.017	1.017	1.010

^a Bold face indicates high tide. All other records at low or half tide.

NOTE. This marsh was not ditched at the time of taking this record. All other records are from ditched marshes.

The significance of these figures appears to be this:

1 The salt tolerance of the different species is rather uniform in each pit from reading to reading. And it is quite clear that the salt tolerance of salt meadow grass (*Spartina patens*), black grass (*Juncus gerardi*) and spike grass (*Distichlis spicata*) differs as between eastern and western Long Island, just as the figures for the bay waters differ, as shown earlier in this report.

2 It is still safe to say that salt meadow grass (*Spartina patens*) is generally more tolerant of salt than black grass (*Juncus gerardi*) or spike grass (*Distichlis spicata*). But again, as in the earlier discussion of the salt tolerance of salt marsh grass (*Spartina alterniflora glabra*), generalizations are apt to be vitiated by some of the readings.

3 What is fairly obvious is that the four species do retain their relative positions in the marshes, whether the saltiness of the water comes within the comparatively high range of western Long Island or the much lower ranges of salinity found at Beaver Dam creek and Mastic beach.

4 In other words, the figures appear to indicate that the specialized environment of the marshes is composed of not one factor for their vegetative stability but of several.

It does not seem to matter if the whole salinity range is low or high. In either case upland or fresh water marsh or swamp plants do not enter the society of salt marsh plants. The latter, having a considerable range of salt tolerance, seem to be able to use this capacity to maintain the vegetative integrity of the salt marsh plant society and to keep out intruders that find competition too severe. This whole question of the *relative* salinity as a limiting factor has a considerable bearing upon the waters found in mosquito ditches, to be discussed in another section of this report. Before doing so, there are several other salt marsh plants which should be considered as, under favorable conditions, they occur in fairly pure stands of some extent.

SECONDARY SPECIES

Besides the four primary species that play such an important part in making the marshes what they are, there is a secondary group which plays scarcely any rôle at all in the permanent structure of the marshes, but often covers considerable areas in many marshes and even forms exclusive growths under certain conditions to be discussed presently.

It is among this secondary group of species that nearly all the color of the marshes is found. A few are annuals and their permanency of occupation is apt to be fleeting. One or two are perennials, but these are generally found far up on the landward edge of the marsh and thus "saline" to a very limited extent.

These secondary species and some notes on their average salt tolerance and distribution are:

1 **Salt reed grass** (*Spartina cynosuroides*). A tall grass closely related to salt marsh grass (*Spartina alterniflora glabra*), but never having much to do with creating a site. It grows five to seven feet high, and is scattered throughout the salt marsh area of southern Long Island, always at the upper (landward) edge of it. Average salt tolerance is about 1.005, but it grows in such situations that it must survive flooding during storm tides. First flowers were noted July 4th; it was in full flower July 15th-30th; sporadic flowering up to August 20th.

2 **Ditch reed** (*Phragmites communis*). This is the most remarkable grass found in the salt marsh area. Its salt tolerance ranges from fresh water to nearly full strength of sea water. Until the days of hydraulic fill noted in an earlier section of this report, ditch reed was only a sporadic grass on Long Island. It now covers acres of otherwise barren, sandy and gravelly wastes with a growth so dense that it is almost impossible to get through the mass of stout stems and leaves. In full flower and with its subsequent plumes of fruit, ditch reed is by far the showiest plant on the marshes.

In spite of its tremendous vigor on dry sand, it will grow perfectly in standing water, and along the banks of nearly all dug channels it creeps down from the hydraulic fill to, and often into, tide water. While it scarcely ever gets a foothold if there is a dense turf of salt marsh grass (*Spartina alterniflora glabra*), salt meadow grass (*Spartina patens*) or black grass (*Juncus gerardi*), it will often run out over the edge of a marsh, and at Merrick it has captured and sometimes choked a few mosquito ditches. Those charged with the care of ditches consider ditch reed a nuisance, and a dangerous fire hazard in winter. While this may be true, it is still the showiest plant of the marshes, its habit and stature, and particularly its magnificent plummy fruit resembling the famous pampas grass of the Argentine.

3 **Wool grass** (*Scirpus cyperinus*). A tall, rather striking sedge, found throughout the salt marsh area, but almost never in the open marshes. Its favorite habitat is along the edges of fresh water

streams near the place where they become tidal. It stands an average salinity of about 1.005.

4 **Chair-maker's rush** (*Scirpus americanus*). This plant has much the same habitat preference as wool grass (*Scirpus cyperinus*) but occasionally it makes considerable stands toward the upper edge of the salt marshes where the underlying water is nearly fresh. Both this and the wool grass, however, get complete submergence occasionally by sea water during storm tides.

5 **Great bulrush** (*Scirpus validus*). This is a coarse sedge with a rather large, fruiting cluster. The plant is commonly found toward the upper edge of the marshes; never in the dense turf made by the four dominant species. It is fairly common along the marshes that fringe the inner edge of the barrier beach along which runs the dune road from Westhampton Beach to Southampton. At and near Moriches inlet it stands salinities of about 1.019, but its usual range is much nearer 1.005.

6 **Salt marsh bulrush** (*Scirpus robustus*). This and several related species, on Long Island at least, are popularly grouped under the general vernacular of "three-square" from the sharply three-angled stems. The plant, as shown by the salinity records at Mastic, is almost a fresh-water one, but on occasional spring high tides it may survive a flooding with bay water that may be as high as 1.016 or even more.

7 **Marsh elder** (*Iva oraria*). This shrubby herb is normally an inhabitant of the upper reaches of the marshes, but it has a wide range of salt tolerance stretching from almost fresh water to places flooded twice each day with water testing up to 1.021. During much of the season the plant looks exactly like a winter-killed shrub, but by mid-August the old bare stalks of the previous season are nearly hidden by the current foliage.

So much controversy has raged about this plant and the mosquito ditches that a detailed study of its present frequency and distribution is treated in that chapter.

8 **Groundselbush** (*Baccharis halimifolia*). This, the only true shrub found on the salt marshes, is rare in the saltiest sites and normally grows as a shrubby fringe at the extreme upper (landward) edge of the open marsh. It does, however, occasionally push out into locally sandy spots in the middle of the marsh. In fruit its decorative white tassels are very effective. But the plant has little to do with the building up of the true salt marsh site. It is much more common in the salt marsh area of eastern than western Long



FIGURE 12 Ditch reed (*Phragmites communis*) on hydraulic fill at Strong's creek, near Copiague. It covers hundreds of acres on similar sites, but is rare in the true marshes.



FIGURE 13 Upper end of salt marsh at Cedar point, near Sag Harbor. The light-colored shrubby plant at the left is marsh elder (*Iva oraria*) and shows its usual position in an unditched marsh. Oaks and sour gums in the background.

Island, especially so along the upper edges of marshes facing Gardeners bay, east of Sag Harbor, and near Three-Mile Harbor.

9 **Rose mallow** (*Hibiscus moscheutos*). This is by far the showiest blooming plant on the marshes. All the Long Island specimens were either pure pink or pale pink or white, none of the dark-eyed variety being found. Its salt tolerance is rather wide, some plants being near to or even in the bay water, but most of them averaging 1.008 or less. It began to bloom August 6th, was in full bloom about August 12th, and sporadic bloom continued until August 25th. It gives more color to the marshes than any other plant, but has little to do with the process of creating a site.

10 **Glasswort** (*Salicornia europaea*), **sea blite** (*Suaeda maritima*), and **sea lavender** (*Limonium carolinianum*). These three species, all low-growing herbs, are found throughout the marshes, often covering "rotten spots" to be discussed later. The glasswort (*Salicornia europaea*) is especially adapted both to covering such spots with an exclusive growth for a year or two, and to capturing any other open place. But it will often be found among a dense growth of salt marsh grass (*Spartina alterniflora glabra*), rarely among salt meadow grass (*Spartina patens*). In the fall its curious leafless, club-shaped branches turn a brilliant crimson; hence its other name of samphire.

11 **Seaside orach** (*Atriplex patula hastata*). An extremely common annual plant, especially in "rotten spots," or any other open places and found within a wide range of salt tolerance. Its ashy, pale foliage makes a striking contrast to the prevailing greenness of the salt marsh grasses. But the plant has little or no significance in building up the marshes.

12 **Pilewort** (*Erechtites hieracifolia*). A weedy and very common herb in any open place, especially on the turf piled up along the edges of the mosquito ditches, and on some "rotten spots" that are in the process of recovery. In such places it may for a year or two make an almost exclusive growth, but its annual habit prevents the construction of turf and it is thus of no significance in building up the marshes. In fact, the pilewort (*Erechtites hieracifolia*) is a weedy herb found in many open places on the upland, often capturing clearings following a forest fire. Its occurrence on the marshes may well be due to the fact that it finds complete freedom from shade, which is of more importance to it than the comparatively mild salinity that it meets in most of the places occupied by it on the marshes.

13 **Seaside gerardia** (*Gerardia maritima*). This is a low, fine-leaved herb, the beautiful purple flowers of which make it so conspicuous that one may be misled as to its real importance as a constituent of the salt marsh vegetation. In late August and early September it gives brilliant coloring to the marshes, but only toward the upper stretches of them. It is most frequent as a constituent of such vegetation types as salt meadow grass (*Spartina patens*) and black grass (*Juncus gerardi*), especially the latter. In the relatively high salinity conditions of salt marsh grass (*Spartina alterniflora glabra*) the seaside gerardia (*Gerardia maritima*) is rare or almost wanting. The plant makes no turf, and is consequently to be looked upon as of only secondary importance.

14 **Marsh fleabane** (*Pluchea camphorata*). This is a highly aromatic, brightly colored annual herb, flowering profusely toward the end of August and September, often occurring in tremendous numbers, and sometimes in pure stands. It is highly salt tolerant, perhaps more so than any other annual plant on the marshes except glasswort (*Salicornia europaea*). Generally, as it occurs in the turf made by salt marsh grass (*Spartina alterniflora glabra*), salt meadow grass (*Spartina patens*), or black grass (*Juncus gerardi*), the marsh fleabane grows in small patches. But in partially recovered "rotten spots," in any open or sandy place in the marshes, and along the edges of many of them, marsh fleabane (*Pluchea camphorata*) often occurs in great profusion. Its annual habit precludes it from the category of turf-building, and the plant, while very conspicuous for a season or two, does not occupy the same site for long.

15 **Seaside goldenrod** (*Solidago sempervirens*). This, the coarsest-leaved and perhaps the showiest of all our native goldenrods, is primarily a denizen of sea beaches and dunes, where it attains far greater luxuriance than it does in the salt marshes. The plant occurs throughout the marshes and appears to range in salt tolerance from nearly fresh water to open sea water. Often it may be found as isolated specimens among salt marsh grass (*Spartina alterniflora glabra*), and like this grass, partially covered by strongly saline water at every high tide. More often, however, it is scattered in other parts of the marsh and is not infrequent along the edges of mosquito ditches. An interesting criterion of this plant's relative fitness for dune sand and the salt marshes is the fact that it flowers more profusely and about two weeks earlier on the dunes and beaches than it does in the marshes.

16 **Sea pink** (*Sabbatia stellaris*). Few salt marsh plants are so beautiful as this delicate, annual herb, the starlike, purple-pink flowers of which become showy spots of color late in the season. It is in no sense a marsh builder for it makes no turf, and its general salt tolerance is not great enough to permit it to grow in the most salty part of the marsh. Toward the upland, however, and in many open or partially sandy places it grows in considerable profusion. It is much less common than seaside gerardia (*Gerardia maritima*) or marsh fleabane (*Pluchea camphorata*), but like them provides color to the marshes that is not found in more important plants.

* * * * *

This brief list of the secondary plants of the marshes makes no pretense of being complete. Nor should any of them be confused with the four dominant species already discussed.

The latter create the sites upon which the secondary species occur, a point well emphasized by the relatively ephemeral distribution of the secondary species and the rather fixed stability of the four primary ones. Upon such a conception, and all the evidence indicates the essential correctness of this view, the secondary species are episodic, the primary ones fundamental to the business of actually creating the salt marshes.

It is for this reason that these secondary species appear to *flit* about the marshes, if the term may be permitted in this connection, growing here one year and there another, quick to capture a locally favorable environment, and quickly losing it to more permanent types.

While all of them may be scattered among the turf made by the four dominant species, their greatest chances of establishment come not from fixity but change. And change comes to the turf made by the dominants very slowly and sometimes not at all. In spite of a stability of vegetative types, however, based as we have seen on the one never changing ecological factor, the tides, changes do occur in these four dominant species. The greatest of these changes, and the ones most affecting the distribution of the secondary species, are the occurrence of "rotten spots" and, more recently, the cutting of the mosquito ditches. The latter will be considered in a separate chapter, as it introduces a wholly artificial condition into the marshes.

"ROTTEN SPOTS"

The normal stability of the four dominant species may be interrupted anywhere by the development of what are locally called "rotten spots." These are areas from a few square yards to several acres

in extent where complete rotting of fresh vegetation and the turf beneath it may occur. Such rotting, depending on local conditions, mostly minor differences in grade, may be so complete as to leave only standing water (no longer possible in ditched marshes), or the decomposition may be only great enough to kill the vegetation and leave a bare stretch of dead turf which is almost at once occupied by marsh elder (*Iva oraria*), seaside orach (*Atriplex patula hastata*), marsh fleabane (*Pluchea camphorata*), or, in places subject to daily flooding, by glasswort (*Salicornia europaea*). Other plants that often get a temporary foothold in these partially recovered "rotten spots" are rose mallow (*Hibiscus moscheutos*), sea blite (*Suaeda maritima*), sea lavender (*Limonium carolinianum*), and the most weedy of them all, pilewort (*Erechtites hieracifolia*).

Some "rotten spots," while not of the right grade to permit standing water, are full of black, foul-smelling slime or ooze, and it is such places that have given the marshes a bad name among the ignorant and superstitious. There may be no vegetation in such places at all; walking over them is, of course, impossible, and in a few of even the worst of them one may find scattered, and far from happy, plants of marsh elder (*Iva oraria*).

In many marshes, especially some unditched ones in Suffolk county and in New Jersey, these "rotten spots" nearly all progress to the stage of open water, which often, because of evaporation, becomes more salty than the sea itself. In the only pools observed on Long Island (they are rapidly being eliminated by ditching) the sole plant inhabitant is the submerged wigeon grass (*Ruppia maritima*), which makes dense growth in such places. But wigeon grass also, and usually, grows in water far less salty than this, notably in the faintly brackish pond in the Bird Sanctuary at Jones beach (specific gravity 1.001) and in Shinnecock bay (specific gravity 1.010).

Much has been written as to how these "rotten spots" start; why, in other words, what looks like healthy vegetation should be transferred into slimy bogs or open pools. While the actual stages of decomposition are perhaps vague or at least not technically certain, the initiation for the process seems to have a comparatively simple explanation.

Vegetation with such a close underground water source as our test pits reveal, must provide for reasonably rapid transpiration from its foliage, as well as reasonably free evaporation of capillary water from its turf, or even for the evaporation of sheet water, whether caused by rainfall or high tides.

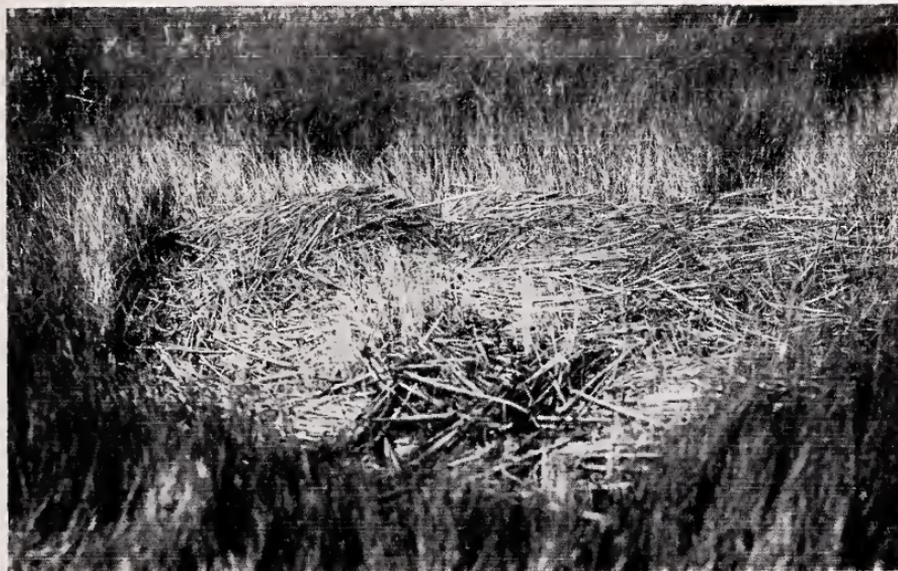


FIGURE 14 Tidal trash on the marshes at Napeague beach, near Montauk. Such trash and cow-licks (see figures 8 and 9) appear to be the origin of most "rotten spots" in the marshes.



FIGURE 15 Typical mosquito ditch through salt meadow grass (*Spartina patens*) at Merrick. Note the plentiful establishment of marsh elder (*Iva oraria*) along the line of the ditch.

If, then, there could be a sudden and reasonably effective stop to this transpiration and evaporation, stagnation and decay not only might, but would be rather certain to occur, especially in the heat of summer.

As it happens there are at least two natural checks to this normal water loss and they seem to be the cause for the start of "rotten spots."

The first is the development of "cow-licks," already discussed. When these first occur the foliage is simply a flattened mat of living grass, stems, and leaves. Later they become more matted, as imprevous as a thatch, and ultimately the plants die. Beneath such a mass of dead vegetation, decay is fairly rapid.

The second and much more fortuitous cause is tidal trash. During on-shore storms that happen to coincide with high spring tides, the whole marsh may be covered several inches deep with bay water. As this evaporates off in unditched marshes, or runs off in the ditched ones, it often leaves large patches of litter. These may vary from a few scattered sticks to a dense mass of trash which completely covers the vegetation and soon smothers it. The effect is exactly the same as in the "cow-licks," except that it may act quicker, depending on the depth of the tidal trash.

However developed, these "rotten spots" are of considerable significance in the distribution of the secondary species on the marsh. Their development means greater frequency for these ephemeral species, and their ultimate recovery is usually completed by the invasion of one of the four dominants. That may not happen for a few years, and in the meantime the area is occupied by a shifting population which could never be so profuse without the "rotten spots."

MOSQUITO CONTROL DELIMITATION OF FIELD

There is much controversy and some confusion as to the merits or evils of draining off all standing water in the program of mosquito control. To remove this report from any uncertainty it should be stated at once that ditching of only the salt marshes on Long Island for the control of the salt marsh mosquito is here under consideration. The conclusions drawn from this study do not apply to the draining of fresh water marshes, ponds, bogs or kettle holes which abound on Long Island.

In the course of many years' study of the vegetation of the island, one accumulates a considerable familiarity with these fresh

water areas and their plants. Some species, notably at Montauk, occur in such ponds, and perhaps nowhere else on Long Island. And the draining of such, permanently transforms the site from a favorable to an unfavorable one. All interested in the conservation of these interesting and often rare aquatic and bog plants must deplore the destruction of so many sites upon which their growth depends.

The suspicion arises sometimes that the assumed benefits of such fresh water draining have been bought at too great a cost. To destroy a natural environment, which Nature may have taken centuries to produce, is too fatally easy. All one needs is a digger, a gang of men, and in a few hours or days the whole environment may be destroyed. Many areas have been thus destroyed, and the unfortunate feature is that once drained, such areas may never regain their old condition, for the draining operation totally destroys a fundamental condition of the environment—fresh water.

With this fact in mind there need be no confusion in what follows, because ditching of the salt marshes *does not fundamentally change the environment at all*. The details of this will be discussed presently, but before doing so some general features of the ditching program are worth recording.

THE MOSQUITO CONTROL DITCHES

About nineteen thousand acres of marsh in Nassau county have been ditched for many years. More recently Suffolk county has begun, and nearly finished, the ditching of the much less extensive marshes of eastern Long Island.

While this report will confine itself to the changes that ditching has caused to the vegetation, it seems worth recording here both recent observations and those stretching over 20 years' work on Long Island and some familiarity with its curse—the salt marsh mosquito.

During last summer, in walking miles over many ditched marshes in Nassau county, we found mosquito bites so rare as to cause comment. On a single unditched salt marsh island near Fire Island Lighthouse (since ditched) the mosquitoes were as bad as have been experienced in any tropical locality, notably the notorious salt lake shores of Inagua in the Bahamas.

The effectiveness of the ditches in controlling mosquito breeding is so overwhelming, and the benefits to the adjacent communities so unquestioned, that there seems no reason to oppose the ditching of all salt marshes. But some have opposed it and one of their

contentions has been that ditching has materially changed the vegetation of the marshes. Attempting to determine the facts led to the present study.

There is no doubt that ditches allow water of varying degrees of salinity to reach areas of the marsh that would be without such water if the ditches did not exist. To determine the effects, if any, of this twice-daily flushing of the ditches a rather elaborate series of records have been kept of the water in these ditches at all stages of the tide. The details of this will be shown presently.

The standard open ditch is cut 10 inches wide and 20 inches deep, and in all the old ones the cut turf is piled along one side of the ditch. In some new ditching the turf is pulverized and blown over the surface of the marsh. Yearly cleaning of the ditches, ordinary erosion and tidal scour often increase the width and depth of old ditches, especially near the bay, where some of them may be 20 inches wide and 30 inches deep.

The perfection of plotting the lines, connections and laterals of these ditches is shown by the effectiveness with which they completely drain sheet water off the marsh at practically every tide. Such sheet water may be extensive on any marsh wholly covered by salt marsh grass (*Spartina alterniflora glabra*), or, as so often happens, with scores of small patches of it in otherwise higher sites. As we have seen elsewhere, this most salt tolerant of all marsh plants is, because of that fact, the one most likely to be flooded at nearly every high tide. Without the ditches much standing water would remain over such places, as it often would over some "rotten spots," and of course in all salt marsh pools. But ditching operations, wherever well done, do not allow any standing or sheet water on the marshes.

PHYSICAL EFFECTS OF DITCHING

Whether or not ditching affects salt marsh plants would seem to rest upon how much ditching really changes the environment. Three lines of evidence seem to be demanded, and are here included:

1 Does ditching change the *level* of the undersurface water? Upon this, as we have shown, the continuity and extent of the salt marsh plant society may be assumed to depend.

2 Has ditching changed the *salt content* of this undersurface water? Upon this depends the segregation of the four dominant species already described.

3 Exactly what is the salinity, depth, temperature and time period of the waters entering and leaving the ditches twice daily?

The answers to these three questions appear to provide a clue as to the effects of ditching upon the vegetation. The record of the level and salinity of the water under the marshes need not be duplicated here, because the records of the 11 test pits already given are conclusive upon this point.

Those 11 pits were dug in both ditched and unditched marshes. In the ditched marshes some of the pits were only eight feet from a ditch or main drainage channel while others were as far as 120 feet from any ditch, as at Strongs creek near Copiague. The figures on pages 52-57, which are based upon records taken at all stages of the tide and over a period of many weeks, show the following:

There is no indication that ditching has changed the fundamental level or salinity of the water under the marsh. The level does not vary between one tide and the next, although there are small fluctuations as between neap and spring tides, and for a few hours or days after heavy rains. This is shown clearly both for unditched marshes, as at Mastic, and in the pits dug at various distances from ditches at Merrick, Strongs creek (near Copiague) and at Beaver Dam creek (Brookhaven). The only exception to this statement is that all pits dug under salt marsh grass (*Spartina alterniflora glabra*), whether in ditched or unditched marshes, were usually or often flooded at high tide, but always sank to a general level, several inches below the surface, at low tide.

The significance of this failure of the ditches to change the level or salinity of the water *under* the marshes can scarcely be exaggerated when it comes to the question of what ditching has done to the vegetation.

So far as the four dominant species are concerned, there is no evidence that ditching materially changes their distribution or frequency. The purely physical evidence of stability supplied by the test pits appears to be matched by a similar stability in the vegetation, so far as the four major plants that create this plant society are concerned.

Such a conclusion does some violence to theories of succession in the marshes. But succession in them seems not to play the rôle it unquestionably does in other vegetation types. The reason for this is that no vegetation type except the salt marshes is subject to such a constant and absolute control as provided by the tides.

Nothing in any upland vegetative succession can approach the steady impact of the tides as a major factor of the environment. Upon the stability of those tides, the water under the marsh, and the adjustment of the four dominant species to these conditions, depend the survival and continuity of the salt marsh vegetation. And, because

ditching has made no fundamental change in these incomparably steady controls, we find no fundamental change in the vegetation as the result of ditching.

What the cutting has done to the vegetation along the line of the ditches is quite another, and a far less important matter. But, as it happens, it is precisely the changes along the lines of these ditches that have been the origin of most of the controversy. Again facts and not theories appear to give a reasonable answer.

THE DITCH WATER

The volume of water carried far up in the marshes by the ditches is enormous. Twice daily they are filled and drained, and it seemed important to know just what sort of water and how deep it was and for how long it stayed in the ditches.

To determine these points records were kept at the stations established for the test pits, except at Mastic, where there were no ditches. Frequent readings were made in several types of ditches. Physically, of course, the ditches are all alike, but for these readings ditches were selected that ran through the major plant associations and through a few others. In all, seven ditches were under observation during the summer as follows:

Merrick

- 1 Main drainage ditch through salt marsh grass (*Spartina alterniflora glabra*)
- 2 Ditch through marsh elder (*Iva oraria*)
- 3 Ditch through ditch reed (*Phragmites communis*)

Strongs creek (near Copiague)

- 1 Main drainage ditch through salt marsh grass (*Spartina alterniflora glabra*)
- 2 Ditch through black grass (*Juncus gerardi*)

Beaver Dam creek (near Brookhaven)

- 1 Ditch through salt marsh grass (*Spartina alterniflora glabra*)
- 2 Ditch through salt meadow grass (*Spartina patens*)

In addition to the records of water in these seven ditches, a record of the salinity and temperature of the open bay or stream that was the source of such water was also kept. Before presenting this in detail it is well to record the effect of drainage of fresh water from the upland into tidal creeks, many of which furnish the only supply of water for ditches too far up on the marshes for direct contact with bay water.

There are many fresh water streams that empty into tidal creeks, and depending upon the volume of fresh water and the stage of the tide, the water in such tidal creeks varies almost hourly as to salinity. As such waters are, in some cases, the only source of ditch water, it seemed necessary to study several of these creeks with this in mind. From this mass of data, the details of only one creek, at Biltmore Shores, are presented, as this is a fairly representative case of the merging of fresh and tidal waters.

The creek at Biltmore Shores is tidal from the bay for about 2000 feet northward, where it ends at a dam over which runs a considerable volume of fresh water testing, as caught from the waterfall, 1.000. This figure was verified several times during the summer.

The open bay water, also tested many times, shows a specific gravity varying from 1.019 to 1.020. Along this stream of approximately 2000 feet, therefore, we find a range of salinity from fresh water to open tidal water, but nowhere, except near its mouth does this stream maintain any steady salinity. It varies at each change of the tide. Generally speaking, at low tide the effects of fresh water are strongest in the upper reaches of the stream, while at high tide the fresh water is masked by the volume of tidal water.

To determine the exact effects of these twice-daily changes stations were established at the bay, and mostly at 200-foot intervals up to the pool at the bottom of the dam over which the fresh water falls into the tidal creek. Several sets of records were made along this stream, but only two are necessary to understand the condition—one at low tide, the other at high tide.

TABLE 14
Record of tidal creek at Biltmore Shores

	SPECIFIC GRAVITY AT	
	<i>Low tide</i>	<i>High tide</i>
Open Bay	1.019	1.020
200 feet upstream	1.015	1.019
400 feet upstream	1.014	1.018
600 feet upstream	1.012	1.018
800 feet upstream	1.012	1.017
1000 feet upstream	1.011	1.017
1400 feet upstream	1.010	1.017
1700 feet upstream	1.009	1.016
1900 feet upstream	1.006	1.014
Pool below fresh water dam	1.003	1.008



FIGURE 16 Where tide water and fresh water meet. These fresh water streams are nearly always drowned at high tide, and at this point occurs a tension zone between fresh water and salt water vegetation. Seaford.



FIGURE 17 Marsh elder (*Iva oraria*) on both sides of an old ditch at Merrick, but there are miles of ditches without any marsh elder along them. Ditch cut through salt-marsh grass.

These figures may vary with the amount of daily tidal range, which is scarcely ever the same for two consecutive days. Thus, at spring tides, the pool has registered 1.012 at high tide, while a low tide reading on a neap tide gave at the same place 1.001.

Such figures merely illustrate what must be obvious to any observant person. The waters of tidal streams, and hence the waters flowing into ditches, vary when this ditch water is not derived directly from bay water. With this in mind it is safe to record what has been found in the ditches selected for study.

THE DITCHES AND THE TIDES

Most ditches are without water, or nearly so, for longer periods than they are filled. In other words, they are draining off water, or are without it, for more hours than are consumed in filling them.

The reason for this is obvious to those who have observed them in actual operation. The entrance to most ditch systems is several inches above the level of mean low water. This means that from the moment the tide falls below the entrance point until it rises again to drown that point, the ditch is draining, whether the tide is rising or falling. This period differs depending on the daily range of the tide and the height of the marsh above mean low water. It also varies because both low water and high water are never the same from day to day, and they differ every 24 hours as between night and day tides.

With a variation so great it is quite obvious that the amount of water and period of flooding in the ditches must also vary. It does, and as the figures already quoted show plainly, this diurnal flooding of the ditches seems to bear little or no relation to the level of the water under the marsh.

For the sake of the record, however, it seems well to state the actual water conditions in one or two ditches, both as to amount, duration and salinity, especially as there appear to be no figures covering any of the three. For simplicity only one of the detailed records will be quoted here, that at Merrick. The records for another series of ditches, at Beaver Dam creek near Brookhaven, will be considered presently.

The selection of the Merrick records is partly because of their completeness and partly because the daily range of tides is far greater than for any station in this study. In other words, we can here observe the operation of the ditches in a huge marsh area, where ditching has been in operation for years.

The marsh at Beaver Dam creek, like all the rest on eastern Long Island, is much less extensive, the tidal range is less and the ditches are more recent.

Three ditches at Merrick were under observation. To make the records from them intelligible it is necessary to understand where they were, how far from the source of salt water, and through what sort of vegetation they happened to be running when the observations were taken. The ditches were:

1 Main ditch, running through salt marsh grass (*Spartina alterniflora glabra*), and the station 25 feet from main tidal stream

2 Lateral ditch, running through a mixture of salt meadow grass (*Spartina patens*) and marsh elder (*Iva oraria*), approximately 500 feet from main tidal stream

3 Lateral ditch, running through a miscellaneous growth of black grass (*Juncus gerardi*), marsh elder (*Iva oraria*), sea lavender (*Limonium carolinianum*), seaside orach (*Atriplex patula hastata*), and marsh fleabane (*Pluchea camphorata*), but in process of capture by ditch reed (*Phragmites communis*); in other words, a ditch far up on the marshes and approximately 1000 feet from the main tidal stream.

The table below shows the date of record, depth and temperature of water, salinity of water and state of the tide at all three ditches.

TABLE 15
Ditch water records, Ditch 1

DATE	STATE OF TIDE	DEPTH OF WATER IN INCHES	TEMPERATURE OF WATER	SALINITY OF WATER
June 21	High	15		
June 21	Falling	11		
June 21	Nearly low	$\frac{1}{2}^a$		
June 23	Low	0 ^a		
June 23 10.40 a.m.	Rising	$2\frac{1}{2}$		
June 23 11.10 a.m.	Rising	7		
June 23 1.10 p.m.	High	$13\frac{1}{4}$		
July 2	Low	$\frac{1}{2}^a$	88	1.019
July 2	High	21	74	1.020
July 23	High	20	78	1.020
July 27	Half high	$7\frac{1}{2}$	73	1.020
July 30	Low	$\frac{1}{2}^a$	73	1.020
Aug. 6	High	$23\frac{1}{2}^b$	70	1.020
Aug. 14	Low	$\frac{1}{2}^a$	90	1.021
Aug. 22	$\frac{3}{4}$ low	dry		
Aug. 30	$\frac{1}{2}$ low	$\frac{1}{2}^a$	79	1.021
Sept. 3	High	$23\frac{1}{2}^b$	69	1.022
Sept. 11	Low	$\frac{1}{2}^a$	74	1.022

^a During, before, and after dead low tide this ditch had no standing water, and the records were made from a trickle of water that ran out of the ditch until the point of intake was drowned by the next incoming tide.

^b These were the two spring tides, and the highest of the summer.

TABLE 16
Ditch water records, Ditch 2

DATE	STATE OF TIDE	DEPTH OF WATER IN INCHES	TEMPERATURE OF WATER	SALINITY OF WATER
June 21.....	High.....	10	.....	.....
June 21.....	Falling.....	6 $\frac{1}{2}$	.....	.....
June 21.....	Nearly low.....	1 $\frac{1}{4}$	.....	.....
June 23.....	Low.....	1 $\frac{7}{8}$	.....	.....
June 23 10.40 a.m.....	Rising.....	2 $\frac{3}{4}$	.....	.....
June 23 11.10 a.m.....	Rising.....	2 $\frac{3}{4}$	.....	.....
June 23 1.10 p.m.....	High.....	7 $\frac{3}{4}$	.....	.....
July 2.....	Low.....	.....	83	1.017
July 2.....	High.....	14 $\frac{3}{4}$	76	1.020
July 23.....	High.....	14 $\frac{1}{2}$	79	1.020
July 27.....	Half high.....	7	73	1.019
July 30.....	Low.....	1	79	1.018
Aug. 6.....	High.....	18	70	1.020
Aug. 14.....	Low.....	1	88	1.020
Aug. 22.....	$\frac{3}{4}$ low.....	8	78	1.021
Aug. 30.....	$\frac{1}{2}$ low.....	$\frac{3}{4}$	79	1.016
Sept. 3.....	High.....	18	68	1.022
Sept. 11.....	Low.....	dry	.....	.....

TABLE 17
Ditch water records, Ditch 3

DATE	STATE OF TIDE	DEPTH OF WATER IN INCHES	TEMPERATURE OF WATER	SALINITY OF WATER
June 21.....	High.....	3	.....	.....
June 21.....	Falling.....	3	.....	.....
June 21.....	Low.....	2 $\frac{3}{4}$	.....	.....
June 23.....	Low.....	2 $\frac{1}{4}$	.....	.....
June 23 10.40 a.m.....	Rising.....	2 $\frac{1}{2}$	.....	.....
June 23 11.10 a.m.....	Rising.....	2 $\frac{1}{2}$	.....	.....
June 23 1.10 p.m.....	High.....	2 $\frac{1}{2}$	.....	.....
July 2.....	Low.....	1 $\frac{1}{2}$	87	1.008
July 2.....	High.....	5 $\frac{1}{2}$	73	1.016
July 23.....	High.....	4	80	1.018
July 27.....	Half high.....	Dry	.....	.....
July 30.....	Low.....	Dry	.....	.....
Aug. 6.....	High.....	6 $\frac{1}{2}$	69	1.019
Aug. 14.....	Low.....	Dry	.....	.....
Aug. 22.....	$\frac{3}{4}$ low.....	Dry	.....	.....
Aug. 30.....	$\frac{1}{2}$ low.....	Dry	.....	.....
Sept. 3.....	High.....	7	66	1.022
Sept. 11.....	Low.....	Dry	.....	.....

The meaning of these figures seems to be plain enough. Those ditches nearest the source of tide water have more and saltier water in them and for longer periods than one such as Ditch 3 which is

dry for considerable periods between tides. Also, the water in Ditch 3, except at spring tides (notably on September 3d), is not so salty as that in ditches nearer the bay. The significant thing about the latter statement however, is that the plants growing along such ditches, while generally adapted to water of low salt content, seem able to stand water up to the usual salinity of sea water.

A curious reading at Ditch 3 on September 3d shows that it actually had more salt in the water than did the stations nearer the bay at Ditches 1 and 2. Traces of this tendency were many times observed also at Ditches 1 and 2, which actually showed for a few minutes more salt in the ditch water than in the bay water from which it is derived. All such readings came after a prolonged low tide, that is, an empty ditch, and the presumption appears to be justified that the first flush of the incoming tide picks up some salt which was deposited by evaporation along the sides of the ditch by the last outgoing tide.

EFFECTS OF DITCHING

Except for the minor changes to be outlined presently, there is no evidence that ditching has caused any fundamental change in the four primary species which constitute the vegetation of the marshes; this for the reason that, as the foregoing plainly shows, the ditches have not changed the fundamental underwater conditions of the marsh.

The only exception is that on extreme high spring tides some overflowing occurs on ditches running through salt marsh grass (*Spartina alterniflora glabra*), which subjects that vegetation to an hour or two of flooding. As we have seen, however, this, the most salt tolerant of all marsh plants, is indifferent as to whether it is submerged or not so long as its roots are in relatively salty water.

There is ample evidence that along the immediate line of the ditches vegetative changes have occurred because of the cutting. Such changes may be divided into two categories:

1 Because of the greater aeration provided by the ditches the plants along their immediate edge grow a little more luxuriantly and flower a little more freely than those in the open marsh. See in this connection the similar response made by salt marsh grass (*Spartina alterniflora glabra*) to a reduction in salinity as outlined on pages 43 and 44.

2 Many plants of secondary successional significance become established along the lines of certain ditches, especially where the turf taken from them is left along the line of the ditch. The artificiality of such an arrangement does provide an opportunity which



FIGURE 18 The rucksack is on the Nassau-Suffolk County line on the inner side of the beach near Jones Beach Bird Sanctuary. Note lack of marsh elder.



FIGURE 19 Looking west from Nassau-Suffolk County line, from point shown in figure 18. Note lack of marsh elder in any quantity in this Nassau County marsh which has been ditched for years.



FIGURE 20 Looking east from Nassau-Suffolk County line, from point shown in figure 18. Note similar lack of all but a negligible amount of marsh elder in this Suffolk County marsh which was ditched only recently.

apparently is seized eagerly by marsh elder (*Iva oraria*), sea blite (*Suaeda maritima*), seaside orach (*Atriplex patula hastata*), pilewort (*Erechtites hieracifolia*) and marsh fleabane (*Pluchea camphorata*). Of these by far the most important is marsh elder (*Iva oraria*).

It is precisely this plant which has been the cause of most of the controversy as to the merits or demerits of ditching the marshes. As shown in an earlier chapter, the salt tolerance of this plant is very wide and its capturing of the lines along the ditches does not seem to be dependent upon the salt content of the water flowing in these ditches.

There have been attempts to prove that ditching has caused a tremendous increase in the area occupied by marsh elder (*Iva oraria*), a fancied example of this being on the line between Nassau county and Suffolk county on the inner side of the barrier beach at the Jones Beach Bird Sanctuary. The claim that the ditched marshes of Nassau county provided until recently a better environment for marsh elder (*Iva oraria*) than the unditched adjoining marshes of Suffolk county is scarcely borne out by observation on the spot nor by the accompanying photographs (figures 18-20). While it is quite true that marsh elder (*Iva oraria*) fringes many ditches, especially that part of them nearest the upland, there are miles of ditches in Nassau county, some of them of many years' standing, which are not fringed by marsh elder (*Iva oraria*).

As for the other plants which occasionally fringe the ditches, they are, for the most part, in such places precisely for the reason that they occupy the "rotten spots" already dealt with—because of the freedom from competition.

Another factor of quite secondary importance is that while the salt marsh turf, which as we have shown is saturated by capillarity with salt water, regularly tests at pH 7.5 or 8.0, the excavated turf along the line of the ditches very soon becomes pH 4 to 4.5. It is upon this highly acid excavated turf that pilewort (*Erechtites hieracifolia*) and sea blite (*Suaeda maritima*) are particularly common, but marsh elder (*Iva oraria*) rarely occupies such sites.

CONCLUSIONS

The final conclusions of this study are thus summarized:

1 Ditching has made no fundamental change in the makeup of the salt marsh vegetation because ditching has not changed materially an environment predicated upon a very constant factor—the character and level of the salt water *under* the marsh.

2 The undoubted changes that have come along the edges of the ditches appear to be due to conditions of aeration, freedom from competition and the changes in the hydrogen-ion concentration of the peat stacked up along the ditches. Such changes affect only plants of secondary successional significance, and the effects of such changes are about as important as the edging along a perennial garden border, the contents of which may be permanent, while the edging, like that along the ditches, may be changed from season to season. The only exception to this is marsh elder (*Iva oraria*), which, once it has captured a line of ditch, appears to stay. But there are miles of ditch where marsh elder (*Iva oraria*) has not come in, even after nearly 20 years of ditching.

There is one final caution to be observed in using these data. They apply only to the area studied. Whether ditching areas with a greater tidal range, or of different soils, or with different plants in them would provide similar results is purely speculative. There seems to be some evidence that tides of greater magnitude provide such a different set of conditions from those found on the south shore of Long Island, that ditching in such marshes might well result in very different conclusions than those presented here.

MOSQUITOES AND MOSQUITO CONTROL ON LONG ISLAND, NEW YORK, WITH PARTICULAR REFERENCE TO THE SALT MARSH PROBLEM

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INTRODUCTION

The present study was made on Long Island, N. Y., during the summer of 1936 for the New York State Museum, and I am indebted to the Museum for the facilities provided for the field work, and to Dr R. D. Glasgow, State Entomologist of the State Museum staff, for supervision of the project.

The author's sincere thanks are due to the Long Island mosquito commissions, the New York City Mosquito Commission, the Nassau County Extermination Commission and the Suffolk County Mosquito Extermination Commission, for their cooperation and assistance during the summer of 1936. Acknowledgment is particularly due the Nassau County Extermination Commission and Superintendent R. H. Sammis of that Commission, for making possible the author's continuation of field work until the end of the fall season.

HISTORY, METHODS AND PRESENT STATUS OF MOSQUITO CONTROL ON LONG ISLAND

The beginnings of mosquito control on Long Island were made by village planning boards, the members of which were motivated partly by a desire for more comfortable and more healthful living conditions, and partly by a desire to enhance real estate values and to attract new residents. One of the first practical and successful experiments in controlling the breeding of mosquitoes on the salt marshes was carried out in the summer of 1900 at Lloyd's Neck on Cold Spring Harbor by W. J. Matheson under the direction of Dr L. O. Howard, then Chief of the Division of Entomology of the United States Department of Agriculture. It is really to the efforts of Doctor Howard that credit is due for the inauguration of these early control experiments, and the success obtained is in large part the result of his plans and leadership.

In 1900 the Civic Committee of Richmond Hill inaugurated a house-to-house antimosquito campaign with excellent results. During the same year similar campaigns were also being started in New Jersey and in Virginia.

Because of the encouraging results from the work at Lloyd's Neck, much more extensive work was begun in August 1901 under the auspices of the Northshore Improvement Association. This forward-looking group obtained the services of the engineer who had performed the work of ditching the marshes at Lloyd's Neck in 1900 and on Center island, Oyster Bay, earlier in 1901; and also obtained

the services of five biologists, four of whom studied the mosquitoes and their habits, while the fifth studied the ecology of the marshes and related subjects. The results of this work were published in book form by the North Shore Improvement Association early in 1902. This book contained detailed reports by each of the specialists employed; and, together with bulletins by Doctor Howard for the United States Department of Agriculture, and by Dr John B. Smith for the New Jersey Experiment Station, formed the first important published contributions on the subject of the scientific control of mosquitoes, and on the biology of mosquitoes in relation to their control.

In 1902 the North Shore Improvement Association continued its activities, and at the end of the season published the considerably elaborated report of its entomologists. Work was continued in these separate areas for several years; and on December 16, 1903, New York City had the honor of being host to "the first general convention to consider the questions involved in mosquito extermination," at which leaders from most if not all of the states attempting mosquito control presented their findings and views.

In these early days one frequently heard that the aim of a mosquito control program was the absolute extermination of all mosquitoes. This was especially the thesis of E. Winship, one of the first directors of mosquito control in New York City. Laudable and desirable though mosquito extermination is, it soon became apparent that, although it might occasionally be attained in some small and especially favorable areas, it was as impossible as man's attempts to rid the Middle West of its frequent plagues of grasshoppers. Mosquitoes can be controlled almost universally to below the nuisance level but there is at present no indication that they will ever be exterminated. Accordingly the mosquito control programs and commissions have of necessity been planned as permanent, and they will probably remain as permanent institutions around densely populated centers.

The early work on Long Island was not pushed forward as strongly as in neighboring New Jersey, although interested parties continued to agitate for action and adequate legislation. The work in New Jersey under the able leadership of Dr John B. Smith and later of Dr T. J. Headlee became the model for other areas, and in 1914 resulted in the formation of the New Jersey Mosquito Extermination Association, the annual meetings of which, despite the title, have assumed a national scope, character and importance.

About this time interested groups were formulating the legislation that was designed to make mosquito control work possible and effective in New York State. At the same time local groups, particularly around Rockaway peninsula, were carrying on local programs financed by private contributions. New York City soon followed suit by letting the largest single contract yet issued for ditching—the marshes in and around Jamaica bay—more than six million feet of drainage ditch.

The work in New York City was—and still is—under the direct supervision or sponsorship of the City Department of Health. The work on the rest of Long Island has been carried on by the respective county mosquito commissions. The original plans called for a Nassau-Suffolk mosquito extermination commission; but due to indifference on the part of the residents of Suffolk county, the law was amended, before being passed on May 3, 1916, to provide a county commission in Nassau county only.

The year prior to the passage of this law, extensive work was begun in southeastern Nassau county by the Rockaway Peninsula Mosquito Extermination Association. The original plans of this group called for ditching part of the Jamaica Bay marshes; but these plans were abandoned in 1916 when New York City undertook the task of ditching all the Jamaica Bay marshes.

Late in 1916 the Nassau County Commission began to function *per se*, but the Rockaway Peninsula Association continued its activities through 1917 although part of its projects were taken over by the county commission. In 1918 the Rockaway Peninsula Association ceased its activities which were then taken over in full by the county commission. The Nassau County Commission continued the work on a countywide basis and about 1921 completed the original ditching projects including practically all the salt marsh areas of both the north and south shores. The remaining bits of salt marsh were ditched in the next few years and the upland areas were concurrently treated by whatever methods seemed best, frequently by ditching.

The very first ditching was performed by manual labor with specially devised spades, but the bulk of the salt marsh ditching both in Nassau county and New York City was done by contract with companies using the Eaton mechanical ditcher perfected in New Jersey. Maintenance and recutting have always been performed by manual labor, as has also most of the upland ditching and the cleaning of stream and pond margins etc. The construction of a large series of reservoirs by the New York City Water Board



FIGURE 21 Typical view of low salt-marsh island with patch of "tidal float" in center. Jo-Co marsh, Jamaica bay. Vegetation mostly *Spartina alterniflora*.



FIGURE 22 Old salt-marsh mosquito ditch now almost completely obliterated. The old ditch (dug about 1917) extends from the camera to the man standing in the ditch in the left foreground. These old ditches show more clearly in aerial photographs than from the ground. Jo-Co marsh, Jamaica bay.

has resulted in the complete elimination of many bad breeding places, especially of marshes along streams near the bay. Hydraulic filling for real estate has reduced greatly the amount of salt marsh although at times it adds other problems (see below).

With little change the Nassau County Commission has functioned every year from its formation in 1916 to date. Decreased appropriations in 1934 greatly curtailed the activity of the commission and allowed the salt marsh ditches to fall into disrepair. House-to-house inspections were also reduced. One result was that the Rockaway Peninsula area (now controlled by the Branch Village Officials Association) became dissatisfied and again established a local unit, this time to supplement the county commission's activities, largely by house-to-house inspection. With the increased budget of 1936 and the further increased budget for 1937, however, the Nassau County Commission is reconditioning its marshes and is increasing its house-to-house work.

With the decreased budgets of 1934-36 the Nassau County Commission managed to augment its activities by utilizing labor supplied by the Temporary Emergency Relief Administration, Works Progress Administration and Emergency Relief Bureau. These laborers were used in cleaning and recutting ditches under the supervision of the county commission. (For further details on Nassau county see the Annual Reports of the Nassau County Extermination Commission.)

In New York City, after the first extensive work from 1916-22, work was allowed largely to lapse until recent years. Lately it has received considerable governmental help, especially labor and supervisors employed by the Works Progress Administration. With this help New York City has reconditioned its marshes which had been allowed very largely to go untended and to return practically to their original state (figure 22). Much of the early New York City ditching was done on the old "checkerboard" system. Parallel ditches are now known to be fully as satisfactory. Accordingly one of the activities of the New York City Commission under W. P. A. has been to fill the cross ditches and so reduce the amount of ditching in need of maintenance. The commission has also been active in eliminating many breeding areas by utilizing them as dumps until they are filled and can be graded. The construction of the grounds for the coming World's Fair of 1939 is eliminating another very bad area. New York City now has a very comprehensive program, still largely under W. P. A., one feature of which is a detailed check of breeding by means of trap-collections, the results being

plotted against weather conditions (Mosquito Control Entomological Analysis 1935-36. N. Y. City W. P. A. 1936).

In Suffolk county, although the county as a whole withdrew from the proposed Nassau-Suffolk Mosquito Commission (1915-16), local work was begun as early as 1916 in certain sections, especially by owners of large estates and resorts. About 1925 a county organization was formed to sponsor and seek legislation for a county mosquito commission. This group employed the Gorgas Memorial Commission to make a survey and set of recommendations. After a long period of agitation and work, the county commission was finally authorized by state law early in the summer of 1934.

In 1933, one year prior to the formation of the county commission, the relief organizations, finding in mosquito control work a ready medium for uniform employment and general benefit, launched an extensive mosquito control program in Suffolk county. With the formation of the County Mosquito Commission in July 1934, the work came under the direction of this commission, although most of the labor and materials were still supplied by the relief organizations (begun under the direction of the Suffolk County Emergency Work Relief Bureau, and carried on successively under the Federal Civil Works Administration, Temporary Emergency Relief Administration and Works Progress Administration). Because of this source of funds and labor the work in Suffolk county has perforce been carried forward exclusively with manual labor and the specially constructed mosquito-ditching spades. This is in sharp contrast to the large-scale mechanical ditching programs that established the basis of control in Nassau county and New York City. Despite this drawback the greater part (70 per cent) of the estimated 70,000 acres of salt marsh in Suffolk county has been completely ditched, including all of the most strategic breeding areas located particularly in and around Great South bay, Moriches bay, Shinnecock bay and Peconic bay, more than six and a quarter million linear feet of salt marsh ditches.

With the necessarily prerequisite salt marsh work well under way, the Suffolk County Commission turned part of its efforts towards controlling the upland or fresh-water breeding. In this connection about one and a half million feet of streams have been cleaned and straightened, and about six hundred thousand feet of upland drainage ditches have been installed, an estimated 60 per cent of the work needed.

For the first time the Suffolk County Commission performed a complete house-to-house inspection throughout the county during the



FIGURE 23 Raisable gate at lower end of mosquito ditch. This gate is supposed to be raised during incoming tides and lowered during outgoing tides in order to allow entrance of fresh salt water and killifish during high tides and yet prevent the water from being removed at low tides. These gates require constant attention and are at best a poor makeshift in comparison with the automatic tide gates used in certain other states. Jones Beach Bird Sanctuary.



FIGURE 24 Solid dam at lower end of mosquito ditch. This dam holds the water on the marsh and in the ditches (where it frequently becomes too hot for killifish) and does not allow interchange of water or entrance of killifish except during extremely high tides that cover the entire marsh. This dam was installed by the custodian at the site where raisable gates had previously been used. It was installed because the raisable gates were not considered satisfactory by the caretaker because of the continual attention required, and because it was thought necessary to retain as much water as possible on the marshes. Its installation created a mosquito menace from all the area previously drained by this system of ditches. Jones Beach Bird Sanctuary.

summer of 1936. In considerable part this inspection was designed as public education. The expense of regular house-to-house inspections is so large that the commission was forced to abandon this phase, at least temporarily, after the one comprehensive inspection. Some of the villages, seeing the great benefit derived, have decided to add this to the general village activities. While on the whole and over a long period of time, local group activities are not so satisfactory as a comprehensive county program, there is no doubt of the value of local house-to-house work when the county commission is not prepared to assume this duty. (For further details on Suffolk county see the Report of the Suffolk County Mosquito Extermination Commission for 1936.)

CONTROL METHODS IN USE TODAY ON LONG ISLAND

Control methods are now largely standardized and have been treated in detail too often to warrant more than a very brief resumé in this report (see Headlee, 1921; 1930; Matheson, 1929; and various special papers, especially those by Headlee and Ginsberg, in the Proceedings of the Annual Meetings of the New Jersey Mosquito Extermination Association).

Ditching. The vast expanses of salt marshes, particularly along the south shore, make the first job of the mosquito exterminator on Long Island one of controlling the breeding on and adjacent to these tidal marshes since the results of any other work would be largely nullified if not preceded by adequate control of the marsh breeding. The control of the marsh breeding is obtained largely by ditching (figure 34), the ditches being installed either by machines or manual labor with specially devised spades (in a few cases they were dug by the use of dynamite).

These ditches do not drain the marshes because of the daily and monthly rise and fall of the tides. True drainage can be obtained, and has been in some places, particularly in New Jersey, by the installation of dikes and automatic tide-gates in conjunction with ditches. Although this method was tried on the north shore of Long Island during 1900-2, it has never been in general use on Long Island and no dikes or tide-gates exist there today. The formation of the marshes and the lay of the land render their use on Long Island prohibitive and otherwise undesirable.

In the absence of dikes and tide-gates, the daily high tides rise over the lower marshes and the monthly high tides cover practically all the salt or tidal marshes. The system of ditches, then, allows

the bulk of the surface water to drain off at low tides, usually to be replaced by more water at the next high tide, and allows more complete accessibility of all parts of the marsh to killfish, which are voracious destroyers of mosquito larvae. This technic has been called "concentrating the water on the marshes in the ditches," and to a large degree this is true. It certainly is not true drainage of the marsh.

For most effective results these ditches should not be too long. The size most commonly used is a ditch 10 inches wide and 20 to 30 inches deep with perpendicular sides; but main ditches receiving numerous spurs are frequently made two cuts wide, the width increasing a few inches each time the ditch is recut. The greater the tide drop and the shorter the ditch, the greater is the efficiency of the ditch and its ability to keep itself clean. When possible the ditch should be planned so as to have a strong tidal outlet; and as a general rule, no ditch depending on a single outlet should be more than a quarter of a mile in length. Longer ditches are less efficient and tend by the rushing waters of the ebb and flow of the tides to wear more rapidly and to require an excessive amount of maintenance work. In Suffolk county certain ditches have been made considerably longer than a quarter of a mile. The author knows of one such ditch in Suffolk county that, seemingly unnecessarily, is more than a mile in length and perfectly straight. It must be admitted, however, that the conditions at this point are unusual. This ditch is located between Great South bay and Moriches bay in an area where the tide-drop is very slight, averaging 6 to 8 inches difference between daily high and low tides. This may offset the usual excessive wear of a long ditch (the ditch itself is too recent to judge from). The ditch does seem to fulfil its purpose despite its length.

Another technic was developed in Nassau county and to date has been used only in that county. A machine called a "mole plow" is used to dig subterranean tunnels through the marsh turf, and these "mole ditches," like open ditches, allow free entrance and egress for the tides. The advantage lies in the elimination of the various objections to open ditches while accomplishing the same results. Perhaps the greatest single advantage lies in eliminating the vegetative changes that occur along open ditches. Marshes treated in this manner in Nassau county in 1932 showed no vegetative changes by the end of 1936 although control of mosquito breeding was obtained by virtual elimination of the standing water on the marsh. These underground ditches continue to function now, four years after installation, although they have received no maintenance work and



FIGURE 25 Pool dug on salt marsh with elevated island in center. At low tide when this photograph was taken the area is partly dry but when construction is completed tide gates are to be installed to maintain a constant depth of water yet allow entrance of tides and killifish. Along north shore of barrier beach south of Shinnecock bay.



FIGURE 26 A view of extreme western end of the same pond showing connection with mosquito ditches and with the bay (extreme background). This photograph also shows excavated turf piled around the outer margins as well as on the central island.

are at times located only with difficulty (Nassau County Extermination Commission, 1934).

Cleaning. Mosquitoes breed almost exclusively in stagnant or scarcely moving water. Accordingly the area of available breeding places on the uplands can frequently be reduced greatly by cleaning and straightening the margins of creeks and streams so as to eliminate as far as possible the eddies and stagnant pools along the margins (figure 31). This work, like the cleaning of open ditches, must be repeated at frequent intervals, preferably every year, to eliminate the obstructions and changes that develop from time to time and form new breeding spots.

Filling and impounding. Filling followed by proper grading eliminates the possibility of breeding in the area so treated. New York City has taken advantage of the vast amount of dump material available in the metropolitan area, and has had large quantities of this utilized under the direction of the mosquito commission to fill and eliminate from the roster of mosquito-breeding places numerous spots, especially ones that could not be drained readily.

Real estate developments have resulted in such a reduction of the size of the salt marsh areas in Nassau county that today there are only approximately half as many feet of salt marsh ditches as there were when the original installation of ditches was completed about 15 years ago. Today there are only about four million feet of salt marsh ditches in Nassau county. Hydraulic filling of the marsh areas is being continued, and there are persons who think that the salt marsh areas of western Long Island will eventually be practically or completely eliminated by this process.

Theoretically the filling in of marsh areas by hydraulic fill for real estate developments should result in complete elimination of mosquito breeding from such areas; but in actuality it frequently does not. In the first place, this fill is usually placed along the water front; and when, as frequently happens, the entire area is not filled, the marsh on the upland side is cut off from the bay and creeks (into which the mosquito drainage ditches must open), and new ditches must be cut to connect the area with the bay. Because of the lay of the land these ditches are often not thoroughly satisfactory, and constant patrol and frequent oiling are necessary because of flooding by rains. Secondly, when the fill contains much mud it may crack on drying, and these cracks hold water and breed mosquitoes (figure 32). Thirdly, at times such a real estate development may not mature as anticipated, and the fill dumped on irregularly may be

abandoned for some years without grading. When this occurs pockets are formed between the hillocks of the fill. These pockets hold water, breed mosquitoes and at times are difficult to treat. A bad example of this is at the northeastern end of Jamaica bay (Brooklyn). And, finally, the parts of the fill that are not immediately utilized tend to become covered with dense growths of fox-tail grass which renders both inspection and oiling difficult and deters evaporation of surface water. So, while real estate developments of this sort may eventually eliminate large areas of marsh land, they always require close inspection by the mosquito commission for several years; and, in parts, not infrequently require continual attention.

The impounding of water to form reservoirs, and the stocking with fish, and maintenance of these reservoirs with clean margins has been a big help, particularly in southern Nassau county, in eliminating a considerable number of marsh areas, both in the higher uplands and on the upland adjacent to the tidal marshes. Much of this type of control and improvement has been done in the parks by the Long Island Park Commission. Rarely does this lead to trouble when the reservoirs are properly maintained, but there is one series of ponds in southern Nassau county that were formerly free from mosquito breeding, but which, following use of this stream as a drainage for the local sewage plant, has become a serious mosquito menace, partly because of the virtual elimination of the fish in the ponds, partly because of the high organic content of the water, aiding and accelerating mosquito (*Culex pipiens*) development.

Cesspools. The eastern half of Long Island, including much of Nassau county, has no sewage system despite the density of its population. Eventually there probably will be such at least throughout Nassau county; but at present, thousands of cesspools are to be found, even many in communities that have sewage systems. These cesspools, unless tightly sealed or buried, breed *Culex pipiens* in countless millions. While the necessity for house-to-house inspections will not be eliminated by the universal installation of sewers, the numbers of the house mosquito that succeed in emerging and plaguing the community will be greatly decreased by the elimination of all cesspools, and the yard inspections performed by the house-to-house inspection force will be speeded and yet give better results.

In this connection it might be well to mention the serious breeding possibilities of sewage filter beds. These filter beds are ideal breeding places for the house mosquito (*Culex pipiens*), and require

at least weekly inspections. The only satisfactory control is obtained by oiling. This kills the mosquitoes present, but the oil is soon destroyed by the bacteria in the sewage. Even so, it is far easier and far less expensive to control breeding on a few filter beds than in a thousand scattered cesspools.

Pastures. Dairy farms, particularly when on the edge of the salt marsh frequently present special difficulties and require constant attention. When cattle are allowed to graze on ditched land it is almost impossible to keep the ditches open and functioning. The cows tend to cross habitually at certain places, and damage the ditch and more or less completely block off the part above where they cross (figures 35-37). Even this, however, is not so serious as the innumerable hoofprints the cows make in all the soft parts of the pasture. These hoofprints (figures 39-40) hold water very effectively, both rain and tidal, and breed hordes of mosquitoes unless constantly patrolled and oiled at very short intervals throughout the entire season. Large amounts of oil or larvicide are required on such pastures as all the damp areas have to be sprayed generously. The worst example of this seen on Long Island by the author is the Rice Milk Dairy, Merrick, Long Island, a large pasture extending from the upland far out onto the large adjacent stretch of salt marsh. The size and seriousness of such areas may be judged from the fact that the Nassau County Commission was forced to spray eight hundred gallons of larvicide on this one pasture on September 24, 1936 (figures 33-42).

Oiling. The most satisfactory oil to use is a number 2 fuel oil. The New Jersey Agricultural Experiment Station recommends an oil with a specific gravity of 32-37° Baumé, flash point of 150°F., cold test: pour at 0°F., boiling range 350-675°F., color straw to yellow, viscosity 50-100 Sayb. /100, and a surface tension of 20 dynes per cm. These specifications are approximately those of number 2 fuel oil. Light oils have a direct toxic effect but poor lasting quality; heavy oils have good lasting quality but little or no direct toxicity and kill chiefly by suffocation. Intermediate oils, such as number 2 fuel oil, combine to a certain degree all the desirable properties (high toxicity and long lasting powers) and are accordingly most generally satisfactory. (Ginsberg, 1929.)

Larvicide. Dr J. M. Ginsberg, of the New Jersey Agricultural Experiment Station, has developed a synthetic larvicide, partly because of the need for something to replace the use of oil in certain situations. The active ingredient is pyrethrum. The chief advan-

tages of this mixture lie in the fact that used properly it is not toxic to plants or fish and does not leave an unsightly mess: Accordingly it can be used on ornamental ponds where fish are present, but where the vegetation, particularly algae and grass grown margins, is so dense that the fish can not destroy all the mosquito larvae. It is also used on bird sanctuaries, duck farms etc, where oil might injure the birds. In addition it can be used for general work except as noted below. Incidentally this mixture is cheaper to use than oil.

The formula and method of preparation in use on Long Island today are:

- 1 Put 100 gallons of light fuel oil in tank.
- 2 Add sufficient pyrethrum extract to equal 1 pound of dried flower heads to a gallon of oil ($6\frac{3}{4}$ gallons of an extract of pyrethrum, each gallon of which is equivalent to 15 pounds of dried pyrethrum flower heads).
- 3 In second tank put 50 gallons of water.
- 4 Add 6 pounds of gardinol (Duponol) to no. 3.
- 5 Mix water and gardinol until foam begins to form.
- 6 Add oil containing pyrethrum (nos. 1 and 2) slowly. When all the oil has been added continue pumping until the entire mixture has passed through the hose and back into the tank at least three times (20-30 minutes).

This makes what is called the concentrated solution. This concentrated solution is mixed with nine times its volume of water before use. The diluted solution has killing powers comparable with oil.

In a study comparing the efficiency of this larvicide with that of oil, Ginsberg (Proc. 21st Ann. Mtg N. J. Mosq. Exterm. Ass'n 1934) reports that the larvicide is as efficient as oil, despite its very short lasting power, on:

- 1 Clear, fresh or salt water
- 2 Ornamental ponds
- 3 Swimming pools
- 4 Fish and game preserves
- 5 Catch basins
- 6 Filter beds that have no scum

but that it is decidedly less effective than oil on:

- 1 Fresh or salt water covered with heavy vegetation or débris
- 2 Filter beds heavily charged with sewage and scum
- 3 Salt water covered with a heavy scum
- 4 Places where the long-lasting effect of oil is absolutely essential



FIGURE 27 Another partially finished pond in the salt marsh (compare figures 25 and 26). In this case the excavated turf is all piled on the central island. Along north side of barrier beach south of Shinnecock bay.



FIGURE 28 A view of the extreme western end of the same pond showing connection with mosquito ditches

Mechanics of spraying. Large-scale spraying can be economically applied (and most satisfactorily dispersed) only by pressure pumping from a specially fitted tank truck. Such trucks are also most efficient for other kinds of spraying such as catch basin routes. Smaller jobs, where only a little oil or larvicide is used, may be handled with hand-pressure spray cans, or, as a last resort, with a garden watering can.

In Nassau county it was shown in 1934 that large marsh areas, or even such relatively small areas as filter beds, could be economically and satisfactorily sprayed by means of an autogiro. This is especially true of periods of peak load, when due to unusual tides or rains or both, breeding is occurring over most or all of the marshes, and it is necessary to apply large quantities of oil or larvicide over a wide acreage in a few days. Although proved satisfactory, the method has not come into general use, perhaps because such peak-load periods (the only time such a method is needed) are not sufficiently often to warrant the reservation of planes for this purpose.

Another highly efficient type of spraying, known as "marginal oiling," was devised in Nassau county. The eggs of the various species of *Aedes* are laid not directly on the water, but on wet mud near the water. They later hatch upon the stimulus of wetting. Accordingly, the Nassau County Commission has for several springs sprayed the banks of certain streams and ponds with oil. This spraying serves the dual purpose of killing such mosquito eggs as are present above the water line, and so reducing the size of the early broods that hatch in those places, and killing the marginal vegetation, and so tending to form cleaner margins—a decided advantage in mosquito control.

Natural enemies. The only efficient natural enemies are top-feeding minnows, both fresh and salt-water forms. These will be discussed in the section on biology of Long Island mosquitoes.

GENERAL COMMENTS

Educational programs. These are carried on more or less extensively by all mosquito commissions. The aims are twofold: (1) to retain support for the commission and its work, (2) to awaken the cooperation of the citizens in cleaning up domestic breeding and domestic breeding places. The second aim is far more difficult to realize than the first. A portion of the people do cooperate actively but the remainder are either apathetic, well-meaning but dilatory, uncooperative or openly opposed to the program. Little or nothing

can be done with the latter types unless the commission risks public censure by serving them with a summons for committing a misdemeanor by maintaining mosquito breeding situations on their property.

Educational programs take a number of forms. Perhaps the most productive form is the contact between the inspectors and the residents, particularly when breeding is found on the premises and can be shown to the resident. At this time the inspector can point out how this breeding might have been prevented by simple precautions on the part of the resident, and at the same time comment on other sources of breeding that he sees might occur on the premises. This is further advanced if the inspector can leave a short pamphlet, such as the House-to-House Circular of the Nassau County Commission, setting forth the types of violations likely to be found on residential premises and the precautions that should be taken to avoid the possibility of domestic breeding.

Lectures to progressive civic organizations and schools covering the activities of a mosquito commission, the places where mosquitoes breed and the methods used to control the various types of breeding are another important feature of educational programs, especially when illustrated by motion pictures.

A third important feature of these programs is exhibits of various types placed in public places. Such exhibits usually contain photographs of various types of violations and methods of correcting them, particularly types of domestic breeding places, samples of breeding, and educational or "advertising" leaflets that may be taken by interested persons.

Other forms of public education are sometimes used: newspaper releases, signs on the marshes calling attention to mosquito control work there etc.

Activities of local groups today. The first mosquito control work on Long Island was performed, and excellently executed, by local civic groups. Today the situation occasionally arises where the county commissions are unable for financial reasons to give the degree of inspection and control that they would like. This is especially true of house-to-house inspections, which, because of the number of inspectors required, are expensive. As a last resort, local action is always justifiable but it is not so effective, at least not for the sum expended, as an efficient county commission supplied with necessary funds.

There are two current examples on Long Island. Due to the decreased budget of 1934, the Nassau County Commission was



FIGURE 29 Typical "salt hole" on the salt marsh. Such sheet-water areas are the favored breeding places of the salt-marsh mosquitoes and frequently become little more than wet masses of larvae and pupae of *Aedes sollicitans*. Jones Beach Bird Sanctuary. This is the "salt hole" from which larvae and pupae were obtained for the tests summarized in tables 18 and 19.

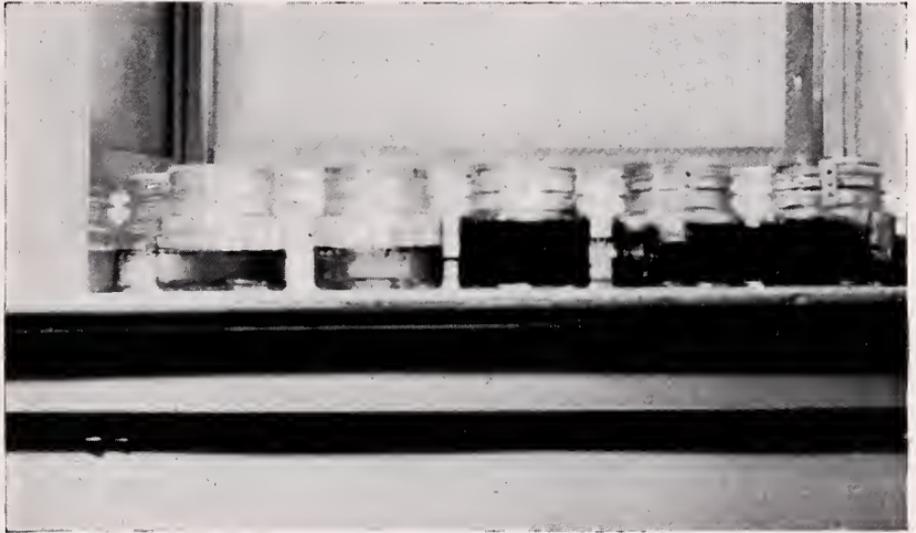


FIGURE 30 Set-up used for the tests summarized in tables 18 and 19. The two jars on the left contain only water and mosquito larvae and pupae (table 18); the central jar is one of the controls containing mud and turf; the two jars on the right contain damp turf (table 19).

forced to curtail its house-to-house inspections. Certain communities became dissatisfied and one of these formed a local mosquito unit. This unit could not function as efficiently as the county commission because, first, it did not have the authority to enter any and all property (it circumvented this by assuming this authority and, encountered no difficulty); second, it had to patrol more than its own territory, and even so would have had its results nullified were it not for the field activities of the county commission; third, having no modern equipment and being too small a unit to consider obtaining such, it had to use the crudest of manual methods with consequent inefficiency; and fourth, the results obtained seem out of proportion to the expenditure since the same sum added to the budget of the county commission would have produced greater general results because the commission has the best of equipment and furthermore the local group was to a considerable degree duplicating the county commission's efforts. At the time this group began its activities in 1934 the additional work was certainly needed, regardless of the source from which it came; but now that the county commission has had its budget restored, it would seem better for the local group to withdraw and turn the work back in full to the county commission as its predecessors did in 1918.

The second case has been mentioned above. The Suffolk County Commission, finding house-to-house inspections very expensive, dropped this phase of activity. In a few villages the work was continued locally during the remainder of the 1936 season.

These cases have been mentioned, not to disparage local activities, but in an attempt to show that local groups, (1) depend on the more general activity of the county commission and yet frequently duplicate the work of the county commission, (2) are likely to encounter legal difficulties, (3) do not obtain, as a rule, as effective control per dollar expended as a countywide unit, and (4) are to be considered only as a last resort since the same funds will usually produce greater results when administered by a commission with wider authority.

Effect of the Long Island Park Commission's work. On the whole, this commission has greatly aided the mosquito control program, as already mentioned, by making reservoirs of bad breeding marsh areas when possible on park property and maintaining these reservoirs in good condition. When, as in Heckscher park, considerable marsh occurs, it has cooperated with the mosquito commission in having these areas properly ditched (by the mosquito commission, of course). One of the park commission's projects, how-

ever, has caused some difficulty, namely, the long causeways leading to Jones beach. These areas of hydraulic fill are graded off unevenly to the bay, especially the Meadowbrook causeway, and hold sheet water that must be constantly inspected. Near the upland matters are more serious for the hydraulic fill tapers off across the marshes, blocking the former ditches and holding sheet water that frequently breeds immense numbers of mosquito larvae (figures 32-33).

Relation of mosquito control to wild life. In recent years considerable criticism of mosquito control has been raised by naturalists who claim that the methods used to control mosquitoes are injurious to the wild life of the salt marshes, especially water fowl. Although this is the primary cause for the present work being sponsored by the New York State Museum, it is not the author's purpose to enter into a detailed discussion of this difficult subject in this preliminary, reconnaissance report. Certain studies are in progress, others planned, which when completed should give a sounder basis for discussion. A few, largely obvious facts seem worth recording, in some cases repeating, here.

Long Island, especially the western half, is essentially a residential suburb of New York City. As such, the problem here has some different aspects from that of areas elsewhere that are far removed from great metropolitan centers. One of the most fundamental points is that the desirability of waterfront real estate has led to an enormous amount of hydraulic filling of the marshes. This has already resulted in a reduction of the salt marsh acreage of southern Kings county and Nassau county to approximately half of the original amount. There are those who think, and not without reason, that there will be an eventual loss of all the marshes, except possibly some of the lower islands which are so tide-swept as not to be serious mosquito breeding grounds and not especially adapted to the needs of water birds.

Because of this residential development, present and future, no large sanctuaries and no hunting grounds of any consequence seem likely to be permanent, at least on the western half of Long Island, unless they are purchased and endowed or turned over to a permanent institution. The conditions mentioned above would render any sanctuary in western Long Island largely of only secondary educational value, but on such a basis it could become a very worth while project.

In such a region human health and comfort are of greater importance than the abundance of game and other birds. Desirable



FIGURE 31 Pocket of still water along margin of small creek overgrown with vegetation and with a small amount of *Chara* sp. on the surface of the water. Upland part of pasture of the Rice Milk Dairy, Merrick. When this photograph was taken (September 14, 1936) *Culex pipiens* and *C. territans* (= *restuans*) were breeding here.



FIGURE 32 Mud flats of hydraulic fill extending from the Meadowbrook causeway in the background onto the upland and salt marsh pasture of the Rice Milk Dairy. An old mosquito ditch, obliterated by the hydraulic fill, is defined by the double row of shrubs in the center of the picture. When flooded by either tides or rains, as it frequently is, this area breeds mosquitoes prolifically (the species of mosquitoes depending largely on the salinity of the water.)

though the latter are, they must inevitably give way to the former unless some practical and workable compromise can be reached whereby both may continue. It is toward this end that several of the agencies of the Federal Government and numerous state and county departments are bending their efforts.

One of the first attempts to circumvent this and other difficulties was the development of the "mole plow" by the Nassau County Extermination Commission in 1932 (see section on ditching). Judging from the present conditions of marshes ditched four years ago, the use of this plow accomplishes mosquito control, eliminates most of the open ditches, does not cause noticeable vegetative changes, and accordingly would seem to have a minimum effect on the marsh and its wild life. Unfortunately, due to circumstances outside its control, the Nassau County Extermination Commission has not been able to put this system into full use, and for divers reasons the method has not been tried elsewhere.

Three other studies on Long Island should be mentioned. Norman Taylor, for many years a botanical ecologist on Long Island, carried out studies for the New York State Museum on the relation of tide levels to the vegetation of ditched and unditched marshes and the effect of ditching on the vegetation of Long Island salt marshes.

The Suffolk County Mosquito Extermination Commission has dug several ponds in the marshes along the barrier beach south of Shinnecock bay and connected these ponds with the bay by ditches. When completed, gates are to be placed at lower ends of the ditches to maintain the water at a predetermined level slightly lower than the general surface level of the marsh. The water is to be sufficiently deep to allow a resting place for ducks and also to allow killifish to live there constantly although they may go in and out on monthly high tides. These ponds, of an experimental nature, are of several types: in some the sod is placed around the edges, in others it is placed in the middle, presumably to allow land-cover for the birds. Unfortunately, the Suffolk County Mosquito Extermination Commission does not intend to place any vegetation on the piled-up sod and no one else seems likely to do so. The elevated sod will doubtless die as it dries and as the salt is washed out by rain, and natural vegetation will be rather slow in developing. The idea of building such ponds is to allow resting places, especially for ducks during bad weather. It remains to be seen how valuable these ponds will be but they are certainly a commendable experiment (figures 25-28).

In a study relating to the spacing of mosquito ditches, the New York City Mosquito Commission is in the process of making a study of the changes, if any, in subsurface water level (soil water table) due to the introduction of mosquito ditches on a salt marsh. This work is being done under the direction of Herman L. Fellton.

Many statements without factual basis have been made during the course of this controversy. No comment will be made on them here except to point to these experiments and observations on Long Island, and others that are being performed elsewhere as the bases on which the case will be eventually settled. Mosquito control in one form or another will certainly continue in and near densely populated areas.

On Long Island so much of the controversy has been waged over the Jones Beach Bird Sanctuary that a few statements concerning it may not be amiss. Within recent years this area has been successively in the hands of private sportsmen (for duck hunting), the town of Oyster Bay (the real owners), leased to the Long Island Park Commission as a bird sanctuary, then leased to the United States Bureau of Biological Survey as a migratory water fowl preserve, and since August 1, 1936, when the Federal Government refused to continue its free lease, it has been lying idle in the hands of the town of Oyster Bay.

Records of the Nassau County Extermination Commission show that this area was completely ditched more than 12 years ago. Accordingly, any deleterious effects of the ditching should have been felt long since and before the installation of raisable gates. As these were not considered satisfactory by the caretaker because of the continual attention required, solid dams in the key ditches were built (figures 23-24). Since August 1, 1936, these dams have been undermined and now the tides ebb and flow freely.

How much value this small area possesses as a sanctuary may be judged from the refusal of the Bureau of Biological Survey to continue holding its lease, even with the mosquito ditches dammed. This action was in part due to the small size of the sanctuary, but it was in part motivated by the unsatisfactory status of the water fowl. The status of the wild life seems in no small part due to the changes concurrent with the development of Jones beach, the construction of the state road along the barrier beach, and the cutting of a state boat channel along the inner side. In the course of building the road a vast amount of sand was pumped across the marsh and transformed the greater part of that portion of the future bird sanctuary south of the boat channel into an area of hydraulic fill (figure 43). Most



FIGURE 33 Ditch on salt marsh with mud flats of the Meadowbrook causeway in the background. In the foreground are many pockets resulting from hoofprints made by the cattle. Rice Milk Dairy, Merrick.



FIGURE 34 Typical ditch in good condition on the upper part of the salt marsh. Pasture of the Rice Milk Dairy. Vegetation *Spartina alterniflora* with a patch of *S. patens* in the right center. The water of this area is salt or brackish and breeds accordingly.

discussions this author has heard have overlooked the fact that this is a far more fundamental change than anything that may conceivably have resulted from the ditching by the mosquito commission. Yet it was only after this that the area became a bird sanctuary. It would seem that if any area could have possibilities as a sanctuary under such conditions, one of the compromise arrangements possible with the mosquito commission could make the mosquito work certainly not unduly deleterious to the bird life. (A project has been partially planned to eliminate the more serious mosquito breeding areas by transforming them into ponds and impounding the water in fundamentally similar manner to, but more extensive than, the experimental ponds mentioned above as being constructed in Shinnecock bay. It is still uncertain whether or not this plan will be carried through. Incidentally, the large pond on the sanctuary needs dredging as it is so shallow that late in the summer season of 1936 it dried out almost completely and became virtually a large mud flat.)

Mosquito-borne diseases. Near the end of the last century, the discovery that malaria is transmitted by certain mosquitoes gave increased interest in the possibility of mosquito control and resulted in the devising and perfecting of methods of control. This, together with the effects of mosquito control on human comfort and real estate values, resulted in the laws and appropriations that rendered general work possible. The discoveries a few years later proving that yellow fever, dengue and filariasis are also transmitted by mosquitoes gave added impetus to man's war against these dangerous and annoying insects. A few other diseases of man and animals are now known or thought to be transmitted by mosquitoes but since malaria is the only one that has been important on Long Island it is the only one that will be mentioned here.

It is now quite generally known to the public that mosquitoes are responsible for the transmission of malaria, and that adequate mosquito control results in control of the spread of this disease. This is well illustrated by the history of malaria on Long Island. Before the World War tertian malaria was a common disease here. Complete statistics are not available but a small section of Nassau county had 475 cases in 1914 and 476 cases in 1915. In 1916 the mosquito commission was authorized by law on a countywide basis, and in this year the number of cases dropped to 57 for the entire county. In 1917, the first year of full countywide activity of the mosquito commission, the number dropped to 51. In 1918, the second year of full activity of the commission, the number of cases dropped to five,

in 1919 to three, in 1920 and 1921 none were reported, and in 1922 only two cases were reported. From 1922 to 1936 no cases have been reported from Long Island that have not been proved to have been contracted elsewhere or to be erroneous diagnoses or due to other causes such as blood transfusion.

Actually this reduction in malaria on Long Island can be due only in part to the activities of the mosquito commission. For largely unknown reasons malaria decreased to almost nothing, and its most important vector in this region, *Anopheles quadrimaculatus*, decreased greatly in numbers in both controlled and uncontrolled areas in northeastern North America. For instance, Suffolk county had no mosquito control program until a few years ago yet malaria has disappeared there as well as in Nassau county, and it disappeared at about the same time. Headlee suggests water pollution as the cause of the decline of the species. This might explain the decrease in urban New Jersey but does not seem possible in more rural sections. Matheson suggests that extremely cold winters such as that of 1917-18 probably destroyed the hibernating adults of *A. quadrimaculatus*, because he has seen very few of this species since then. In central New York *A. quadrimaculatus* has been replaced in the biota by *A. maculipennis*, also a serious vector of malaria, but *A. maculipennis* is not known from Long Island and *A. quadrimaculatus* is still to be found in small numbers. If one is to say that *A. quadrimaculatus* has been replaced in the biota of Long Island by another mosquito, it must be by a nonvector of malaria. The author does not consider any of those suggestions adequate for general application but can think of no alternative or supplementary suggestions.

Malaria is transmitted only by certain species of the genus *Anopheles*. These include all of the three species known to occur on Long Island, namely, *Anopheles punctipennis*, *A. crucians* and *A. quadrimaculatus*. Of these, *A. punctipennis* has been made to transmit the parasite under laboratory conditions but seemingly rarely or never does so in nature. *A. crucians* is an important vector in the Southern States but for unknown reasons seemingly is not in the Northern States since its distribution and prevalence have shown no correlation to the distribution of malaria. *A. quadrimaculatus* is the serious vector and seemingly the only important vector on Long Island.

On Long Island *A. punctipennis* is common, *A. crucians* uncommon, and *A. quadrimaculatus* very uncommon with present control methods. So long as *A. quadrimaculatus* continues to be controlled



FIGURE 35 Ditch on upland pasture adjacent to salt marsh, showing complete blocking of the ditch by cows making path across it. Rice Milk Dairy, Merrick.



FIGURE 36 Another ditch on upland pasture adjacent to salt marsh, showing how the edges are broken down by cows at places other than their regular paths. Rice Milk Dairy, Merrick.

so that adults are rare, as they are now, no serious outbreak of malaria need be feared unless *A. maculipennis* is introduced and becomes established. But if *A. quadrimaculatus* is ever allowed to increase to its former abundance an outbreak may occur any year since there are always a few persons carrying the parasite in their blood, but apparently not suffering from the disease, and since occasional persons coming to or returning to the metropolitan area bring back the disease from the South and from the Tropics.

State law relative to mosquito control. The following excerpts from article 21 of chapter 408 of the State Laws of 1916 cover the points of law that are of general interest. They show the nature of the commission, its duties and powers. The other sections, as their titles indicate, are not of general interest. The quotations given below are from a copy of the laws for Nassau county but the laws for Suffolk county, passed in 1934, are in all fundamental respects similar. These laws became effective for Nassau county on May 3, 1916 (sections 411, 412 and 413 were amended effective March 23, 1922, chapter 196 of the State Laws of 1922).

County Mosquito Extermination Commission

Section 400. *Establishment; appointment of commissioners.* In any county of the State of New York, having a population of less than two hundred thousand adjacent to a city of the first class, having a population of over three million there is hereby created an appointing board to consist of the county judge, the county clerk and the county comptroller, to be known as "The (here shall be inserted the name of the county in and for which such appointing board shall act) County Board" for the appointment of a county mosquito extermination commission, as hereinafter provided. The members of such appointing board shall serve without pay, except that the necessary expenses of each member for actual attendance at any meeting of such board shall be allowed and paid. Within ten days after the presentation of a petition signed and acknowledged in the same manner as are deeds entitled to be recorded, by two hundred residents of such county, it shall be the duty of the county judge to convene the said board, at the most suitable and convenient place, or otherwise arrange for concerted action, for the appointment of four resident taxpayers in any such county, who, with the chairman of the board of supervisors and one member, to be appointed by the state commissioner of health, as provided by sections four hundred and one and four hundred and two of this article, shall constitute a board of commissioners to be known as "The (here shall be inserted the name of the county in and for which the commissioners are to be appointed) County Extermination Commission."

401. *Chairman of board of supervisors ex-officio member.* . . .
402. *State commission of health to appoint one member of such commission.* . . .
403. *Members to serve without compensation.* . . .
404. *Commissions; terms of office.* . . .
405. *Official oath; officers.* . . .
406. *Commission a body corporate and politic; powers.* From and after the appointment, qualification and organization of such commissioners, such mosquito extermination commission shall become and be a body corporate and politic, under the name given in such petition, and by such name and style may sue, be sued, execute contracts, have a corporate seal, and shall have all powers herein conferred upon it within the counties wherein it is appointed.
407. *Secretary of commission; salary.* . . .
408. *Clerks and assistants.* . . .
409. *Duties of clerks and assistants.* . . .
- 409-a. *Accumulation of water a nuisance.* Any accumulation of water in which mosquitoes are breeding, or are likely to breed, is hereby declared to be a nuisance.
410. *Powers and duties of commission.* Said commission shall use every means feasible and practicable to exterminate mosquitoes, of every variety, found within the county for which such commission is appointed. Such commission shall have the power and authority to enter without hindrance upon any or all lands within the county for the purpose of draining or oiling the same and to perform all other acts which in its opinion and judgment may be necessary and proper for the elimination of breeding places of mosquitoes or which will tend to exterminate mosquitoes of fresh water, salt water and every other kind of variety found within such counties.
411. *Publication of notice of entry, claims, damages and payments.* . . .
412. *Estimate of annual requirements; powers and duty of state health commissioner.* . . .
413. *Powers and duties of boards of supervisors.* . . .
414. *Disbursements by county treasurer.* . . .
415. *Annual report.* . . .
416. *Reservation of powers.* . . .
417. *Temporary provision for nineteen hundred and sixteen.* . . .
418. *Obstructions; interference.* Any person who obstructs or interferes with the entry of the commission or its employees upon land or who obstructs or interferes with, molests, or damages any of the work performed by the commission shall be guilty of a misdemeanor.

NOTES ON THE BIOLOGY OF THE MOSQUITOES OF LONG ISLAND, N. Y., WITH SPECIAL REFERENCE TO THE SPECIES FOUND ON AND ADJACENT TO THE SALT MARSH

THE SALT MARSH AND ADJACENT UPLANDS

Low salt marsh islands. Islands that are so very low that they are covered by the average daily high tides present no mosquito problem since the presence of killifish and the daily flushing preclude the possibility of mosquito breeding. There are many other islands which may be called "low," but which are sufficiently high not to be swept by the average daily tides and are sufficiently low to be completely covered by the monthly high tides. Of course, whether an island presents a problem or not depends on the tidal range or fluctuation rather than on the actual elevation of the island. In areas where the range of tides is relatively great, for example, Jamaica bay, a higher island can be considered "low" from a mosquito breeding standpoint than in areas where the range of tides is not so great, for example, the area between Great South bay and Moriches bay.

The Jo-Co marsh in Jamaica bay will serve as an example of an island marsh that is not a mosquito breeding menace. The marsh was ditched about 1917 as part of the contract for ditching all the marshes of Jamaica bay (see pages 88-91). Since then it has received no maintenance and the ditches have practically disappeared although their position can be determined by very slight linear depressions that remain. The ditches are completely overgrown with *Spartina alterniflora* and are functionless (figures 21-22). Because no breeding has been found on this island in recent years, the New York City Mosquito Commission has not recut the ditches. The same is true of a number of other islands in Jamaica bay. The suggested explanation given by the New York City Mosquito Commission is that the tidal range in Jamaica bay is so great that these islands are completely swept by the monthly high tides, and, presumably killifish are introduced sufficiently often so that, with evaporation and natural drainage or seepage, mosquito breeding is negligible.

East Fire island in Great South bay is an example of a low island that is a serious mosquito breeding problem. Although seemingly no higher than Jo-Co marsh, the tidal range there is not so great, seepage and natural drainage seemingly are not so good, and numerous bare, slightly sunken areas hold sheet water several inches deep. These

areas of brackish sheet water breed the mosquito *Aedes sollicitans* in countless numbers.

The apparent differences between islands such as Jo-Co marsh, which does not breed mosquitoes, and East Fire island, which does, are the tidal range and the topography. Differences also exist in the invertebrate forms of the two marshes but the author suspects these are likely by-products of the tidal range and not particularly concerned with mosquito breeding. The greater tidal range allows more frequent and stronger sweeping by the tides, more frequent access to the marsh of killifish, and the washing away of "tidal float" (figure 21), which if left in one spot causes decay of the underlying vegetation and formation of bare depressed areas. The topography is partly a by-product of the tides, particularly the bare, depressed areas due to tidal float. Bare spots are also caused by other things, such as scalding and sulphur bacteria.

The water on such low islands usually has the same salinity as the water of the bay surrounding the island. Hydrometer tests made at East Fire island on July 1, 1936, showed the same salinity for water from the bay channel, island creeks and sheet water areas well inland. The salinity is so high that it is favorable only to the development of *Aedes sollicitans*. Accordingly, as one would expect, a rough census of the mosquito population on East Fire island on July 1st, showed hordes of *A. sollicitans* and only a few *A. cantator* present. The author estimated from rough counts of the specimens alighting on his person that at least 200 and possibly 400 *sollicitans* were present for each *cantator*.

Higher salt marsh islands and salt marsh along edge of uplands. Biologically the most interesting point is the sequence of species in relation to the degree of salinity of the surface water. An excellent picture of this sequence was seen on the large pastures of the Rice Milk Dairy at Merrick (figures 32-42). On August 19, 1936, during low high tide period no breeding was found in the lowest, most saline portions of the marsh; a fair amount of breeding was taking place in the higher brackish and fresh water areas. At the lower edge of the breeding areas, mature larvae of *Aedes sollicitans* and small and medium-sized larvae of *A. cantator* were found breeding together in a ditch filled with water giving a hydrometer reading of 1.016 at 83° F. (figure 34). (Clear fresh water has a specific gravity of 1.0; salt water from the bay and ocean along Long Island has a specific gravity of about 1.023-1.024. Intermediate readings indicate brackish water. The method is subject to some error due to the effect



FIGURE 37 Ditch without water on pasture, showing how the bottom is covered with holes, (that retain water until it evaporates) made by cows' hoofs. Rice Milk Dairy, Merrick.



FIGURE 38 Same ditch as figure 37 but from slightly different position and on day when filled with water. Rice Milk Dairy, Merrick. This ditch usually contains fresh water and was found to be breeding *Aedes sollicitans*, *A. vexans*, *A. taeniorhynchus* and *Culex pipiens* on August 19, 1936 (hydrometer reading 1.0081 at 83° F.); storm tides cover this area with salt water and after such a tide this ditch was found breeding a pure culture of *Aedes sollicitans* on September 24, 1936.

of other matter than salts in the water but seems sufficiently accurate for field salinity determinations so long as fairly clear water is used for the determination. Rain water on upland marshes adjacent to a salt marsh, even when turbid gives a hydrometer reading of only a small fraction over 1.0. Higher temperatures lower the reading slightly and occasionally result in obtaining a reading below 1.0. The error in salinity determinations as determined by hydrometer readings, when an error occurs, is always in the direction of indicating too high a salinity, never too low. Water can not contain more salts than the hydrometer reading indicates.) Farther upland three different breeding places filled with rain water yielded respectively in the first, larvae of *Aedes vexans*, *A. taeniorhynchus* and *Culex pipiens* (hydrometer reading 1.0081 at 83° F.) (figure 38); in the second, larvae of *Aedes sollicitans* (hydrometer reading 1.0075 at 82° F.) (figure 40); and in the third, larvae of *Aedes vexans* (hydrometer reading 0.998 at 84° F.) (figures 41-42). On this date, then, the area could be divided into a saline area, the lower part of the marsh, that was not breeding; an intermediate strip that was highly brackish and contained larvae of *Aedes sollicitans* and *A. cantator*, and a higher area inundated by rain water that contained larvae of *Aedes vexans*, *A. taeniorhynchus*, *Culex pipiens* and one culture of *A. sollicitans*.

On August 28th, just prior to the monthly high tides, approximately the same distribution of species was found on this pasture. On September 14th the area was almost wholly dry. On September 24th, however, the area was again badly flooded by both tides and rains and breeding heavily, but the distribution of species was greatly changed, this change being well correlated with the change of salinities. The high storm tides of the preceding week carried the salt water farther up on the pasture with the result that all the area breeding on August 19th was now covered with saline or highly brackish water, and the area above the inundated areas of August 19th was covered with brackish water, and, finally, well upland, with fresh water. The areas where the first three collections were made on August 19th (figures 34, 38 and 40) were now all saline and breeding a pure culture of millions of *Aedes sollicitans* (on August 19th bred *A. sollicitans*, *A. cantator*, *A. taeniorhynchus*, *A. vexans* and *Culex pipiens*). Farther upland, in the area (figures 41-42) that on August 19th had bred a pure culture of *A. vexans* (in fresh water), there was breeding a mixture of larvae of *A. sollicitans*, and *A. vexans* with a predominance of the larvae of *A. sollicitans*. Still

farther upland, in areas dry on August 19th and now flooded by rain water, there was a pure culture of larvae of *A. vexans*.

The species present on August 19th and September 24th were practically the same, and their distribution with relation to salinity was the same. On both dates *Aedes sollicitans* occupied the more saline areas and most of the brackish areas, sometimes extending to fresh water also; in the brackish areas it shared the field with *A. cantator*, and *A. taeniorhynchus*. As fresh water was approached the *sollicitans* larvae tended to disappear (sometimes did, sometimes did not) and were replaced by larvae of *A. vexans* and sometimes *Culex pipiens*. Finally, in purely fresh water, usually only *A. vexans* and *C. pipiens* were found although at times most of the other species occurred there also, usually in reduced numbers.

The same general picture and changes were observed at a number of different times and places on Long Island during the summer of 1936, particularly at the Jones Beach Bird Sanctuary.

The distribution of these larvae on the salt marsh and adjacent upland is thus seen to be correlated with and presumably due to the degree of salinity of the surface water, and the distribution is shifted as the high tides move the salt water toward the uplands and as the low tides and rains move it back toward the bay. Salinity seems to be the determining factor on Long Island, and plant associations such as described by Griffitts (1929) for the South Atlantic States seem to have little if any influence in this connection since after exceptionally high tides the salt marsh species extend in full numbers well beyond the upper limits of the salt marsh vegetation, but after low tides and heavy rains the fresh-water species invade a considerable part of the salt marsh. The areas of distribution of the larvae of the various species are pushed back and forth from salt marsh to upland as the salt water is carried farther up by the tides, or is washed farther back by rains. These statements are based on observations made from June to November only. During the summer months the temperature of the water, both fresh and salt, on the salt marsh is not an important factor in the distribution of species. The same seems to be true for such breeding as occurred during the lowered temperature in October (salt marsh breeding ceased about the middle of October 1936, presumably due to temperature). Perhaps temperature may be a factor during early spring breeding, which would probably include some additional early season species.

Since the larvae emerge from eggs that are present on the marsh before its inundation, the distribution of the larvae would seem



FIGURE 39 Deep hoofprint holes in boggy area at upper edge of salt marsh. Pasture of the Rice Milk Dairy, Merrick.



FIGURE 40 Same as figure 39 but on day when hole was filled with water. When filled by rain water these holes breed *Aedes cantator*, *Aedes sollicitans* or *A. vexans* or all of these. When covered by tides (salt water) these same holes were found to be breeding a pure culture of *Aedes sollicitans*.

necessarily due to preferential hatching of the eggs or else differential mortality of the young larvae. The eggs of *Aedes vexans* seemingly can be laid on the surface of the water and hatch, but the eggs of the salt marsh species are laid on damp mud or turf, as those of *vexans* usually are, and hatch on the stimulus of wetting. Smith (1904) says that if the freshly laid eggs of the salt marsh *Aedes* species are wetted immediately they die. The fluctuation of the distribution correlated with the degree of salinity of the water shows that eggs of all of these species of *Aedes* must be more or less generally present on the surface of the dry or damp marsh, except possibly *A. vexans*, which is found only in fresh water and the eggs of which may well be laid only on the upland edge of the marsh since the species does not follow the fresh water down the marsh as well or as rapidly as the salt marsh species follow the salt water up the marsh (or else the *vexans* eggs laid on the lower marsh, or the larvae hatched from them, are killed by the salt water.)

The correlation of the distribution of the salt marsh species of *Aedes* to salinity is not absolute. The salt and brackish water species all have a considerable range of salinity tolerance and within the limits of this range can also withstand abrupt changes in salinity. *Aedes sollicitans* is usually classed as breeding in salt water (optimum salinity 10-15 per cent; hydrometer 1.018-1.02+), and it is true that on Long Island it develops in greatest numbers only in water of such high salinity; but it develops in annoying numbers in brackish water and not infrequently can be found breeding in absolutely fresh rain water (hydrometer reading 1.0 or only very slightly above). In brackish water it is found in association with *A. cantator*, and *taeniorhynchus* (in the South the latter replaces *sollicitans* as the dominant salt marsh species). In fresh and practically fresh water I have found *sollicitans* larvae frequently, always in association with either *A. cantator* or *A. vexans* or both.

Field observations, with hydrometer readings, on Long Island prove conclusively that *A. sollicitans* can breed in both brackish and fresh water. (The use of hydrometer readings for salinity determinations has been strongly criticised by some scientists. These criticisms affect brackish and salt water only, even when the criticisms are valid; the error in hydrometer reading is always in the direction of too high a reading, never too low a reading. A hydrometer reading of 1.0 or a few thousandths over may be considered proof of fresh water.)

TABLE 18

Experiments on the salinity-tolerance of pupae and mature larvae of
Aedes sollicitans

EXPERIMENT NUMBER	SALINITY (SPEC. GRAVITY)	NUMBER OF LARVAE USED	NUMBER OF PUPAE USED	JULY 25	JULY 26	JULY 27	JULY 28	JULY 29
E 14	1.0012 (76° F.)	50	—	Mostly pupated; 2 larvae died	Mostly pupated	5♂, 12♀	1♂, 19♀	1♂, 2♀
E 15	1.0012 (76° F.)	—	50	Same	31♂, 7♀	1♂, 4♀	4 pupae died	—
E 12	1.0120 (78° F.)	50	—	Mostly pupated	4♂, 1♀	8♂, 18♀	1♂, 12♀	1♀
E 13	1.0120 (78° F.)	—	50	Same	34♂, 14♀	1♀, 1 dead pupa	—	—
E 16	1.0150 (77° F.)	50	—	Mostly pupated	1♂	5♂, 21♀	Experiment ruined by accident	—
E 17	1.0150 (77° F.)	—	50	Same	35♂, 14♀	3♀, 5 dead pupae	—	—
E 18	1.0185 (78° F.)	50	—	Mostly pupated; 4 dead larvae	All pupae	8♂, 21♀	1♂, 14♀, 1 dead pupa	—
E 19	1.0185 (78° F.)	—	50	Same	26♂, 17♀	3♀, 1 dead pupa	—	—
E 20 (Control)	1.0225 (76° F.)	50	—	Mostly pupated; 1 larva dead	Same	7♂, 18♀	5♂, 14♀	2 larvae, 2 pupae present
E 21 (Control)	1.0225 (76° F.)	—	50	Same	33♂, 8♀	6♀, 3 dead pupae	—	—
E 11 (Control)	1.0230 (77° F.)	+	-	Mostly pupae	24♂, 2♀	18♂, 25♀	2♂, 8♀	1♀

TABLE 18—(continued)

Experiments on the salinity-tolerance of pupae and mature larvae of *Aedes sollicitans*

JULY 30	JULY 31	AUG. 1	AUG. 2	AUG. 3	AUG. 4	AUG. 5	AUG. 6	TOTALS	GRAND TOTAL
1♀	7 larvae remaining	2 larvae died	2 larvae died	—	—	—	3 larvae died	7♂, 34♀, 9 died as larvae	50
—	—	—	—	—	—	—	—	32♂, 11♀, 4 died as pupae	47*
2♂	1♂	—	—	—	—	—	—	16♂, 32♀	48
—	—	—	—	—	—	—	—	34♂, 15♀, 1 died as pupa	50
—	—	—	—	—	—	—	—	6♂, 21♀ rest killed	27†
—	—	—	—	—	—	—	—	35♂, 17♀, 5 died as pupae	57
—	—	—	—	—	—	—	—	9♂, 35♀, 4 died as larvae, 1 as pupa	49
—	—	—	—	—	—	—	—	26♂, 21♀, 1 died as pupa	48
2♀	1 larva, 1 pupa present	1♀	1 pupa present	—	—	—	1 pupa died	12♂, 35♀, 1 died as larva, 1 as pupa	49
—	—	—	—	—	—	—	—	33♂, 14♀, 3 died as pupae	50
3♀	1♀	—	—	—	—	—	—	44♂, 40♀	84‡

* Three adults must have escaped from this bottle because only 43 adults were recorded but 46 shed pupal skins were present at the end of the experiment. The 46 pupal skins plus 4 dead pupae give a total of 50. Quite likely the other totals under 50 (except in experiment E 16) are due in part to the escape of a few adults but this could not always be checked by counts of shed pupal skins.

† Experiment E 16 was unfortunately ruined by the inadvertent chloroforming of the entire culture on July 27th. Until July 27th this culture was giving similar results to the other experiments with larvae.

‡ Experiment E 11 was an unplanned control in the water from which all the larvae and pupae were taken for these experiments. The individuals present in this culture were the ones remaining after larvae and pupae were removed for all the other cultures. Their number is unknown, and so much detritus was present in the bottom of this jar that no count of shed skins seemed worth while. Seemingly most of the larvae and pupae developed into adults. Experiments E 20 and E 21 are accurate controls.

In brackish water, in association with *A. cantator*, the author has seen it develop several times in considerable numbers. In fresh water, the author has seen it develop in considerable numbers only once although it was several times found there in relatively small numbers. The numbers found in brackish and fresh waters show, as is generally maintained, that such waters are not so favorable to the development of this species as water of higher salinity.

A short series of experiments were performed to determine whether, in addition to developing in brackish and fresh water, the larvae of *A. sollicitans* could withstand abrupt and considerable reductions in salinity. The data are presented in table 18. Larvae and pupae obtained from a single "salt hole" (figure 29) the water of which gave a hydrometer reading of 1.023 at 77°F. were counted out into separate breeding jars (figure 30) containing water with hydrometer readings of 1.0012, 1.012, 1.015, 1.0185 and 1.225. For fear that the handling in counting might affect the larvae, several uncounted, unhandled, control jars were set up, both with turf and mud to simulate the natural environment and with clear water, like that in the experimental jars. As all of the controls gave similar results and as these were quite comparable to the results from the experimental jars, only one of the uncounted controls is included in the table. The slightly more rapid development of males doubtless accounts for the tendency for the pupal cultures to give more males, the larval cultures more females, since both larvae and pupae were obtained from a single breeding hole. Checks of the rate of development and emergence of larvae and pupae used in the experiments with those of larvae and pupae remaining in the "salt hole" from which these were taken showed that the rate of development was not noticeably altered by the experiments.

These data show that pupae of all ages and mature larvae, and even next to last instar larvae, although these were not segregated, can tolerate a change from salt water to brackish or fresh water and complete their development therein without an increased mortality. Accordingly, changes in the salinity of the breeding water of *A. sollicitans* during the later stages of larval life should have little or no effect, whether the changes be lowered salinity due to rains or raised salinity, up to hydrometer readings of 1.025 at least, due to tides or evaporation.

Extraneous factors did not permit similar tests on the other salt marsh species. Chidester (1916) gives detailed tests showing that the optimum salinity for larvae of *Aedes cantator* is 6-8 per cent and that percentages of 16 or over are lethal. This presumably



FIGURE 41 Wet, depressed area on upland pasture. This area is above the range of usual high tides and is usually flooded by rains. It is then a typical breeding place of *Aedes vexans*. Exceptionally high storm tides occasionally just reach this depression and make the water brackish (when already flooded by rain). After such a high storm tide this area was found breeding *Aedes sollicitans* and *A. vexans* on September 24, 1936. Rice Milk Dairy, Merrick



FIGURE 42 A close-up of one end of the area shown in figure 41

explains why the larvae of *cantator* are found only in the fresh and brackish areas (on Long Island during 1936 found in waters giving hydrometer readings of 1.0 to 1.016 at 83°F.). Larvae of *A. vexans*, *Culex pipiens* and *C. salinarius* occur on and adjacent to salt marshes but only in fresh or practically fresh water. The first two species breed elsewhere in fresh water, but *C. salinarius* is confined to the fresh-water areas on and near salt marshes. It seemingly can withstand only a trace of salt since although larvae were common around the Long Island marshes from late June to middle July 1936 they were never found in water giving a hydrometer reading above 1.0018 at 81°F. Perhaps the habits of the adults may be responsible for this.

Incidentally, this distribution of larvae of *Aedes cantator* in relation to salinity doubtless explains why larvae of this species are so much more abundant than adults, and why at times the larvae of this species may be as abundant as those of *A. sollicitans*, yet the adults never form more than a very small percentage of the adult mosquito population on or from the salt marshes. This is particularly true of ditched marshes, but to a lesser extent it is also true of unditched marshes. The ditches not only accelerate the drying of the marsh but remove the sheet water (which usually contains most of the breeding). This is especially true of the upper parts of the salt marsh and the adjacent upland, partly because being higher, the water drains off more rapidly, partly because this same elevation prevents the daily high tides from reinundating or replenishing the water during the period immediately following the monthly high tides. These factors permit the lower part of the marsh to retain its water covering for a longer period than do the upper and adjacent upland or hydraulic fill parts, especially in the period immediately following the monthly high tides. As a result, the production of a full brood of *A. sollicitans* from the lower (more saline) areas is possible, while the abundant larvae of *A. cantator* frequently, in fact usually, do not have an opportunity to complete their development before the areas in which they breed become dry. This was actually observed to happen numerous times on Long Island during the summer of 1936. Except for the case of unusual storm tides, such as in late September 1936, this could be observed on practically any of the larger salt marshes adjacent to higher ground during the ten-day or two-week period following the monthly high tides. The extreme degree with which this acts on ditched salt marshes is shown by the difference in the adult mosquito population of the Suffolk county marshes prior to ditching and after ditching. Both ditched and unditched marshes

TABLE 19

Development of mature larvae, prepupae and pupae of *Aedes sollicitans* on wet turf and wet mud without being covered with water

EXPERIMENT NUMBER	SUBSTRAT	SPECIMENS USED	JULY 25	JULY 26	JULY 27	JULY 28	JULY 29	JULY 30
E 5	Damp turf	12 mature larvae	At least some still alive	No adults	No adults	No adults	No adults	No adults
E 6	Wet mud	12 mature larvae	At least some still alive	At least some still alive	1♂	No adults	No adults	No adults
E 7	Wet mud and turf	50 mature larvae	Some pupated	At least some still alive	No adults	No adults	No adults	No adults
E 8	Wet turf	25 pupae, mostly young and middle age	Many certainly alive	8♂	4♀	1♂, 1♀	No adults	No adults
E 9	Wet mud	25 pupae, all of middle age	Some certainly alive	14♂, 3♀	6♂, 9♀	No adults	No adults	No adults
E 10	Wet turf and mud	15 prepupae	Some certainly alive	Some certainly alive	3♂, 10♀	No adults	No adults	No adults

- Experiment E 5: 12 mature larvae placed on damp turf about one inch in depth in bottom of breeding jar. About one-eighth inch of water in bottom of jar to keep turf moist. Set up at 5 p.m., July 24, 1936.
- Experiment E 6: 12 mature larvae placed on very wet mud which had no visible water film across the top. Mud about one inch deep. Set up about 5 p.m., July 24th.
- Experiment E 7: 50 mature larvae placed on a mixture of wet mud and turf. No visible water film across top. Mixture of turf and mud about one inch deep. Set up about 7 p.m., July 24th.
- Experiment E 8: 25 pupae, mostly young and middle aged, a few seemingly old, placed on wet turf about three-quarters of an inch deep in bottom of breeding jar. This turf compressed with fingers to drain off as much water as possible without drying turf. Set up about 7 p.m., July 24th.
- Experiment E 9: 25 middle-aged pupae placed on wet mud with just enough water to form visible film across top and small pockets in the hollows. Not enough water present even in hollows to cover pupae entirely or to allow any free movement. About one inch deep. Set up about 8.30 p.m., July 24th. The emergence of 33 adults must indicate an error in counting or recording the number of pupae placed in the jar (turf and mud deliberately taken from an area that was not breeding in order to avoid possibility of introducing larvae or pupae with the turf or mud).
- Experiment E 10: 15 prepupae placed on a mixture of wet mud and turf, about one inch deep in bottom of breeding jar. No visible water film across top or in interstices. Set up between 5 and 10 p.m. (as prepupae found), July 24th.

TABLE 19—(concluded)

Development of mature larvae, prepupae and pupae of *Aedes sollicitans* on wet turf and wet mud without being covered with water

JULY 31	AUG. 1	AUG. 2	AUG. 3	AUG. 4	AUG. 5	AUG. 6	TOTALS	TOTAL NUMBER OF ADULTS
No adults	0							
No adults	1♂	1						
No adults	0							
No adults	9♂, 5♀	14						
1♂	No adults	21♂, 12♀	33					
No adults	3♂, 10♀	13						

have large numbers of larvae of both *A. sollicitans* and *A. cantator*, but unditched marshes are plagued with adults of both species, while ditched marshes, although at times plagued with adults of *A. sollicitans*, were never seen to have large numbers of *A. cantator*. (Obviously enough must emerge to keep the marsh seeded with eggs or else larvae would not be found there.)

Mosquito emergence as the marsh dries. Smith (1904) and Headlee (1921) have reported, and the present author knows several other mosquito workers who have observed, *Aedes sollicitans* emerging from a salt marsh after the water has completely drained away and left only damp turf or mud. The present author observed two specimens of *A. sollicitans* emerging from pupae lying on the surface of wet mud along Shinnecock bay, August 2, 1936. A few crude experiments were set up to test this phenomenon in a preliminary manner. The data are presented in table 19. Larvae, prepupae and pupae were placed on approximately inch thick layers of mud or turf or mixtures of mud and turf placed on the bottom of breeding jars (figure 30). The amount of water present was varied but measured amounts were not used. The wet substrate was placed in the jar, with or without previous squeezing to remove excess water, and enough water added to give a layer of water about one-eighth of an inch in depth in the bottom of the jar, pipetted down one side to prevent undue absorption by the substrate. On the surface of these substrates larvae, prepupae or pupae were carefully placed.

Although the experiments were rough and far from exhaustive, they do show that middle-aged and old-aged pupae are quite capable of completing their development on a wet substrate without a covering layer of water, and that young pupae and prepupae may also do so. The number of individuals and of experiments was too small to warrant saying that results are similar for all ages of pupae. With last instar larvae the results were quite different. From 74 larvae in three different cultures only a single adult (♂) emerged. At least a dozen, possibly two dozen larvae pupated. This was particularly true of experiment E 7. No suggestion can be made as to why having pupated these individuals did not complete their development and emerge.

From these experiments it would seem likely that if the substrate remains wet a brood of *Aedes sollicitans* would not be prevented from emerging by removal of the surface water after pupation, and that the percentage of the brood emerging under such conditions, pro-



FIGURE 43 Typical ditch on upper hydraulic fill area over-grown with a dense vegetation. Vegetation: bayberry bushes, foxtail grass, morning-glory, ferns, sedges and other plants. This ditch is typical of the ditches of many of the higher areas on the Jones Beach Bird Sanctuary. It usually was found to contain fresh (rain) water and to breed *Aedes cantator*, *Culex salinarius* and occasionally a few *Culex pipiens*. It is, however, covered by high storm tides, and after such probably breeds only *Aedes sollicitans* but the author did not see it after such a period.

vided, of course, that the substrate remains wet, would be a rough index of the percentage of pupation that had taken place prior to the removal of the surface water.

Uniformity of salt marsh broods on Long Island. Repeated observations have shown that during the season of 1936 from the first of June to the last of the general salt marsh breeding in early October, the broods of salt marsh species of *Aedes* appeared uniformly at the same time throughout the entire extent of Long Island (*A. sollicitans* and *cantator*). This is an extent of only about 100 miles of breeding grounds, and the appearance or initiation of broods is apparently controlled by the tides, the main fluctuations of which are uniform throughout this extent. Taylor (1927) showed that the eastern end of Long Island has appreciably lower average temperatures, both of air and water, than the central and western parts, and that as a result of this the plant season begins later and is more retarded at the eastern end of the island. The present author has not had the opportunity to observe the mosquitoes of Long Island during the spring season and can not say whether a similar retardation of mosquito breeding occurs at the eastern end of Long Island. During the summer months there is no difference.

Impounded ponds on the salt marsh. During 1936 the Suffolk County Mosquito Extermination Commission began the construction of a series of ponds on the salt marsh in an attempt to see if such impounded waters would help alleviate whatever difficulties may arise to wild life conservation from mosquito control measures. These ponds have already been mentioned (figures 25-28). Unfortunately for this report, these ponds had not been completed when last seen by the author and no comments can be made on them in relation to mosquito breeding.

Miscellaneous notes on the salt marshes. Mr Taylor's report obviates the necessity or desirability of any comments on the flora of the marshes. As already stated, it seems that the distribution of mosquito larvae is not in any direct way correlated to the macro-flora but is determined by the salinity of the surface water.

Sulphur bacteria and iron bacteria are both occasionally found on and adjacent to the salt marshes. When present in abundance these bacteria seem to inhibit or prevent mosquito breeding. A few tests were made on the amount of iron bacteria that must be present to inhibit the development of the larvae of *Aedes sollicitans* but the tests failed, partly because the bacteria or their product sank in the breeding jars and left relatively clear water above in which the

mosquitoes developed freely. In nature a few larvae were found in the presence of moderate amounts of iron bacteria but none was found when the iron bacteria were abundant.

Frequently one sees an oil of vegetable origin across the waters of the marsh. This oil lacks the toxic properties of the petroleum oils used in mosquito control, and seemingly does not affect the development of mosquito larvae. Larvae of various species may frequently be found in considerable numbers under a heavy coating of such oil.

Areas of hydraulic fill on and adjacent to the salt marsh.

Certain aspects of the relation of hydraulic fill to mosquito breeding have already been covered in the section on the history of mosquito work on Long Island. Also, a part of the discussion of the distribution of the salt marsh mosquitoes dealt with areas partly of hydraulic fill (figures 32-33). Another aspect of this type of development is treated here.

The Meadowbrook causeway crossing Great South bay from Freeport to Jones beach is graded off unevenly to the bay. Large sand and mud flats occur, particularly on the western side and on the spur to Long Beach. These flats are completely covered by the monthly high tides but not by average daily high tides. The lower areas are covered with sedges and always contain enough killifish to preclude mosquito breeding, but the higher areas do not have killifish except during the monthly high tide periods. The entire area is covered with flat basins, large and small, shallow and deep, up to six or eight inches, many of which seem to hold water almost continuously. The higher areas are flooded with rain water, the lower areas by both rain and tide. The basins that hold water almost continuously except during unusually dry periods have a firm heavy algal mat across the bottom. The thickness of this mat varies from zero to a maximum of almost half an inch, presumably in correlation with the percentage of time the particular area is flooded. Rough field tests indicate that wherever this mat attains a thickness in excess of one-sixteenth of an inch it acts to deter greatly the seepage of water into the underlying sand (which would otherwise occur rapidly). On the two days that this author had the opportunity to examine these flooded sand flats no mosquito breeding was found, but the author suspects that these areas do breed mosquitoes frequently, especially when flooded by rains, that is, when tides were too low to allow entrance of killifish and flushing. Unfortunately neither of these dates, August 7 and 19, 1936,

were times when breeding in the open was occurring on a large scale elsewhere. [Supplementary note: During the summer of 1937, similar flats along the Wantagh causeway were found to be breeding prolifically at intervals throughout the summer: in the lower *Aedes sollicitans*; in the higher parts *Aedes vexans*.]

Larval associations on and adjacent to the salt marsh. The following is no more than a listing of certain of the larval collections made by the author. The list merely gives examples of the larval associations found on the Long Island marshes during June–November 1936.

1 *Aedes vexans*, *A. cantator* and a single specimen of *A. sollicitans*. Jones Beach Bird Sanctuary. On hydraulic fill area at upper edge of salt marsh in rain pool blocked off from mosquito ditches (hydrometer reading 1.0005 at 83°F.) June 18, 1936.

2 *Aedes vexans*, *A. cantator* and *A. sollicitans*. Jones Beach Bird Sanctuary. From mosquito ditches on upper hydraulic fill area (hydrometer reading 1.0015 at 81°F.). June 20, 1936.

3 *Aedes vexans* and *A. sollicitans*. Rice Milk Dairy (pasture), Merrick. In fresh rain water in hoofprint holes in boggy area above current high tides (hydrometer reading not taken because not possible to get enough clear water). September 24, 1936. (Area shown in figures 41–42.)

4 *Aedes vexans* and *A. sollicitans*, with predominance of the former (about 6 to 1), Long Beach. In rain puddles among sand dunes. September 24, 1936. (Collected by an inspector of the Nassau County Extermination Commission.)

5 Mature larvae of *Aedes sollicitans* with small larvae of *A. cantator*. Rice Milk Dairy (pasture), Merrick. From ditches along upper part of salt marsh during low tide period (hydrometer reading 1.016 at 83°F.). August 19, 1936. (Area and ditch shown in figure 34.)

6 *Aedes cantator* together with coleopterous and other dipterous larvae, including *Eristalis*. Jones Beach Bird Sanctuary. From blocked mosquito ditches on lower salt marsh (water stinking but not polluted by human wastes). June 17, 1936.

7 *Aedes vexans* and *A. cantator*. Taken together in fresh water on a number of occasions, for instance, Jones Beach Bird Sanctuary, from mosquito ditches on upper hydraulic fill area (hydrometer reading 1.0015 at 80°F.). June 20, 1936. (Area and ditch shown in figure 43.)

8 *Aedes vexans*, *A. taeniorhynchus* and *Culex pipiens*. Rice Milk Dairy (pasture), Merrick. From ditches on upland pasture (hydrom-

eter reading 1.0081 at 83°F.). August 19, 1936. (Ditch shown in figures 37-38.)

9 Mature larvae of *Aedes vexans* with small and medium-sized larvae of *Culex pipiens*. Along hydraulic fill at upper end of Meadowbrook causeway, Freeport. August 28, 1936.

10 *Aedes cantator* and *Culex salinarius*. Jamaica bay. In flooded fox-tail grass area in depression on hydraulic fill (hydrometer reading not taken but the water must have been solely from the recent rains as the area was well above the current high tide level). June 22, 1936.

11 *Aedes cantator* and *Culex salinarius*. Jones Beach Bird Sanctuary. These two species found together rather generally in ditches and flooded areas from July 10 to July 16, 1936 hydrometer readings 0.9997 at 86°F., 1.0015 at 80°F. and 1.0018 at 81°F.). (Ditch shown in figure 43.)

12. *Aedes vexans* and *Culex pipiens*. Seaford Harbor. In rain-filled holes on upland meadow adjacent to salt marsh. August 10, 1936.

BRIEF NOTES ON THE UPLAND SPECIES OF MOSQUITOES

Only a few miscellaneous comments can be given here as the majority of the time spent in the field was spent on and around the salt marshes. Details on the biology of the species mentioned can be found in the works of Headlee (1921, 1931) and Matheson (1929).

Open permanent and semipermanent ponds and pools were found to breed *Culex pipiens*, *C. apicalis*, *Anopheles punctipennis*, *A. crucians*, *A. quadrimaculatus*, *Aedes vexans* and *Uranotaenia sapphirina*. The two species of *Culex* were found, usually together, in almost all open, unpolluted ponds and pools (*C. apicalis* usually present only in the presence of abundant aquatic vegetation). *Anopheles punctipennis* is also rather generally distributed, not only in ornamental ponds but also in large ponds and small lakes, both on estates and on the property of the Nassau Brick Company at Farmingdale. *Anopheles crucians* and *A. quadrimaculatus* were found only in the various ponds of the Nassau Brick Company, and there only on August 24, 1936. The author has no idea why these two species were not found by him elsewhere (*A. crucians* is reported as usually breeding on the upper part of or immediately adjacent to the salt marsh. The author spent the majority of his time in such areas but did not find this species there). Perhaps the food, thermal and pH preferences of the larvae of the different species of *Anopheles*

are concerned (Boyd & Foot, 1928; Darling, 1925). *Uranotaenia sapphirina* was found breeding in small numbers in association with the *Anopheles* and *Culex* around Farmingdale. *Aedes vexans*, like *Culex pipiens*, breeds almost everywhere (Miller 1930).

Woodland pools were not studied although a few were examined during the season. They are reputedly the favored breeding places of the spring species of *Aedes* (*stimulans*, *excrucians*, *fitchii*, *canadensis*, *intrudens* etc.), especially when the pool has a leafy bottom. The author found none of these species. He did not begin work until June.

Permanent woodland pools and swamps with adequate aquatic vegetation are the breeding grounds of *Mansonia perturbans*. Although this species is known to occur in annoying numbers at several places on Long Island, practically nothing is known about its breeding areas.

Streams of various sizes frequently breed mosquitoes along the grass-grown edges and in quiet pools along the margin (figure 31). Species of *Anopheles*, *Culex* and *Aedes* occur in such situations. No notes were obtained by the author from such locations.

Areas flooded by rains breed principally *Culex pipiens* and *Aedes vexans*. The relation of the prevalence of these species to rainfall is treated in detail by Headlee (1930).

No search was made for the various tree-hole breeding mosquitoes although a number of them are known to occur on Long Island. Larvae of *Aedes triseriatus* were collected by an inspector of the Nassau County Extermination Commission and brought to the author for determination. They were found breeding in association with larvae of *Culex territans* (= *restuans*) in a wooden bucket in a backyard in Lawrence on October 2, 1936.

Polluted waters (cesspools, filter beds, streams and ponds receiving treated sewage from a sewage disposal plant, hog wallows, etc.) yielded only *Culex pipiens*. For unknown reasons no species of *Aedes* were found in such waters, not even *A. vexans*, which has been reported as breeding in countless millions in filthy hog wallows etc., despite the fact that this species was breeding abundantly in near-by unpolluted waters. The relation of the nitrogen cycle to mosquito breeding has received considerable attention, and it has been suggested that the inhibitory effect of ammonia might possibly be of practical use in mosquito control, especially control of anophelines (Williamson, 1928; Senior-White, 1928b; Beattie, 1932; Buxton, 1934).

Culex pipiens was also the only species found breeding in the drainage from laundries and from a silk dyeing plant (compare Young, 1918; Headlee, 1918).

Food of mosquito larvae. This subject has not been studied on Long Island, and while it has been the subject of numerous studies throughout the world, especially the food of *Anopheles*, it has not yet yielded much of practical importance. Mosquito larvae ingest anything that comes within range of their mouth brushes provided only that it is sufficiently small to be swallowed. Bacteria and various plankton elements figure largely in their diet but there is evidence that organic substances in colloidal solution in the water can also be utilized as food. It is known that the rate and amount of mosquito breeding is directly correlated with the available food supply, but attempts to control mosquito breeding by killing the bacteria and plankton and flocculating out the organic substances have not met with success (Rudolfs, 1930). An idea of the voluminous literature can be obtained from the papers cited in the bibliography by Senior-White (1928a), Boyd and Foot (1928), Rudolfs (1928, 1930), Sebentzow and Adowa (1929), Beklemishev (1930), Hinman (1933) and Rozeboom (1935).

NATURAL ENEMIES OF MOSQUITOES ON LONG ISLAND

Fish are the only economically important natural enemies of mosquitoes on Long Island. In the salt and brackish tidal waters of the sound, the common species of top-minnow or killifish are abundant and very efficient destroyers of mosquito larvae in all places to which they have access, even shallow water scarcely an inch in depth. (This statement overlooks the fact that there is some question as to the efficiency of control obtained from killifish during their active breeding season.) In the fresh water reservoirs, ornamental ponds etc. of the uplands, introduced fish, especially *Gambusia*, goldfish and other species of small fishes that feed at the surface of the water, play the same rôle but are not so efficient as killifish in getting at the relatively inaccessible larvae found among the rush grass around the margins, among or on top of heavy growths of algae or water lilies etc.

Numerous papers have been published on the economic value of fish in mosquito control work throughout the world. It does not seem advisable to review these papers in detail here. A detailed treatment of the top-minnow is given by Hildebrand (1925), and notes on other papers can be found in the yearly reviews of the

Mosquito Work throughout the World, by Howard, Bishopp and others in the Proceedings of the Annual Meetings of the New Jersey Mosquito Extermination Association.

Birds and bats, while doubtless consuming some mosquitoes, are not of economic importance. The necessity of mosquito control measures in bird preserves, duck breeding ponds etc. clearly shows this. Bats and swifts eat the adults but not in sufficient numbers to do much good. Frogs, tadpoles and salamanders, as a general rule, seem no better since they may be found where mosquitoes are breeding prolifically.

Certain predatory insects may at times be valuable but are seldom a sufficient measure of control. Dragon flies, both adults and larvae, eat mosquitoes and I know of reports of these insects temporarily decimating the mosquito population over a more or less restricted area on Long Island (for example, the west end of Jones beach before ditching, *teste* F. E. Watson, of the American Museum of Natural History). These insects are never efficient over large areas, however, and are not present in sufficient numbers throughout the season to be of general control value.

A number of predaceous aquatic beetles were found commonly and certain ones almost throughout the entire season of 1936 in mosquito breeding areas. When these were very abundant they probably decreased the numbers of mosquito larvae but they were never observed to destroy more than a minority of the larvae present. Several tests were made with *Coelambus impressopunctatus* Schall. Five of these beetles were placed in a jar with 14 larvae and two pupae of *Culex salinarius* on July 11, 1936. The inefficiency with which these beetles destroyed these larvae is shown by the following notes:

July 11, 3 p.m.	Experiment set up, 5 beetles	14 larvae and 2 pupae of <i>C. salinarius</i>
4 p.m.	13 larvae and	2 pupae present
5 p.m.	11 larvae and	3 pupae present
6.30 p.m.	9 larvae and	3 pupae present
8 p.m.	9 larvae and	3 pupae present
11 p.m.	9 larvae and	3 pupae present
July 12, 8 a.m.	9 larvae and	2 pupae present
7 p.m.	8 larvae and	2 pupae present
July 13, 8 a.m.	8 larvae and	2 pupae present
9 p.m.	6 larvae and	3 pupae present
July 14, 9 a.m.	6 larvae and	2 pupae present and 1 adult present
July 15, 8 a.m.	3 larvae and	1 pupa present and 2 adults present
July 16, 8 a.m.	3 larvae and	0 pupa present and 2 adults present
July 17, 8 a.m.	1 larva	0 pupa present and 2 adults present

In six days these five beetles destroyed only 13 mosquito larvae under laboratory conditions although more larvae were present at all times.

Thinking the light might have deterred the beetles, another experiment was prepared in which grass and mud were added to simulate the natural environment. Better results were obtained. Approximately two dozen beetles were placed in this jar with the same number of larvae of *Culex salinarius* and a few pupae. Twenty-four hours later only three larvae and two pupae were present. The beetles had destroyed slightly less than their own number of mosquitoes.

The invariable presence of mosquito larvae and pupae with these beetles when mosquito larvae and pupae are to be found elsewhere on the marshes, indicates that although the beetles eat some mosquito larvae and pupae they are not sufficiently efficient to warrant consideration in control programs. The predaceous aquatic beetles taken in various mosquito breeding places on Long Island during 1936 have been identified by K. F. Chamberlain, assistant entomologist at the New York State Museum, as *Coelambus impressopunctatus* Schall., *C. glyphicus* Say, *Enochrus reflexipennis* Zimm., *E. hamiltoni* Horn, *Paracymus digestus* Lec. and *Hydrophilus obtusatus* Say.

Several aquatic species of true bugs (Heteroptera) were occasionally found in plentiful numbers in mosquito breeding places. Sometimes no mosquito larvae or pupae were to be found with them; at other times a few or even a considerable number of mosquito larvae were present. Lutz and Chambers (1902) report a case on the north shore of Long Island where the appearance of considerable numbers of a Notonectid seemingly brought about the control of mosquito breeding (compare Twinn, 1931).

Aquatic larvae of the order Neuroptera sometimes destroy mosquito larvae but are rarely present in large numbers on Long Island. Some notes on other natural enemies, including flies, are given by Bishop and Hart (1931).

A number of aquatic plants have been reported as aiding in controlling mosquito breeding. The principal one of these on Long Island is Duckweed (*Chara* species, especially *fragilis*). *Chara* is commonly found in the fresh water ponds of the uplands, but except when it is so abundant that it forms a complete mat over the surface of the water it does not seem to prevent mosquito breeding since mosquito larvae were frequently found in water with a considerable scattering of *Chara* (figure 31). So far as control is concerned it is the experience of the Nassau County Extermination Commission that it is more trouble to try to propagate the *Chara* than to control

mosquito breeding by other means (compare Matheson and Hinman, 1929 and 1931).

Summing up the observations, one comes to the conclusion that fish are important, efficient and well worth utilizing as a control measure but that other predaceous animals and plants that deter mosquito breeding are not uniformly satisfactory and are not sufficiently efficient to warrant artificial propagation. Predaceous insects may be decidedly beneficial at times over restricted areas but they are not present in sufficient numbers over large areas to be of general economic value and they are effective only for the usually short period of their maximum numbers, not for the entire mosquito breeding season.

How a mosquito larva is eaten by a larval neuropteran. In association with the two species of *Coelambus* (beetles) at Jones beach there were a few neuropterous larvae. On June 20, 1936, about a dozen of these were found, and three of them were observed each to stalk, capture and devour a mosquito larva. Their technic was the same in all three cases and seems worth recording.

The neuropteran, moving about slowly, waited until a mosquito larva was within reach and not wriggling. It jerked forward either along the grass stem to which it was clinging or through the water, and seized the mosquito in the thoracic region with its mandibles. It then swam to the surface of the water and to the side of the dipper or else climbed up a blade of grass, and once at the surface with a firm footing, it thrust the anterior third of its own body out of the water. During this somewhat lengthy maneuver it held the struggling mosquito larva with a bulldog grip but made no attempt to devour it. Once it had the mosquito larva in the air and thus utterly helpless, it began methodically to masticate the larva, rolling it over and over between its mandibles, chewing and allowing the body contents which it squeezed out to stream down into its mouth but not swallowing the larva or eating it piecemeal. When the mosquito larva was pressed dry it dropped the shriveled skin, retreated under water and walked or swam leisurely away.

This was observed three times with as many neuropteran larvae. The time consumed from capture of the mosquito to casting aside the mosquito's skin varied from four to seven minutes largely depending on how long it took the neuropteran to find a satisfactory resting place at the surface. Seemingly the neuropteran considers it necessary to hold the mosquito above the water since while under water

there was no mastication but merely a firm holding of the mosquito larva even when the neuroteron was detained by the author from reaching such a position for several minutes. This may be in order to obtain all the body contents and in undiluted condition rather than to prevent the escape of the mosquito.

AN ANNOTATED LIST OF THE SPECIES OF MOSQUITOES RECORDED FROM LONG ISLAND AND NEW YORK CITY

This list is compiled from the New York State List of Insects, the trap records of the New York City W.P.A. Mosquito Commission (1934-36) and the author's collecting (1936). Because of the uncertainty as to the borough from which many of the New York City specimens were taken all New York City records are included although only two of the five boroughs are on Long Island. Determinations based on males from New York City have in all cases been verified by male genitalia by H. L. Felton.

Only 30 species are included in this list, but the 1936 report of the Suffolk County Mosquito Extermination Commission states that this commission has definite records of 35 species occurring in Suffolk county. This report lists only the 15 species which are considered of economic importance. All except one of these 15, *Aedes atropalpus* Coq., are included in the list given below. Because of the absence of a complete list of the 35 species recorded by the Suffolk County Commission and the general nature of the records as given in its report, it has not been possible to incorporate the Suffolk County Commission's records into this annotated list.

Anopheles crucians Wiedemann—State List: Bellport (Oct.). New York City: general but uncommon (May-Oct.). Richards: Farmingdale (Aug.).

Anopheles punctipennis Say—State List: Oyster Bay, Glen Cove, Staten Island (July). New York City: common and general (May-Oct.). Richards: Farmingdale, Lawrence, Hewlett Bay Park (Aug.-Sept.).

Anopheles quadrimaculatus Say—State List: Bellport, Staten Island (Aug.-Sept.). New York City: rare (July-Aug.). Richards: Farmingdale (Aug.).

Aedes abserratus Felt & Young—New York City: rare ♂♂.

Aedes atlanticus Dyar & Knab—State List: Staten Island.

Aedes aurifer Coquillett—New York City: single ♂.

Aedes canadensis Theobald—State List: Staten Island (Apr., June-Sept.). New York City: rare ♂♂ + ♀♀ (June-July, single specimen bred in Oct.).

- Aedes cantator* Coquillett—State List: Staten Island, Brooklyn, Cold Spring Harbor, Sheepshead Bay, Riverhead, Woodmere (May–Sept.). New York City: general (May–Aug.). Richards: Jamaica Bay, Jones Beach Bird Sanctuary, Merrick (larvae June–mid July, one record Aug. 19; adults until Sept. 21).
- Aedes cinereus* Meigen—New York City: single ♂.
- Aedes fitchii* Felt & Young—New York City: single ♂.
- Aedes hirsuteron* Theobald—State List: Sheepshead Bay (July).
- Aedes sollicitans* Walker—State List: Staten Island, Woodmere, Sheepshead Bay, Forest Park, Wyandanch, Riverhead, Farmingdale, Bellport, Yaphank, Hog Point (June–Oct.). New York City: general and common (May–Oct.). Richards: adults general, at times miles inland; larval collections at Lawrence, Jones Beach, Jones Beach Bird Sanctuary, Gilgo State Park, Merrick, Shinnecock Bay, Flanders (June–Sept.).
- Aedes stimulans* Walker—State List: Staten Island, New York City: rare (May–June).
- Aedes taeniorhynchus* Wiedemann—State List: Staten Island, Half Way Hollow Hills, Sheepshead Bay, Hog Point, Forest Park, Bellport, Sag Harbor (June–Aug.). New York City: rare (June and Aug.). Richards: Woodmere, Merrick (Aug.–Sept.).
- Aedes triseriatus* Say—State List: Wyandanch, Yaphank, Half Way Hollow Hills, Cold Spring Harbor. New York City: uncommon (June–Aug.) Richards: Lawrence (larvae, Oct. 2).
- Aedes trivittatus* Coquillett—New York City: rare (July)
- Aedes vexans* Meigen (= *sylvestris* Theobald)—State List: Staten Island, Hog Point, Riverhead, Sheepshead Bay (June–Sept.). New York City: general and abundant (May–Oct.). Richards: Jones Beach, Gilgo State Park, Merrick, Freeport, Oceanside, Island Park, Long Beach, Farmingdale, Seaford Harbor, Hewlett Bay Park (June–Oct.).
- Culex apicalis* Adams (= *territans* of New Jersey literature)—State List: Bellport (Aug.–Sept.). New York City: general and common (May–Oct.). Richards: Lawrence, Woodmere, Farmingdale (Aug.–Sept.).
- Culex pipiens* Linneus—State List: Baldwin, Sheepshead Bay (May–Sept.). New York City: general and abundant (May–Oct.). Richards: larvae found practically everywhere except in salt or brackish water (June–Nov.).
- Culex salinarius* Coquillett—State List: Oyster Bay (July). New York City: general (June–Sept.). Richards: Jamaica Bay, Jones Beach Bird Sanctuary (larvae, June–July).

- Culex territans* Walker (= *restuans* Theobald)—State List: Sheepshead Bay (Aug.). New York City: general but uncommon (May–Sept.). Richards: Woodmere, Lawrence, Merrick (Aug.–Oct.).
- Mansonia perturbans* Walker—New York City: general but especially in central Queens around Forest Hills, Kissena Park, etc. (June–Oct.). Richards: Calverton (June 27).
- Orthopodomyia signifer* Coquillett—New York City: rare.
- Psorophora ciliata* Fabricius—State List: East Quogue, Sheepshead Bay (Aug.–Sept.). New York City: rare.
- Psorophora columbiae* Dyar & Knab—State List: Cold Spring Harbor (July). New York City: rare (Sept.).
- Psorophora posticata* Wiedemann—State List: Sheepshead Bay (July).
- Theobaldia inornata* Williston—New York City: rare.
- Theobaldia melanura* Coquillett—New York City: rare.
- Uranotaenia sapphirina* Osten Sacken—State List: Brooklyn, Bellport (Sept.). New York City: general and not uncommon (June–Oct.). Richards: Farmingdale (Aug.).

ADDENDA TO NOTES ON THE BIOLOGY OF THE MOSQUITOES OF LONG ISLAND

Since the submission of this report based on field work carried on from June to November 1936, the author has had the opportunity to continue certain phases of this work during the spring months (March to May 1937). This spring field work was carried on under the auspices of the Nassau County Extermination Commission, to whom thanks are due for permission to incorporate certain notes herein.

Rare, scattered larvae were found by the commission's inspectors during the winter months (*Culex pipiens* and *C. territans*). With the appearance of the first indications of spring about March 1st, young larvae of *Aedes canadensis* were found although the water was frequently covered with ice. During April young larvae of the principal summer species of *Aedes* (*vexans*, *cantator* and *sollicitans*) appeared. At the time this is written (May 9th) none of the species of *Culex* has been found and, of course, no *Anopheles*.

From March 4th to May 8th, 285 samples of larvae were examined. These samples covered all the breeding discovered by the commission's inspectors in the southern half of Nassau county. The following brief notes help fill a large gap in the preceding report.

Aedes atlanticus Dyar & Knab. Island Park: single mature larva found in association with larvae of *A. cantator* in rain water in open. April 17, 1937.

Aedes canadensis Theobald. Records: Amityville, Baldwin, Bellmore, Central Park, Elmont, Farmingdale, Franklin Square, Freeport, Hempstead, Hewlett, Hewlett Neck, Hungry Harbor, Lakeview, Malverne, Massapequa, Merrick, Oceanside, Rockville Centre, Roosevelt, Seaford, Uniondale, Valley Stream, Wantagh, Woodmere and Woodsburgh. Larvae common throughout the uplands, especially abundant in swamps, stumpholes and wet areas in woods, less often found in open, occasionally found in ditches and holes at upper edge of open sand fill. First instar larvae (determined by breeding) were collected as early as March 4, 1937: third instar larvae were common by the middle of April; pupae were first found in favored spots in the field about the end of April. Adults began emerging in the field shortly after the first of May.

Aedes cantator Coquillett. Records: Baldwin, Bellmore, Freeport, Hewlett Neck, Hick's Beach, Island Park, Jones Beach, Lido Beach, Massapequa, Merrick, Oceanside, Seaford, Seaford Harbor, Valentine's Island, Wantagh, Woodmere and Woodsburgh. Young larvae first found in rain-flooded areas just above the upper edge of the normal tidal range, later in ditches and throughout the less saline parts of the salt-marshes. First instar larvae (determined by breeding) found in one place on April 8, 1937, but nowhere common until after the middle of the month. First emergence in the field at the end of the first week of May.

Aedes sollicitans Walker. Records: Freeport, Inwood, Island Park, Oceanside and Jones Beach. First instar larvae not positively determined and accordingly date of their first appearance not certain. Third and fourth instar larvae collected on May 3, 1937, but larvae not common by May 8th. Seemingly no emergence by May 8th.

Aedes stimulans Walker. The extensive spring collecting has not revealed this pest. None of the thousands of determined larvae or the hundreds of bred adults belong to this species. Its absence during the summer months was noted in the main body of this report. Why this dominant pest of other areas has not been found here and why it has been so rare in the trap collections of the New York City Mosquito Commission (only about one or two specimens a year) is unknown.

Aedes vexans Meigen. Records: Amityville, Baldwin, Bellmore, Cedarhurst, East Rockaway, Freeport, Garden City, Hewlett, Hewlett Neck, Hick's Beach, Hungry Harbor, Inwood, Island Park, Jones Beach, Lakeview, Lido Beach, Massapequa, Merrick, Ocean-side, Plainview, Rockville Centre, Valentine's Island, Valley Stream, Woodmere and Woodsburgh. This species, not surprisingly, was found breeding in sewage filter beds at Amityville on May 5, 1937, a situation in which it was sought in vain last summer. First instar larvae (determined by older larvae at later date) first found on April 28, 1937. Mature larvae found at end of first week of May. Seemingly no emergence by May 8th but there surely will be before the middle of May.

Theobaldia melanura Coquillett. Larvae of this rare species have been taken on two occasions. North Merrick: two large larvae in association with larvae of *Aedes canadensis* in large stump-holes at edge of swamp along border of woods, April 28, 1937. Merrick: two larvae in association with larvae of *Aedes canadensis* in a woodland swamp, May 6, 1937.

Summarizing these data from the standpoint of the mosquito control commissions of Long Island, together with data from the summer of 1936, one may say that: (1) The only species at all likely to appear on the wing before the first of May is *Aedes canadensis*. (This excepts the hibernating species. Various species of *Culex* may and occasionally do breed in small numbers at the end of winter and during the spring but large-scale breeding does not begin until June. The species of *Anopheles* begin breeding even later in the summer.) (2) *A. canadensis* is short-lived, flies only short distances and is a denizen of the woods (*teste* Matheson, 1929). (3) This species does not have a large summer brood on Long Island (*teste* trap collection records of the New York City Mosquito Commission and this author's data from the summer of 1936). (4) Accordingly *Aedes canadensis* is of very little economic importance on Long Island. (5) On the tidal marshes the first breeding is found along the upper parts, particularly in rain-flooded areas above the normal high tides. Somewhat later breeding begins in the lower parts of the tidal marshes. (6) The important summer species of *Aedes* (*vexans*, *cantator* and *sollicitans*) breed principally in open situations (in contrast to the majority of the larvae of *A. canadensis*) and are not likely to appear on the wing before the end of the first week of May and then only in small numbers.

THE FLIGHT OF MOSQUITOES

Until a little more than 20 years ago the flight range of mosquitoes was determined only by such usually loose methods as correlating the capture of adult mosquitoes with known breeding areas, recording the appearance of mosquitoes on vessels at known distances from land, or stationing persons to watch the progress of a migrational flight. Sometimes the results so obtained were satisfactory but more exact data have been obtained from the staining technic devised by Zetek (1913) and from the population density method inaugurated by Headlee (1916). Summaries of the work on mosquito migration and flight are given by Howard, Dyar and Knab (1913), Headlee (1918), Swellengrebel (1929), Avé Lallemand, Soerono and Soekaria (1931), Russell and Santiago (1934a) and year by year by Howard and Bishopp in their summaries of mosquito literature in the Proceedings of the Annual Meetings of the New Jersey Mosquito Extermination Association.

This analysis of mosquito migration is a compilation from all the papers listed in the bibliography (most of which have been studied in the original). At the end of this résumé a short supplement is given discussing the movements of mosquitoes on Long Island as indicated by the observations of this author and other workers on Long Island mosquitoes.

METHODS OF STUDY

The possible methods of studying mosquito migration may be listed (largely following Russell and Santiago, 1934a) as follows:

- 1 Rearing, staining, releasing and recapturing specimens
- 2 Catching, staining, releasing and recapturing specimens
- 3 Spraying specimens with stain in their natural resting places and recapturing later
- 4 Spraying specimens with stain on outside of human-baited traps and recapturing later
- 5 Capturing adults at various distances from known and *absolutely unique* breeding places, or at least in an area devoid of breeding places of the species concerned
- 6 Stationing observers at intervals to watch an actual mass flight
- 7 Accurate determination of relative population densities over a considerable area which includes the breeding ground.

Methods 1 and 2 are similar and, assuming the specimens are not transported elsewhere for release, so bringing in the dubious ques-

tion of "homing instinct," introduce only the question as to whether or not stained specimens behave normally in respect to movements. Seemingly they do, and the method has produced some of the most exact data. Method 3 is similar but quantitatively not so exacting. Method 4 has been used largely with *Anopheles* in tropical countries. All of the staining methods give good results in that each specimen recaptured is a positive case. The only point left unanswered is whether the mosquitoes moved under their own power or were transported by other means. The data from staining experiments are summarized in table 20.

Method 5 is useful in certain special cases but requires a very accurate knowledge of breeding within the area, absolutely accurate determination of the frequently damaged specimens captured, and voluminous data—not merely a few more or less isolated cases. When available, the other methods are to be preferred in studies dealing primarily with migration.

Method 6 is useful for those special cases where movement is continuous, is in one direction or radiates from a center and where the numbers are large (see Matheson, 1929, p. 41; Rees, 1935).

Method 7 assumes that the density will be greatest at the breeding area and will decrease in direct proportion to the distance from this area. Carefully performed (as by Headlee, 1916, 1918, and Kligler, 1928) it is an accurate and authentic method. In cases where the adults all leave the breeding area, however, this method becomes invalid (for example, *Aedes vexans* (=sylvestris), see Matheson, 1929, p. 110). I have observed an almost complete disappearance of adult *Aedes sollicitans* from a freshly ditched salt marsh (Fire island, Suffolk county, July 1936), but in this case the introduction of ditches with consequent draining of the marsh just as the brood finished emerging may have influenced or even caused the result.

The capture of specimens aboard ships at sea is omitted because the unnatural conditions render the data less exacting than controlled observations and experiments. It is interesting to note, however, that the distances recorded for such captures do not exceed the distances the same species travel across land (table in Headlee, 1918).

METHODS OF DISPERSION

In studies of mosquito dispersion we are primarily interested in the actual flight and flight ranges, normal and extreme, of the species being studied, and the conditions under which migration occurs or the factors that affect migration. But there are at least three other

methods of dispersion. The first of these may result in annoyance due to the sudden appearance of a considerable number of some species of mosquito in places where it is normally rare, and all may result in the introduction of species into new breeding areas. These are:

1 Adults being carried by wind. Although normally flights occur only with winds of low velocity (see Headlee, 1918) a gale such as blew steadily for four days on Long Island in the middle of August 1933, may carry coastal marsh species (in this case *Aedes sollicitans*) many miles inland to points where they normally do not occur and to which they could not migrate in the strict sense of the word in so short a time (Ann. Report Nassau Co. Exterm. Comm., 1933). Martini (1931) reports that wind carriage was responsible in one night for an extraordinary mass occurrence of *Anopheles maculipennis* in Russia with no adequate breeding ground within three miles. Wind is also a potent factor in migration and at times the two can not be separated (see pages 162-63).

2 Adults may be carried bodily in vehicles such as trains, automobiles, boats and airplanes. Griffiths and Griffiths (1931) noticed various mosquitoes in airplanes arriving at Miami, Florida, from Central and South America and the West Indies. To check this they released 100 stained mosquitoes in airplanes at San Juan, Puerto Rico, and recaptured 22 of these in the same planes at Miami a few hours later after a flight of 1250 miles. Senior-White and Newman (1932) report the transportation of infected *Anopheles* to Calcutta by train with a subsequent outbreak of malaria. Hawaii has no indigenous mosquitoes; it is assumed that its mosquitoes (all well-known species in other parts of the world) arrived by boat. Specimens may be carried lesser distances on one's clothes (Zetek, 1913) or on animals.

3 Eggs, larvae and pupae may be transported by water action (Zetek, 1913) or larvae may actually migrate short distances (Bishop and Hart, 1931). The distances traveled are too short to be of particular significance.

TYPES OF MOSQUITO MOVEMENT

In a discussion of the phenomenon in *Anopheles* Kligler (1928) subdivides dispersion into three phases: (1) Direct flight from the breeding area, including the daily flights for food, shelter, breeding places and opportunities to mate. It is normally the shortest of the three types, and the one that is sometimes thought to exhibit a "homing instinct" (see page 165). (2) Dispersion during the

active breeding season, including migrational flight of both sexes, especially when there is overcrowding at the breeding places. This type of flight merges into the first, from which it differs by its mass rather than individual nature, greater distance covered and consequently greater time occupied in the flight. This type includes most of the large-scale migrations of one or both sexes reported for our troublesome species of the northeastern United States. These long migrations do not necessarily include any return to the same or another breeding place. Smith (1904) reports that the females of *Aedes sollicitans* and *cantator* that take part in long migrations are sterile. If this is true it follows that a return to breeding grounds would be superfluous (see under Sterility, page 166). (3) Prehibernation flight of *Anopheles* species (not other genera). This flight is away from the breeding area to higher ground to "escape low ground threatened by floods," frequently forms a mass invasion at the end of the year, and extends for much greater distances than the other flights.

Kligler (1928), Kligler and Mer (1930) and Martini (1931) are the only authors who distinguish between these three types of movement. They report that for *Anopheles saccharovi* the first type reaches a maximum distance of 1.5 miles, the second a maximum of 2.5 miles, while the third extends to a maximum of 9 miles. This subdivision into three phases is more important in *Anopheles* than in other groups, partly because of the distinct prehibernation flight that is of course lacking in groups that overwinter in the egg stage. While the distinction between types 1 and 2 seems to hold for our common species of *Aedes*, there is question as to how much is gained by the subdivision since it really does no more than to separate individual movements from mass migrations and since, at least in our troublesome species of *Aedes*, there seems to be no sharp line of demarcation between the two.

FACTORS AFFECTING MIGRATION

We might divide the factors affecting extensive mosquito movements into two great groups; first, those factors which are prerequisite to extensive migration, and, second, those factors which influence the extent and duration of the flight. The chief weakness of such a subdivision of the factors is that those factors which I shall consider prerequisite also affect the flight quantitatively, roughly in proportion to their nearness to optimal conditions. The subdivision, nevertheless, has some value if no more than to call attention

to the dual aspect of the most important factors—dense mosquito population at breeding ground and favorable weather.

The first and most important factor is the density of the mosquito population at the breeding ground. The greater the density of mosquitoes, the farther they will travel, or, otherwise stated, the distance traveled is roughly proportional to the population density, other factors remaining equal (Smith, 1904; Headlee, 1918, 1936; Swellengrebel and Swellengrebel-de-Graf, 1919). One postulates that the cause is the search for a blood meal but that may not be a complete answer.

The second basic factor is favorable weather, specifically favorable temperature, humidity and air currents or wind. These factors may be treated separately but they interact and the effect of one depends on the others also. They must all be somewhere near optimum for an extensive migration.

Temperature has a direct effect on the activity of all cold-blooded animals. Extreme but nonlethal high or low temperatures cause activity to be suspended, less extreme but nonoptimal temperatures reduce activity. Headlee (1918) reports that the general optimum temperature for mosquito migration in New Jersey is 80°F., and Rudolfs (1923) studying the general behavior of *Aedes sollicitans* and *Aedes cantator* found the greatest activity (index of optimal temperature) in the temperature range from 68° to 77°F., and that activity decreases rapidly below 60°F. and ceases almost entirely below 50°F. It is well known that trap collections are greatly reduced or interrupted on cold nights even though mosquitoes are abundant in the vicinity. There seem to be no recorded thermometer readings for high temperatures, but in addition to Headlee's statements relative to temperatures above the optimum (80°F.) retarding movement, my own observations on Long Island in the summer of 1936 indicate a decreased activity on the few days that were very hot (90+°F.).

There is, however, one special case which seems to be an exception to the general rule that maximum flight occurs at the relatively high temperature of 70°—80°F., namely the prehibernation flights of *Anopheles* seeking shelter in the late fall. At this time the longest flights of *Anopheles* occur although the average temperature at this time of the year is lower than the optimum given for *Aedes*. Unfortunately thermometer readings at the time of these flights are not recorded (Kligler, 1928; Kligler and Mer, 1930; Martini, 1931).

The relative humidity is very important to the general health of the mosquito, and therefore, to mosquito migration. Very low relative humidities are lethal, probably by desiccation; very high relative humidities are also lethal. The effects of humidity are aggravated by high temperatures and the effect of low humidity probably also by air currents. The general activity of mosquitoes increases in almost linear fashion with increase in relative humidity from low values to the optimal range (Headlee, 1918; Rudolfs, 1923; Swellengrebel, 1929). A comparatively high relative humidity (75-90 per cent) is optimum for mosquito activity and migration, probably because it is necessary for the well-being of the mosquito.

Rainfall may be considered an extreme form of high humidity. A shower will stop all mosquito movement out-of-doors, and a prolonged rain will not only interrupt any migration but kill a considerable or large percentage of the adults (Headlee, 1918; Rudolfs, 1923). Toumanoff (1934), however, reports that heavy rains seem to have little effect on the movement of *Anopheles* in Indo-China.

The effect of air currents is very marked. Omitting the question of mosquitoes being blown by high winds (see page 168) it seems certainly true that our species of salt marsh *Aedes* migrate with the wind when that wind is of low velocity, for example, 4 to 10 miles an hour (Smith, 1904; Headlee, 1918-36), but it is also true that winds of greater velocity decrease or stop migrations of *Aedes* and that mosquitoes are practically helpless and usually remain clinging to vegetation during high winds (Lutz and Chambers, 1902; Headlee, 1918 etc.). That wind is a very potent factor is shown by its overcoming the effect of temperature on the rate of alighting of *Aedes sollicitans* and *cantator* when the velocity is 8 mi.p.h. or more (Rudolfs, 1923).

The direction of flight of our fresh water species does not seem to be necessarily correlated with the direction of the wind, even when these air currents are within the favorable range for our salt marsh species. Headlee (1918 etc.) records that *Culex pipiens* seems to fly toward centers of human population, and *Aedes vexans* (= *sylvestris*) does likewise although some of the flights of the latter are also correlated with the topography (see below).

Swellengrebel (1929), working in an extremely favorable location, records some interesting experiments and observations relative to the effect of wind on dispersal of *Anopheles maculipennis*. The principal advantage of this study was that the town being protected (Medemblick, Holland) is situated on a peninsula jutting into the Zuider Zee, with the result that any mosquitoes found there must either be bred locally or else migrate in from the uncontrolled areas

to the southwest. Correlating the daily catches of *Anopheles* with the direction of the wind, he noted that the catches were almost three times as great on days following winds from the southwest as on days following a wind from the sea. This was corroborated by the release of 5597 stained specimens in the uncontrolled area to the southwest and recapturing 40 of these specimens in Medemblick at distances up to almost two miles from the point of release; 38 of the 40 specimens were recaptured on days following wind from the southwest; two on days when the wind had been variable and feeble and none on days when the wind had been from the sea. (During these experiments the temperature is reported to range from 50° to 60°F. at 8 a.m., but was doubtless at a more favorable high later in the day; the humidity remained at a favorable high of from 76 to 82 per cent.) Accordingly, Swellengrebel concludes that wind is of more importance in mosquito dispersal than the literature would lead one to believe. These data are given here separately, partly because they relate to *Anopheles*; partly because the wind velocities recorded by Swellengrebel are almost twice as great as the optimum recorded by Headlee (1918) for *Aedes* migrations in New Jersey, and partly because these results are in striking contrast to Le Prince and Orenstein's report (1916) that in Panama *Anopheles* species seem to fly almost exclusively against the wind and rarely or never with it though sometimes at right angles to it. Swellengrebel's best results were with wind velocities of 7 and 8 meters a second, or almost 20 mi.p.h. Toumanoff (1934) partially corroborates this for the *Anopheles* species of Indo-China. He says that heavy winds and rain seem to have little effect on the movement of the common species since females engorged with animal blood (determined by precipitin tests) have been taken in the middle of the rainy season in places where cattle were not stalled. Aside from the impossibility of separating wind carriage from dispersion influenced by wind, there may be a difference between *Anopheles* and *Aedes* in this respect. Unfortunately Le Prince and Orenstein do not record weather conditions other than the direction of the wind.

Of the other weather conditions, light is at most of lesser importance, but the avoidance of bright sunlight by most species may explain why the longest migrants are the diurnal species which are stimulated to intense activity by higher light intensities; for example, *Aedes sollicitans* and *cantator* (Rudolfs, 1923). Crepuscular and nocturnal species would have less frequent and less continuous periods of optimum temperature. Although doubtless not the whole story,

this may enter into the explanation of relatively short-migrant species (*Aedes canadensis*, *excrucians*, *stimulans* etc.) traveling farther when protecting wooded areas occur at short intervals (see Matheson, 1929, p. 41).

The only other important weather factor is barometric pressure. No data seem available for the relation of this to mosquito dispersal but it is probably of little practical importance since significant fluctuations in barometric pressure soon become expressed in changes in temperature, humidity and wind. In a general review on the effect of climate on insects, Uvarov (1931) notes that certain insects are almost natural barometers, that is, they migrate immediately preceding storms. This appears not to be true for mosquitoes. In statistical correlations between weather factors and numbers of moths caught in traps, Cook (1921) found that pressure exerted decidedly less influence than either temperature or humidity.

The topography of the country is a minor factor. Mosquitoes will not cross mountain ranges (e.g. *Aedes vexans*, Headlee 1918) but travel across rolling and slightly hilly country unimpeded. Sylvan species naturally will not cross large expanses of open country. Open water and water courses seem neither a barrier nor an attraction since diurnal species have been caught many miles at sea (Headlee, 1918; Hamlyn-Harris, 1933), since staining has proved that the domestic *Aedes aegypti* will fly to land from a boat over half a mile across the bay (Shannon and Davis, 1930), and that *Culex* and *Anopheles* species will cross a channel over half a mile wide (Satyanarayana, 1934), and since migrating species do not follow water courses.

The modifying effect of the density and proximity of human population is stressed by Headlee (1918, 1930, 1936) and by him only for certain species. In his comments in 1936 Headlee says, "So far as I can see from our data, *Aedes sylvestris* (*vexans*) and *Culex pipiens* do not go with the wind. It seems that they go in the direction of the population, which we theorize is due to the attraction exerted by carbon dioxide." Headlee's postulate that these mosquitoes travel up a carbon dioxide gradient may be true since it is well known that some insects possess chemo-receptors over a thousand times more sensitive than humans and so might possibly possess receptors for detecting carbon dioxide in minute quantities, since minute differences in carbon dioxide are known to have definite effects on certain nerve centers, and since carbon dioxide has an exceedingly rapid rate of diffusion.

Possible effects of human population are occasionally mentioned by other authors. For instance, De Meillon (1933) reports that *Anopheles funestus* normally flies less than half a mile but that flights have been recorded up to four and a half miles when no nearer sources of human blood were available.

Homing instinct. There has been considerable controversy as to the truth of this concept. The idea was advanced by Le Prince and Orenstein (1916) based on the occurrence of "malaria houses" and substantiated by observations of a species of *Anopheles* migrating in numbers from a particular breeding area to a small village in the early evening and returning over the same route in the morning. Later Le Prince and Griffiths (1917) claimed additional evidence based on experiments in which three stained specimens of *Anopheles quadrimaculatus* traveled three-fifths of a mile in three to four days and crossed a river 800 feet wide to return to the shack from which they were originally captured. Rather vague supporting data came from other sources: Geiger, Purdy and Tarbett (1919) recaptured nine of their ten stained specimens of *Anopheles quadrimaculatus* close to the place where the specimens were originally captured (not same as place where released). López (1930) stained 927 specimens of *Anopheles pseudopunctipennis* in houses and since of the 17 recaptured 16 were taken on the way to or at the breeding places, he says they tend to return to the breeding place from which they originated. To the best of my knowledge no claims of "homing instinct" have been made for any mosquito other than *Anopheles* species.

Most writers ignore or evade this question, but Kligler (1932) says that it can not be maintained that infected mosquitoes (*Anopheles*) return to the same place after oviposition, except by chance, and that their concentration is seemingly regulated by the same factors as normal specimens (food and shelter). Although it is not disproof of a "homing instinct" Kligler adds that *Anopheles* may change their abode without visiting the breeding grounds.

Two sets of dissenting experiments with Culicines have bearing on this point. Shannon, Burke and Davis (1930) found that the domestic *Aedes (Stegomyia) aegypti* (= *argenteus*) may remain in the same house up to two weeks or may move to neighboring houses. In an ingenious experiment, Sergeant, Sergeant and Castanei (1933) connected a caged breeding place of *Culex pipiens* by tubes to two cages, one containing an infected and uninfected canary, the other containing two healthy birds. If the mosquitoes returned to the

same cage for a second feed the healthy bird caged with the infected one should become infected, and the healthy birds in the other cage should remain healthy. Since all the birds became infected, it appeared that *Culex pipiens* has no instinct to return to the same feeding place. Unfortunately this experiment is of dubious value for the point in question because: (a) a domestic species of short flight range and slight flight tendency was used instead of an *Anopheles* and (b) the conditions of the experiment were too artificial to warrant general conclusions.

My personal opinion is that if any "homing instinct" were an important factor in the movements of Anophelines, and not just a coincidence, it would have been definitely demonstrated before now, since the idea was advanced more than 20 years ago.

Sterility. Smith (1904) reported that the females of *Aedes sollicitans* and *A. cantator* that are found far from the salt marshes almost invariably have small abortive ovaries, and he hypothesizes that this condition was already present before they left the marsh and that it is accordingly a prime factor in stimulating migration (causing "restlessness"). This condition apparently has no effect on their eagerness to bite. The present author knows of no careful study of this point but would judge from Headlee's omission of it that he does not consider it important.

The few migratory females of *Aedes sollicitans* that the present author dissected this summer showed small seemingly functionless ovaries, but no attempt was made to study this point in detail and no attempt will be made to discuss or evaluate the phenomenon. The differences are too great to warrant direct comparison but one is reminded of the seemingly purposeless northern flight of the cotton moth, *Anomis (Alabama) argillacea*, each autumn—a flight that ends in death—and similar migrations.

Effect of control measures. The late J. S. Williamson and other members of the Suffolk County Mosquito Extermination Commission inform me that they have frequently noticed that when adults of *Aedes sollicitans* are abundant on an unditched marsh at the time it is being ditched, the mosquitoes seem to retreat to the yet unditched areas as the ditching progresses. And, further, that the completion of the ditching seems to serve as a stimulus to initiate a migration away from the marsh. The present author observed one of these cases at Fire island during July 1936, and, while it is true that the mosquitoes departed at the completion of the ditching, it is also true that, in this case at least, the mosquito density and the weather con-

ditions were near the migrational optimum. The present author hesitates to comment further on the possible direct influence of control measures on dispersion but is inclined to suspect that they are operative chiefly, when at all, at times when the "prerequisite factors" are at or near the optimum.

One might summarize the factors affecting mosquito migration somewhat as follows, including some possibly significant points not discussed above:

FACTORS IN MOSQUITO DISPERSAL

Prerequisites and modifying factors:

- 1 Dense mosquito population at breeding ground
- 2 Favorable temperature (about 80° F.)
- 3 Favorable humidity (75—90 per cent) and no rain
- 4 Favorable air currents or wind

Modifying factors:

- 1 Light
- 2 Topography
- 3 Human population (search for blood meal)

Factors of unknown or questionable significance:

- 1 Barometric pressure
- 2 "Homing instinct"
- 3 Movements after a blood meal (Kligler, 1932)
- 4 Specific habits with regard to breeding and resting places (see papers by Swellengrebel and others, Kligler etc.)
- 5 Average size and strength of species, including age, sex, virginity, sterility and weight of ova
- 6 Zoophilism (seeking animal blood in preference to human)
- 7 Control measures

MOVEMENT OF MOSQUITOES ON LONG ISLAND

The evidence of extensive mosquito migrations on Long Island is largely circumstantial but none the less conclusive in view of the more exacting observations and experiments that have been performed elsewhere, especially in neighboring New Jersey. A few specific examples will suffice to show that the general principles pointed out in the preceding sections are also valid on Long Island.

The salt marsh mosquitoes. *Aedes sollicitans* is at times abundant throughout the island, which in some areas means a dispersion of more than ten miles from the breeding grounds. At times of heavy breeding along the south shore this species has been known to

travel the full width of the island, more than 20 miles. In August 1933 strong winds blew steadily from the south for several days following a storm at sea. Prior to this the inland and northern parts of the island were practically free of *sollicitans*; during and after these strong southerly winds the entire island was plagued with the species for more than a week. The presumption seems warranted that large numbers were blown from the south shore marshes and distributed all the way across the island (Ann. Rep't Nassau Co. Exterm. Comm., 1933).

A more typical migration across the island occurred in Suffolk county in 1936. On July 1, 1936, the author visited East Fire island, off the south shore but within the barrier beach, in company with members of the Suffolk County Mosquito Extermination Commission. At this time Fire islands were yet unditched and an enormous brood of *sollicitans* had just finished emerging from the salt marshes that cover the greater portion of the islands. A week later, on July 8th, the author again visited Fire island and found very few mosquitoes present. During the intervening week the weather had been warm, the humidity high, practically no rain except for a shower on July 5th and the winds had been relatively mild and from the south and southwest. The late J. S. Williamson, of the Suffolk County Mosquito Extermination Commission, told me that during the week of July 2d-8th a migration of *sollicitans* had proceeded from this general region (presumably from only or at least including Fire islands) in a northeasterly direction across the entire island as shown by the advancing presence of adults reported from various points along the line of flight from day to day.

In discussing *Aedes sollicitans*, Lutz and Chambers (1902) report that this species travels mainly along thoroughfares of traffic, hovering over and following the slow traffic of those days and riding on trains, trolley cars and wagons. It is questionable whether they travel with the faster automobile traffic of today, and the consensus of opinion seems to be that they travel primarily with the wind and only secondarily if at all with reference to topographical variations such as highways.

Less can be said about the other species of salt marsh mosquitoes. The larvae of *Aedes cantator* are abundant but the adults are relatively uncommon even on the salt marsh, presumably because they develop in the upper, more nearly fresh water parts of the marsh which become drained sooner than the lower more saline parts (where *sollicitans* develop in the greater numbers), with the result that a much smaller percentage of *cantator* larvae attain maturity

than *sollicitans* (see section on Biology). *Aedes taeniorhynchus* seems never to become an abundant species. Single specimens were taken during August 1936 about one mile from the nearest salt marsh. *Culex salinarius* is reputedly a local, nonmigrating species. No notes were obtained on its movements on Long Island.

The fresh water mosquitoes. *Aedes vexans* and *Culex pipiens* are the economically important fresh water mosquitoes of Long Island. *A. vexans* breeds so generally throughout the island that only one example of apparent dispersion came to the author's attention. In late September and early October 1936 this species was present in annoying numbers in and around Lawrence, Hewlett Bay Park and neighboring villages, on the south shore, eastern part of Nassau county, but diligent searching by this author and inspectors of the Nassau County Extermination Commission failed to reveal any breeding grounds within several miles. As the author had been actively working in the field in this small area almost continuously from early September until after the outbreak, and determining all larvae found, it would seem that this infestation represents a dispersion into this area from some place at least several miles distant.

Culex pipiens breeds so generally that circumstantial evidence gives no indication of its possible movements. It was sometimes found troublesome at night on and near the salt marshes of the barrier beach (Jones Beach Bird Sanctuary) but the author found it breeding in small but appreciable numbers along the upper, fresh water part of these marshes (figure 43). Accordingly its presence on and near these marshes does not necessitate a flight of more than a few hundred yards.

Mansonia perturbans, an extensive migrant in certain parts of the country (table 21), was reported as abundant near Forest Hills, Queens county, and Calverton, Suffolk county, in July 1936. No indication of extensive dispersion came to hand but the species was taken in almost all the traps in New York City. A knowledge of the breeding places of this species on Long Island is prerequisite to any discussion of its movements.

The other species recorded from Long Island are all reputedly local or at most short migrants with extreme dispersal of one to two miles. Most of these, except *Anopheles punctipennis* and *Culex apicalis*, are uncommon or rare.

The flight ranges of all the important species of Long Island and of several species not found on Long Island are given in tables 20 and 21.

TABLE 20
Summary of the data from staining experiments in various parts of the world

SPECIES	AUTHOR	PLACE	STAINS USED	NUMBER RELEASED	NUMBER RECAP-TURED	NUMBER EXAMINED	TIME RANGE IN DAYS AFTER LIBERATION	DISTANCE IN MILES
<i>Anopheles larimaculata + albimanus</i>	Zetek (1913)†.....	Panama....	Eosin gentian violet, fuchsin, bismark brown, orange G, methylene blue, phenolphthalein, cornstarch	—	—	—	—	—
<i>Anopheles quadrimaculatus</i>	LePrince+Orenstein (1916)†....	Panama....	"Stalped".....	—	40	—	—	0.2-1.2
	Le Prince+Griffiths (1917)†....	S. Carolina.	Aqueous eosin.....	900-1000	6	Several thousand	3-6	0.5-1.0
<i>Anopheles quadrimaculatus</i>	Geiger, Purdy+Tarbett (1919)†.	Arkansas...	Methylene blue.....	4 000	10	19 831	3	0.75-1.0
<i>Anopheles claviger</i>	Sella (1920)†.....	Italy.....	"Alcoholic dyes".....	2 650α	23α	5 332	7-10	0.5-1.0
<i>Anopheles ludlowi</i>	van Breemen (1920)*.....	Java.....	—	—	73	—	—	7-3.87
<i>Anopheles acoutus</i>	Mangkoeimoto (1923)*.....	—	—	—	9	—	—	7-0.25
<i>Anopheles quadrimaculatus</i>	Darling (1927)†.....	Georgia....	"Dusting powder".....	—	—	—	—	7-1.75
<i>Anopheles maculipennis</i>	Missiroli (1927)*.....	—	—	—	—	—	—	7-2.19
<i>Anopheles pseudopunctipennis</i>	Rickard (1928)*.....	Argentina..	—	—	—	—	—	2.5-3.75
<i>Anopheles maculipennis</i>	Swellengrebel (1929)†.....	Holland....	Methylene blue.....	5 672	40	18 042	2-10	0.5-1.8
<i>Anopheles pseudopunctipennis</i>	López (1930)*.....	Argentina..	—	927	16	—	—	0-0.6
<i>Aedes (Stegomyia) aegypti</i>	Shannon, Burke+Davis (1930)†.	Brazil.....	Eosin, gentian violet, methylene blue	3 500	—	—	1-17β	0β
	Shannon+Davis (1930)†.....	Brasil.....	Eosin, gentian violet, methylene blue	32 000	105	—	5-13γ	0.25-0.75
<i>Anopheles acoutus</i> , <i>fuliginosus</i> , <i>kochi</i> , <i>hyrcanus</i> var. <i>sinensis</i> , <i>subpictus</i> + <i>vagus</i>	Avé Lallemand, Soerono+Soekaria (1931)*.....	Java.....	—	—	15	—	—	0-0.5
<i>Anopheles acoutus</i> , <i>subpictus</i> , <i>kochi</i> , <i>hyrcanus</i> var. <i>sinensis</i> + <i>tesellatus</i>	Avé Lallemand, Soerono+Stoker (1932)*.....	Java.....	—	—	9	—	—	0-1.0
<i>Anopheles minimus</i> var. <i>flavirostris</i> , <i>maniponatus</i> , <i>flippinae</i> + <i>tesellatus</i>	Russell+Sanctiago (1934a)†....	Philippines.	Vital red, orange G, dahlia violet, brilliant blue	2 100	8	10 946	3δ	0.25-1.0

<i>Anopheles minimus</i> var. <i>fusirostris</i> †- <i>subpictus</i> var. <i>indefinitus</i>	Russell+Santiago (1934b)†.....	Philippines.	Vital red, orange G, dahlia violet, brilliant blue	10 000	11	31 011	3 ε	0.25-1.6
<i>Anopheles pallidus</i> †- <i>subpictus</i> and <i>Culex</i> sp..	Satyamaryana (1934)*.....	India.....	Methylene blue.....	400	3	—	—	?-0.75
<i>Anopheles maculipennis</i> var. <i>afroparvus</i>	Hill, Olavarria+Rivera (1935)*.	Spain.....	—	—	"Several"	—	"Several"	1.24-3.42

† Original paper examined. No further data given.

* Original paper not seen. These notes are from abstracts in series B of the Review of Applied Entomology, or, from citations by other authors.

α Repeated next year with 1300 and 2200 specimens in two corroborating experiments with similar results.

β Recaptured in house where originally released.

γ Mostly five to eight days, only one specimen after ten days.

δ Seven of the eight specimens were within three days, the eighth was after seven days.

ε In this set of experiments specimens were liberated almost daily over a 15-day period. Specimens were recaptured over a 14-day period beginning two days after the first release and ending one day after the last release. Accordingly the time interval can not be stated with accuracy.

TABLE 21

Recorded flight ranges of certain of the more common and more important mosquitoes of North America, with special reference to those species likely to be troublesome on Long Island, N. Y., exclusive of *Anopheles*

SPECIES	MAXIMUM DISTANCES IN MILES	LOCALITY	AUTHORITY
<i>Aedes aldrichi</i>	10	Western.....	Hearle, 1932
<i>Aedes campestris</i>	10	Utah.....	Rees, 1935
<i>Aedes canadensis</i>	Local	New Jersey..... Central New York.. New Jersey.....	Smith, 1904 Matheson, 1929 Headlee, 1931
<i>Aedes cantator</i>	30-40 30-40	New Jersey..... New Jersey.....	Smith, 1904 Headlee, 1931
<i>Aedes dorsalis</i>	22	Utah.....	Rees, 1935
<i>Aedes excrucians</i>	Local	Western.....	Hearle, 1932
<i>Aedes hirsuteron</i>	"Migrates freely"	Western.....	Hearle, 1932
<i>Aedes sollicitans</i>	30-40 40-60	New Jersey..... New Jersey.....	Smith, 1904 Headlee, 1918, 1931
<i>Aedes stimulans</i>	2+	Central New York..	Matheson, 1929
<i>Aedes taeniorhynchus</i>	65	Gulf States.....	Headlee, 1936
<i>Aedes triseriatus</i>	Local		
<i>Aedes vexans</i> (= <i>sylvestris</i>)....	1-5 10 3 10 5-8	New Jersey..... New Jersey..... Central New York.. Western..... Utah.....	Smith, 1904 Headlee, 1918, 1931 Matheson, 1929 Hearle, 1932 Rees, 1935
<i>Culex pipiens</i>	2.5 (<i>extreme</i>)	New Jersey.....	Headlee, 1916, 1931
<i>Culex apicalis</i>	Local	{ New Jersey..... General..... New Jersey.....	Smith, 1904 Matheson, 1929 Headlee, 1931
<i>Culex salinarius</i>			
<i>Culex territans</i>			
<i>Mansonia perturbans</i>	"considerable" "several miles" 5-8	New Jersey..... Central New York.. Florida.....	Smith, 1904 Matheson, 1929 McNeel, 1932

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