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U.S. IBP-TUNDRA BIOME
REPORT 70-1

TUNDRA BIOME RESEARCH IN ALASKA

The Structure and Function of Cold-Dominated Ecosystems

Jerry Brown and George C. West

November 1970

IBP

U.S. TUNDRA BIOME · ANALYSIS OF ECOSYSTEMS

INTERNATIONAL BIOLOGICAL PROGRAM

This report was prepared in collaboration with the personnel of the Tundra Biome Program. It contains summarized data which have not yet been tested statistically. The interpretations of these data are tentative and final conclusions not yet formalized. However, distribution of this report is unlimited and additional copies may be obtained from Director, Tundra Biome, Box 345, Hanover, N.H. 03755. The data reported are not for use in the open literature prior to publication by the investigators named, unless permission is obtained in writing from the individual or the Director, Tundra Biome.

TUNDRA BIOME RESEARCH IN ALASKA

THE STRUCTURE AND FUNCTION OF COLD-DOMINATED ECOSYSTEMS

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U.S. Tundra Biome – Analysis of Ecosystems
International Biological Program

ACKNOWLEDGMENTS

The research program reported here was possible only through diversified bases of funding and logistics. The individuals involved are far too numerous to acknowledge separately. However, it is imperative to mention the following organizations which undertook a significant role in the planning, funding, and execution of this program:

The National Science Foundation and its staff for providing guidance and the critical research funding to seven separate institutions under the grant entitled *Effects of Perturbations on the Cold-Dominated Ecosystems in Alaska*, J. Brown and G.C. West, coprincipal investigators. This funding formed the fiscal base from which the program was feasible.

The Office of Naval Research which, through the Naval Arctic Research Laboratory, Barrow, Alaska, and its staff, provided without cost the room, board, and logistics for the Barrow phase of the program. Without this support the program in northern Alaska would not have been conceptually feasible during 1970. The Tundra Biome Program makes special recognition of this fact and applauds ONR for it.

The University of Alaska, at College, Alaska, for welcoming the Tundra Biome Program into its research organizations, for providing administrative services for private grants, office space, and other forms of support, and for making available specialized groups within the University, such as the data processing section of the Geophysical Institute. Without this collective support, the Tundra Biome Program would not have been able to operate as an effective research organization.

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The USA Natick Laboratories for providing the expertise, data logger and micromet equipment used in the acquisition of the Barrow environmental information.

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The Trans Alaska Pipeline System (TAPS), now Alyeska, for making sites available, providing air transportation, and freely allowing discourse among its own and contractual research scientists and engineers and the Tundra Biome scientists.

The U.S. International Biological Program National Committee and office staff for providing the framework and encouragement from which the Tundra Biome Program evolved.

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Finally, the editorial, drafting, reproduction, and publication staff of USA CRREL for expeditiously processing this report.

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10 December 1970

ERRATA

TUNDRA BIOME RESEARCH IN ALASKA
The Structure and Function of Cold-Dominated Ecosystems

by

Jerry Brown and George C. West

The primary aim of the authors and editors of this report was publication and distribution in the shortest possible time, as proof of which they offer the following list of errata.

p. 6, line 14: For "100 vascular plants" read "100 vascular species."

p. 49, Table XIX: For "*Calidris puslilla*" read "*Calidus pusilla*."

For Pectoral sandpiper, under "Attempts," change 3 to 6.

Under "Attempts," change Total from 31 to 34.

p. 52: Add Brian Viani to list of participants.

p. 57, line 5: For "*Ranunculus pygaeus*" read "*Ranunculus pygmaeus*."

p. 57, line 1: For "*Cochlearia officionalis arctica*" read "*Cochlearia officinalis arctica*."

p. 57, line 5: For "*Polygonum acutiflora*" read "*Polemonium acutiflorum*."

p. 64, Para. 5, lines 3-4: For "chlorophyll m^2," read "chlorophyll/m^2."

p. 67, Para. 2, line 7: For "unassociated," read "associated."

p. 69, Table XXVII: Insert †† before fourth footnote.

p. 95, Table XXXVI: For "Bacterial biomass lb/in. acre" read "Bacterial biomass lb/acre."

For "Potassium lb/ace" read "Potassium lb/acre."

p. 102, Para. 5, line 9: For "This community" read "The second community."

p. 108, Table XLI: In title, insert asterisk after "classes."

p. 109, Table XLII: Under Secondary Dominants, for *Calamagrostic canadensis* ..." read "*Calamagrostis canadensis* ..." (two places).

Under Lesser Species, for "*Stellaria longpipes*" read "*Stellaria longipes*."

p. 113, Para. 4, last line: For "major species" read "major fungal species."

p. 114, Table XLII: Sample no. 6 – under Organic matter (%), change 23 to 18.

Sample no. 7 – under Moisture content (%), change 24 to 18.

p. 119, Para. 7, line 6: For "*Sparganium miniumu*" read "*Sparganium minimum*"

p. 120, Table XLVII: For "*Loiseleuria procumens*" read "*Loiseleuria procumbens*."

For "*Stereocoulon* spp." read "*Stereocaulon* spp."

For "*Carex cancocens*" read "*Carex canescens*."

p. 124, Table AII: Opposite the headings *Production*, *Plant nutrients*, *Chlorophyll* and *Caloric*, delete the number 4 from Plot 228 and insert it under Plot 226.

p. 145: Delete Table EIV (4). (Duplicate of Table EIV (3).)

Corrected spellings of several participants' names are as follows:

p. 21	Gregor Fellers
p. 29	Dave Hanson
p. 44	Jim Bumbarger
p. 87	Martyn Caldwell
p. 87	Arla Scarborough
p. 97	Kent Gormley

I. PROGRAM OVERVIEW

INTRODUCTION

The requirements for terrestrial ecosystem research in arctic and subarctic regions were dramatized by events immediately preceding and following the discovery of oil in 1968 at Prudhoe Bay. A keen awareness of these "fragile," cold-dominated ecosystems emerged as attempts to mechanically cope with them produced unsightly and destructive evidence of man's intrusions into a natural environment. The proposal to transport hot oil through a pipeline across the state of Alaska raised an additional series of crucial environmental questions.

Until recently, physical and biological scientists had traditionally undertaken research more or less independently – both in time and space. Where integrated research had been attempted, results were still presented by individuals, on discipline-oriented subjects, and often in widely separated types of publications. The ecosystem concept and the methods of investigating, as a total system, the interrelationships of all life forms with their physical environment offered many advantages for the scientific pursuit of ecological assessment in the Arctic and subarctic.

During the spring of 1970, the Tundra Biome Program of the U.S. International Biological Program undertook the design of a series of short-term, interrelated experiments and observations which would produce basic information on the functioning of cold-dominated ecosystems and would also begin to answer questions concerning their responsiveness to natural and artificial impact. The resulting summer research, funded principally by the National Science Foundation, did not constitute the full Tundra Biome Program, although key elements of the more comprehensive integrated research design were introduced. This report highlights the scientific accomplishments of the summer 1970 research, but is not a definitive treatise on the subjects of arctic and subarctic ecosystems. The results, in most cases, were hurriedly abstracted from a voluminous data bank. Field investigations of one season's duration can not be considered complete. Therefore, the interpretations and conclusions are minimal and are considered preliminary. Final reports and interpretations will appear as individual scientists complete their investigations.

The report itself is published at this time for three purposes:

1. To serve as an interim report to the National Science Foundation for its portion of the sponsored research under the grant entitled *Effects of Perturbations on the Cold-Dominated Ecosystems in Alaska.*

2. To review the status of current research within the program, so that a new proposal for 1971 can be developed based upon the 1970 research results. This summary will serve to familiarize prospective projects with the *modus operandi* of the program and current progress in specific research subjects.

3. To demonstrate that a group of scientists from many institutions throughout the U.S., working together as a highly coordinated team, can conduct integrated projects and can report the meaningful results of their findings while current research continues. The ability to do this is the initial criterion for the continuation of this and similar ecosystem programs.

SCOPE, OBJECTIVES AND STRATEGY

The objective of the Tundra Biome Program is to acquire a basic understanding of tundra, both alpine and arctic, and taiga. Collectively these are referred to as the cold-dominated ecosystems. The program's broad objectives are threefold:

1. To develop a predictive understanding of how the wet arctic tundra ecosystem operates, particularly as exemplified in the Barrow, Alaska, area.

2. To obtain the necessary data base from the variety of cold-dominated ecosystem types represented in the United States, so that their behavior can be modeled and simulated, and the results compared with similar studies underway in other circumpolar countries.

3. To bring basic environmental knowledge to bear on problems of degradation, maintenance, and restoration of the temperature-sensitive and cold-dominated tundra/taiga ecosystems.

During 1970, funding limitations prohibited full implementation of these objectives. Nevertheless a research design was developed which focused on bioenvironmental research in Alaska. The principal objective of the 1970 research was to determine initial responses by ecosystem components to a variety of natural and artificial disturbances or perturbations. In so doing, a substantial emphasis was placed on basic research of fundamental processes and properties on undisturbed controlled sites.

The 1970 program is divided into two major subprograms: ecosystems of the arctic coastal tundra and site investigations along a bioenvironmental gradient ranging from the arctic coastal tundra into the interior taiga of subarctic Alaska (Fig. 1). The rationale for this approach was to provide an in-depth research effort on major Alaskan ecosystems.

Research on the arctic coastal tundra was concentrated in the immediate vicinity of Barrow, Alaska. Barrow had previously been designated as the intensive site for the U.S. IBP Tundra Biome. The locale was familiar to several generations of arctic scientists and the results of past studies were available in a variety of forms. It was postulated that these two considerations would permit an extension in the interpretation of the 1970 findings over many years and different types of summer climates. The presence of the Naval Arctic Research Laboratory with its excellent research and logistical facilities permitted this portion of the program to mobilize within a matter of weeks. Other sites on the Arctic Coastal Plain were visited at irregular intervals. The Cape Simpson oil seeps provided an opportunity to examine the long term effects of oil on the tundra ecosystem. Numerous visits to the areas within the Prudhoe Bay oil fields permitted the gathering of information with which comparisons with Barrow and other areas are possible and provided the experience from which long-term research plans can be designed. This concentration of manpower and projects in the arctic coastal tundra was endorsed by an external review committee. The report of that group was distributed with the September Newsletter.

The entire coastal tundra program was under the direction of the Biome Director, Jerry Brown, and the Barrow site was directed by Larry Tieszen.

The bioenvironmental subprogram consisted of comparative investigations along a bioclimatic gradient which parallels the several proposed transportation corridors between Fairbanks and Prudhoe Bay. Selection of sites was largely determined by the location of revegetation plots which were established in 1969 by University of Alaska scientists under contract to the Trans Alaska Pipeline System (TAPS).* The current program undertook basic ecological studies in areas

* Now Alyeska Pipeline Service Company

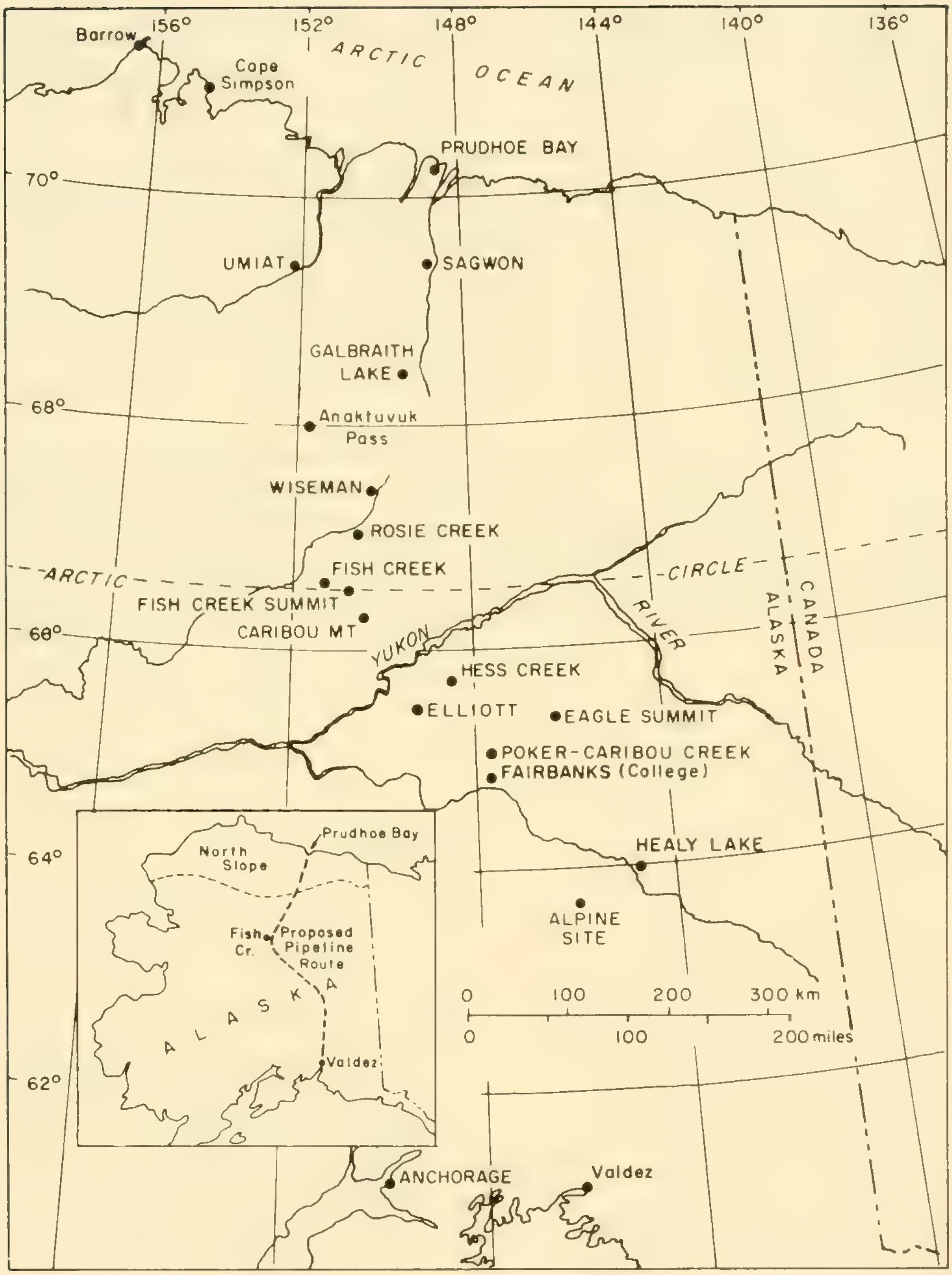

Figure 1. Location map of sites involved in 1970 field observations.

immediately adjacent to these plots. More intensive studies were undertaken at College, adjacent to an experimental buried hot pipe. The TAPS-sponsored research projects are being reported upon elsewhere by those directly involved and do not constitute a formal part of the Tundra Biome Program. However, both approaches, the revegetation studies and the basic ecological studies, stand to gain from their close proximity in time and space. The bioenvironmental subprogram is under the direction of the Biome Deputy Director, George West, and Keith Van Cleve.

The research was performed under a centrally designed and managed ecosystem program. At Barrow, all field projects and participants devoted considerable portions of their time to investigating plots and study sites agreed upon under the design discussed in the following sections. In return, central services in the form of data processing, laboratory processing of samples, and automated acquisition of environmental data were provided by the central program wherever feasible. This integration of individual projects in both time and space was carried over into several other related research projects, particularly those concerning stressed ecosystems at Barrow, Cape Simpson, and Prudhoe Bay. The planning and execution of integrated research on this scale are criteria set forth by the U.S. IBP.

Lists of participating projects and individuals are contained in Table I. Each major section of the remainder of this report has one or more authors and many participants. All participants are listed for each major section. This approach emphasizes cooperation and the interaction between the various subprojects listed in Table I, not only by people but more importantly by disciplines. Several sections of the report are structured according to the four major ecosystem components: abiotic, producers, consumers and decomposers (microbiology and nutrient cycling).

Table I. Projects participating in and cooperating with the U.S. IBP Tundra Biome Program.

Projects	*Sites**	*Principal Investigators and Institutions*
Effects of manipulation of snow and vegetation covers on the thermal regimes of the tundra (NSF)	1	Gunter Weller, Univ. of Alaska Carl Benson, Univ. of Alaska
Simulations of meteorological variation over arctic coastal tundra under perturbed physical interface conditions (NSF)	1	Norman W. Lord, Joseph Pandolfo — Center for Environment and Man, Hartford, Conn.
Bioenvironmental parameters of natural and disturbed ecosystems along the trans-Alaskan transportation corridor (NSF)	1, 2	George C. West, Univ. of Alaska
Photosynthetic responses and adaptations of tundra plants to the arctic environment (NSF/AINA)	1	Larry L. Tieszen, Augustana College South Dakota
Patterns of interactions among ecosystem components using natural and disturbed tundra sites near Barrow, Alaska (NSF)	1	Frank A. Pitelka, Univ. of Calif. Arnold M. Schultz, Univ. of Calif. Paul L. Gersper, Univ. of Calif.
Population ecology and energy utilization of tundra soil arthropods (NSF)	1	Stephen MacLean, Jr., Univ. of Montana (presently Univ. of Illinois)
Phosphorus cycling and its effect on primary production in arctic ponds (NSF)	1	Robert J. Barsdate, Univ. of Alaska
Nitrogen fixation in terrestrial and aquatic ecosystem components (NSF)	1, 2	Vera Alexander, Univ. of Alaska
Metabolic activities of terrestrial decomposers in tundra ecosystems (NSF)	1	Robert E. Benoit, Va. Polytech. Inst.
Short-term nutrient fluctuations in disturbed and natural arctic and subarctic ecosystems (NSF)	1, 2	Keith VanCleve, Univ. of Alaska
The analysis of the structure and function of the wet tundra ecosystem at Point Barrow, Alaska (NSF)	1	Harry N. Coulombe, San Diego State College Phil Miller, San Diego State College Jerry Brown, USACRREL
Rates of thermal erosion and runoff on the arctic coastal plain (AINA and USACRREL)	1	Robert I. Lewellen, Univ. of Denver Jerry Brown, USACRREL
Soil thaw validation under natural and perturbed surface conditions (USACRREL)	1	Jerry Brown, USACRREL Yoshisuke Nakano, USACRREL
Effect of petroleum contaminants on cold-regions terrain (USACRREL) and	1	Jerry Brown, USACRREL Paul R. Murrmann, USACRREL
Effect on the ecology and biochemistry of oil seepages and spills in cold-dominated environment (ARO)	1	Brent McCown, USACRREL
Administration, coordination, and technical services for the U.S. IBP Tundra Biome (ARO-D, USACRREL, BP, ARCO)	1, 2	Jerry Brown, USACRREL George C. West, Univ. of Alaska
Primary production of tundra vegetation at comparative sites in Alaska and Canada (cooperative)†	1, 2	Larry Bliss, Univ. of Alberta Ross Wien, Univ. of Alberta Jerry Brown, USACRREL
Tundra-taiga revegetation study (TAPS-Alyeska)†	1, 2	Keith VanCleve, Univ. of Alaska William Mitchell, Univ. of Alaska
Biological assessment of the extent and consequences of a heated pipe section (TAPS-Alyeska)†	2	Peter Morrison, Univ. of Alaska Brent McCown, Univ. of Alaska
Caribou-Poker Creeks Research Watershed Program†	2	Inter-Agency Technical Committee for Alaska (Charles Slaughter, coordinator)

*Sites: 1. Arctic Coastal Tundra
2. Bioenvironmental Gradients

†Non-Reporting Projects and Programs

II. COASTAL ARCTIC TUNDRA ECOSYSTEM – A LANDSCAPE UNIT

The coastal plain of northern Alaska forms a relatively large and uniform landscape unit in which the structure and function of the wet arctic tundra ecosystem can be elucidated. The region is characterized by numerous lakes of all sizes, small ponds, and low-growing grass and sedge tundra. It extends from west to east across some 900 kilometers and is 180 km wide in its widest north-south extent. Relief is subdued, with elevations near sea level along the coast and rising gently southward to 200 m at the contact with the foothills. Permafrost underlies the entire region from within ½ to 1 m of the surface to over 300 m depth; the exceptions are under deep lakes and major river channels which are free of permafrost in the upper zone. Actively forming polygonal ground is common throughout, with a variety of forms expressed. Drainage is poorly integrated. Small meandering streams and tundra-covered beaded streambeds are common. Lakes of varying depths and dimensions cover as much as 50-80% of the land surface in some portions of the coastal plain. Summer climate is coolest along the coast and warms inland. Conversely, winter climate is more severe inland. The warmer inland summer climate is reflected in the vegetation. Along coastal areas such as Barrow approximately 100 vascular plants are found, while inland the number increases abruptly due to an increase in the variety of habitats as well as a more moderate summer climate.

BARROW RESEARCH DESIGN

Jerry Brown* USA CRREL
Larry Tieszen* Augustana College
Steve MacLean* Univ. of Illinois

Previous studies have shown that the fauna and flora are considerably less diverse than in inland coastal locations. Because of this,ecosystem interactions are fewer and, possibly, more easily defined. In addition, it is generally believed that "simple" ecosystems are inherently less stable than more complex systems, and include fewer potential mechanisms for adjustment following disruption or stress. These reasons make the Barrow ecosystem particularly appropriate for a first attempt at integrated ecosystem research and modeling. Figure 2 is an index map of the Barrow area, showing the locations of major study sites involved in this report.

The Barrow tundra encompasses a complex of habitats distributed along a moisture-dominated gradient related to microtopography and land forms. While the need was recognized to determine the range of biological and abiotic parameters associated with this complete range of habitats, the resources and personnel available in 1970 did not permit a complete study of the entire spectrum of tundra variation. Instead, attention was concentrated on a relatively homogeneous, terrestrial intensive study site (site 2; see Fig. 3) which represents a mid-point along this gradient. Control plots on the intensive site (2) were used to provide data on the seasonal progression of ecosystem parameters for the undisturbed tundra. These data will form the major input or valida-

* Principal authors

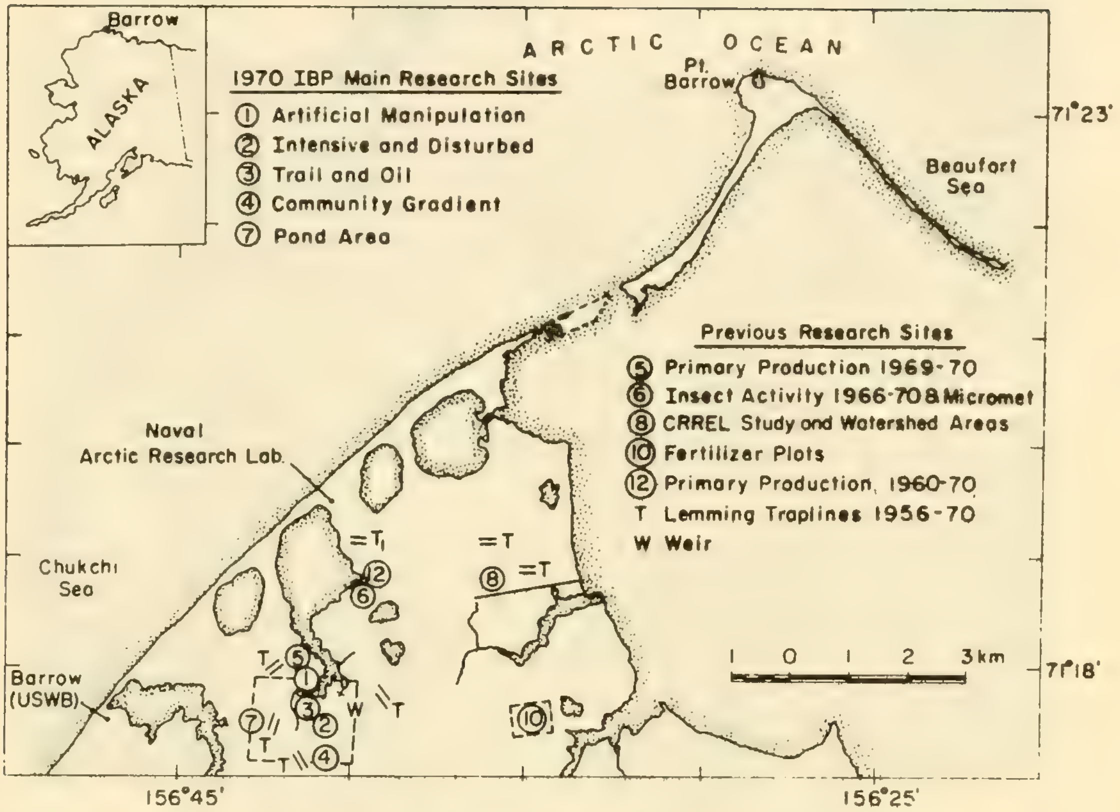

Figure 2. Location map of major study sites involved in the 1970 Barrow investigations.

tion of on-going ecosystem modeling. In addition, these plots served as controls for a series of manipulations or disturbances which were applied to the tundra. The manipulations served two purposes. First, they provided an experimental approach to the study of ecosystem function. The effects of manipulation of one component of the system may be traced to other components, thus revealing pathways and functional forms of interactions between ecosystem components. Secondly, manipulations, or controlled disturbances, were used to determine the sensitivity of the tundra ecosystem to several classes of stress and to reveal the mechanisms of recovery or adjustment following stress. This is directly applicable to the consideration of man's development of tundra resources.

Treatments

Two classes of manipulations or disturbances were recognized in this effort: natural and artificial. The natural manipulations are those which simulate naturally-occurring phenomena that affect rates of nutrient and energy flow through the ecosystem.

Clip and clear. In the winter, which precedes a cyclic population high of brown lemmings, the vegetation over large areas is clipped at the base by grazing lemmings. At the following melt-off the remaining unconsumed portion falls to the ground and may be washed away by draining melt-water. This causes a significant removal of nutrients from the local system, reduces the insulating layer over the tundra soil, and alters the structure of the vegetative canopy and the litter layer. On the clip and clear plot this was simulated by cutting the vegetation just above the moss level, using hedge and lawn trimmers. The cut vegetation was gathered by hand, weighed, analyzed for nutrient and caloric content, and used for mulch on another treatment. Two plots were treated in this manner. One was sampled intensively, while the other was reserved for nondestructive observations and sampling in subsequent years.

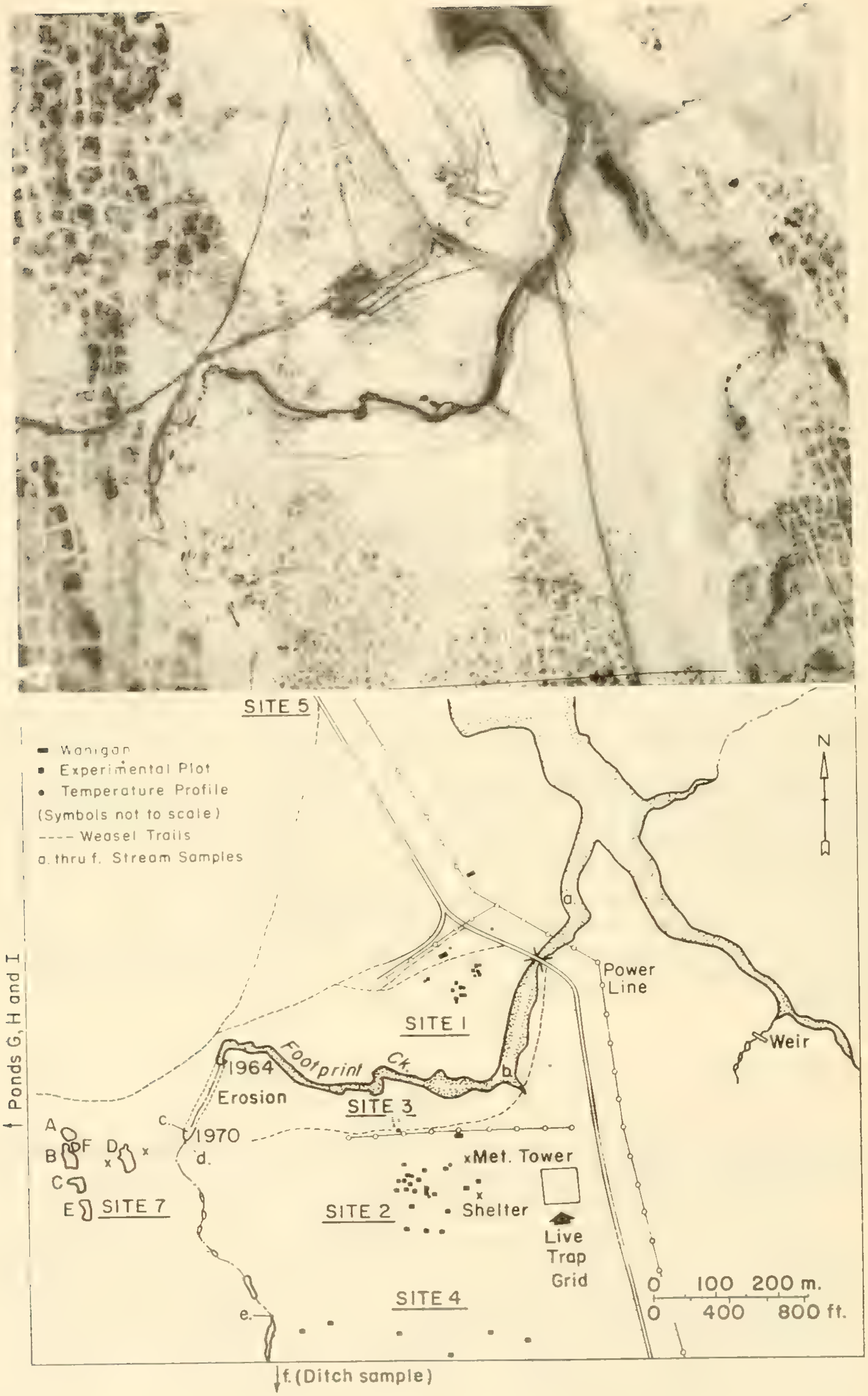

Figure 3. Major ecosystem sites investigated in summer 1970. The aerial photograph of the site was taken in 1964 for USA CRREL. The map on the lower half shows location of sample points and plots discussed in the text.

Figure 4. Site 2.

Clip and uncleared. In many cases vegetation cut by winter activity of lemmings is not washed away, but falls to the ground to enter the litter compartment of the system. The lemmings thus convert material from above-ground "standing dead," where it is subject to very slow decomposition, to litter, where it is subject to much more rapid decomposition by below-ground saprovores and decomposers. Thus, in addition to the physical effects of grazing on the plants, the lemmings cause the sudden input of organic matter into the saprovore food chain. These effects were mimicked on two plots, one sampled intensively and one reserved for nondestructive and future sampling.

Mulch. Plant material cut by lemmings and transported by meltwater frequently accumulates in low areas where drainage is retarded. Such areas experience a large increment of litter and, in addition, a great increase in the insulative layer over the tundra surface. The latter may be expected to influence near-surface temperature, and especially soil temperature and depth of thaw. Two plots were treated with natural plant litter (including that removed from the clip and clear plots). One plot received 107.3 g/m^2, an amount equal to that removed from one clip and clear plot, and approximately equal to the amount of plant material produced in one season. The other plot received a much heavier application of 240.9 g/m^2. The intense application produced a layer of litter which covered the lower portion of the vegetative canopy.

Fertilizer. The treatments were employed to determine the effects of increased nutrient availability without the additional physical effects of cutting the vegetation and alteration of the insulative layer. This was accomplished by the addition of commercial nitrogen-phosphorus-potassium (N, P, K) fertilizers at a rate equal to 400 lb/acre (45 g/m^2). One plot received a 20-10-10 mixture, and the second plot received an 8-32-16 mixture.

Figure 4 is an aerial oblique photograph taken in late August of a portion of the site 2 plots. At that time a majority of the plots had been enclosed to prevent subsequent grazing by lemmings. The large rectangular enclosure will be used for lemming grazing studies in 1971.

The artificial manipulations are those which exceed the range of conditions to which the tundra is ordinarily subjected. In several cases these simulated the real and anticipated effects of man's activities on the tundra. These are located primarily on site 1 and include:

Heated soil. The proposed buried oil pipeline will provide a year-round heat source within the soil. In order to evaluate the effect of warm soils on natural vegetation, a double loop of 1.25 cm copper tubing through which hot fluids circulate was buried at the 10-cm depth in the tundralsoil. Warming of the soil began in early July. In late August, one half of the buried loop covering a 3×6-m area was shut off for the winter. The experimental design and sampling will be discussed in greater detail in a later section.

Heated air. Temperature and wind or a combination of both have often been considered limiting factors in arctic plant growth. In order to test the hypothesis under field conditions, a 5×5-m by 1-m-high Fiberglas greenhouse was installed over an experimental plot. This greenhouse not only permitted elevated air temperatures, but served as a wind shield.

Physical disturbance. The effects of tracked vehicles on tundra vegetation are dramatic and long lasting. In order to ascertain short term influences of physical damage, two plots were rototilled while the surface was still frozen. On one plot, two complete passes at right angles covered the plot. This treatment constituted the intense disturbance. Single passes at right angles on the other plot constituted the light disturbance.

Figure 5. Site 1.

Oil spills. The effects and fate of hydrocarbons in the tundra environment is unknown. Two experiments to qualitatively determine the influence of oil spills on the plants and microflora were established. On site 1 four plots received 5 liters/m², and on site 2 rates between 0.7 l/m² and 12 l/m² were used. Details of this experiment are given in a later section.

Figure 5 is an aerial oblique of the site 1 test plots. Several plots are enclosed by fencing.

The community gradient site, located approximately 200 m south of site 2, was used to investigate the response of several ecosystem components to a wider variety of tundra conditions. This site included six study plots:

Plot 1, in a low, very wet meadow. On June 22, when the plots were marked, this plot had just been exposed by melt-off. Frozen ground was just below the surface, and the plot was covered with standing water.

Plot 2, in a trough between two polygons. This plot differed from the others in being 3 × 12 m rather than 6 × 6 m because of the linear nature of the habitat. Like plot 1, it was quite wet. It was exposed several days prior to June 22, and was covered with standing water on that date.

Plots 3 and 4, on mesic, meadow tundra of very gradual slope. The slope provided some drainage, so that standing water never accumulated. Plot 3 was in an area of weakly developed polygonization, and occupied the center of a low-centered polygon. Plot 4 was on an unpolygonized slope.

Plots 5 and 6, on the tops of well-developed polygons. These plots were quite exposed; snow accumulation in winter was inhibited by wind, and these were the first plots to be exposed by spring melt-off. Plot 5 was bare of vascular vegetation in places and showed evidence of erosion. Plot 6 was more completely vegetated.

The aquatic program consisted of a series of small ponds (Fig. 3, site 7). Control ponds were monitored for the entire summer to determine nautral variations. Several ponds were stressed with nutrients and oil for reasons similar to the terrestrial perturbations. Table II contains a list of plot numbers and treatments for each site.

The main study area was established in late May and early June on both sides of Footprint Creek, 4 km SW of the Naval Arctic Research Laboratory (Fig. 2, 3). This location contained the large areas of relatively homogeneous tundra required for the study and could be supplied with high quality, continuous electrical power from the Barrow camp.

On both sites 1 and 2 a number of study plots, each 6 × 6 m, were selected and marked. The plot size was chosen to provide an area large enough for repeated and replicated sampling at intervals throughout the season, yet small enough to minimize within-plot heterogeneity. After the plots were selected they were gridded, treatments were allocated to the plots at random and a random number process was used to identify sample quadrats in each plot.

The plot selection process was completed immediately after melt-off, and the first set of samples was taken from the site 2 control plots on 15 June. Thereafter samples were taken at 10-day intervals. Certain measurements were taken from the manipulated plots at 10-day intervals, while other measurements were taken twice, once early in the season and once at peak standing crop of the current season's plant production. Wherever possible samples for the various abiotic and biological measurements were taken at the same time and place to allow correlation of the various ecosystem parameters. The sampling schedules are summarized in Appendix A, which shows dates and kinds of samples taken from the various study plots and ponds.

In addition to the seasonally varying observations, several projects measured relationships existing between ecosystem parameters independent of time of season. Examples of such studies include the relationship of photosynthetic rate to air temperature and gas concentration, and the relationship of animal metabolic rate to ambient temperature. These data complement the seasonal observations, especially in our attempt to understand the mechanisms of interaction of ecosystem components, and thus are an important part of the modeling effort.

Finally, measurements on a number of sites which have been under investigation in previous years were conducted so that comparisons with past and current investigations could be drawn (Fig. 2).

Table II. Sites, plots and treatments employed during 1970 Barrow program.

Plot no.	*Treatment*
Site 1	
106	Control
107	Control
111	Heated air (green house)
112	Heated soil (hot pipe)
113a	Oil and fertilizer (5 liters oil/m^2) (20-10-10)
113b	Oil and fertilizer (5 liters oil/m^2) (20-10-10)
114a	Oil (5 liters oil/m^2)
114b	Oil (5 liters oil/m^2)
115	Intense physical disturbance
116	Light physical disturbance
Site 2	
201	Control (nondestructive)
202	Control (nondestructive)
203	Control (nondestructive)
204	Control (nondestructive)
205	Control (nondestructive)
206	Control (destructive)
207	Control (destructive)
208	Control (destructive)
209	Control (destructive)
210	Control (destructive)
226	Clip and clear
227	Clip and clear
228	Clip and uncleared
229	Clip and uncleared
230	Mulch (light)
231	Mulch (intense)
232	Fertilizer (20-10-10)
233	Fertilizer (8-32-16)
234	Wind (not sampled)
235	Grazed (not sampled)
236	Grazed (not sampled)
Site 3	
301	Control for oil
311	Oil (12 liters/m^2)
312	Oil (1.4 liters/m^2)
313	Oil (5 liters/m^2)
314	Oil (0.7 liter/m^2)
303	Track (Intermediate)
305	Track (wet)
306	Track (dry)
315	Not sampled
316	Not sampled
317	Not sampled
326	Not sampled
327	Not sampled
Site 4	
401	Wet meadow
402	Polygon trough
403	Meadow (tundra, low centered polygon)
404	Meadow (unpolygonized)
405	Polygon top (eroded)
406	Polygon top (not eroded)
Site 7 (ponds)	
B	Control
C	Control
D	Phosphorus additions
E	Oil spill
F	Shallow pond
G	Artificial thermokarst pit
H	Control
I	Control

Modeling

An important aspect of the integrated ecosystem research and its design is the interactions of field observations, data synthesis and ecological modeling. Modeling is actively underway at several distinct levels. The initial phase of modeling was the early formation of a word model – a verbal description of the structure and function of the wet tundra ecosystem. The word model is subject to a continuing process of expansion and revision as our understanding of the tundra becomes more precise. The most recent version of the word model appears in Appendix B.

The interrelationships between the major abiotic and biotic components of the wet, arctic ecosystem are emphasized in the graphic model illustrated in Figure B1 (App. B).

Interactions within and between the abiotic and biotic subsystems of the ecosystem are made more explicit in Figure 6. This model reveals the important compartments which contain the bound energy and nutrients of the system, and the pathways by which energy and nutrients are transferred within the system. In some places, as in the well-studied terrestrial consumers, important species

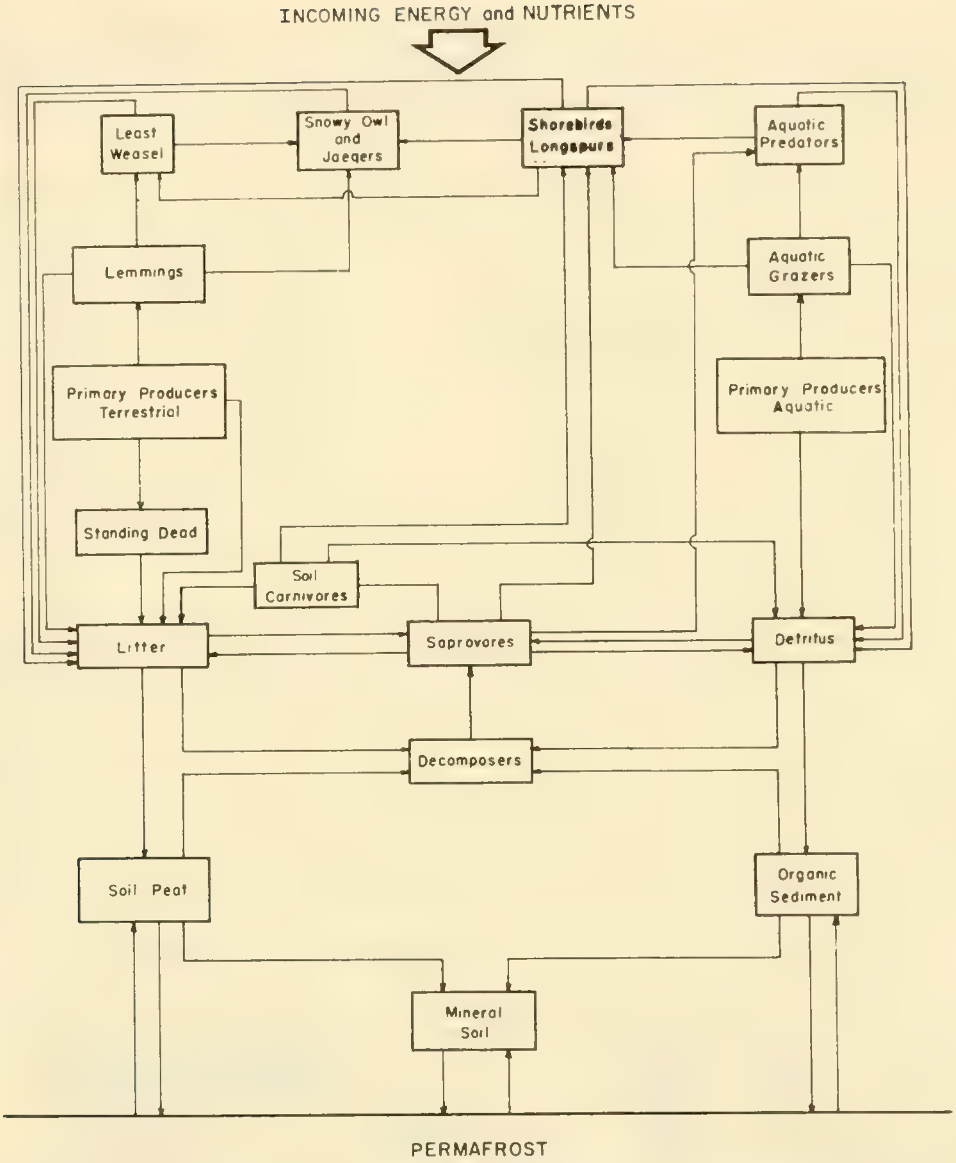

Figure 6. Major pathways of exchange of energy and nutrients in the wet arctic tundra ecosystem.

populations may be identified. In other areas, where diversity is greater and our knowledge is less precise, functional groupings are indicated. The research design may be compared with this model to determine the degree to which the important compartments and transfer processes are being considered. Thus, a model of this nature is useful in directing research.

The next step in modeling is the quantification of a model such as that discussed above. At any given time of the season the quantity of energy, or of some key nutrient, in each of the compartments may be measured or estimated. This produces a static model – a quantitative description of the state of the system at any point in time. The collection of these data was one of the objectives of the 1970 research design.

Each of the transfer processes within the system may be described by an equation which takes into account the quantity of energy (or nutrients) in the compartments directly involved in the transfer and the set of biotic and abiotic factors which influence the rates of transfer. For example, the transfer of energy from terrestrial primary producers (i.e. grass) to brown lemmings is influenced by the amount of grass and lemmings present, the reproductive status of the lemming population (biotic factor), and the ambient temperature (abiotic factor). The effect of each of these on the transfer of energy can be determined, quantified, and described by the equation.

The change in the quantity of energy in any compartment over a period of time is the algebraic sum of all of the processes which add energy to or remove energy from that compartment. Thus, the equations which describe the transfer processes may be combined to describe changes in the distribution of energy within the system. If the quantity of energy in each compartment of the system at the start of a time interval, and the values of the various abiotic and biotic factors which influence transfer processes, are known, the equations can be used to calculate or predict changes in the distribution of energy over a time interval. A model such as this, which predicts changes in the system, is a dynamic model and contains the most information concerning the functioning of the system. This model, in its most general terms, is presently being constructed for the tundra ecosystem. The mechanics of model construction and testing is being done by personnel of the Desert Biome Program at Utah State University, with frequent consultation with Tundra Biome scientists. The model is being built around a set of differential equations which describe the principal transfer processes indicated in Figure 6.

Our knowledge of exchanges between some compartments, particularly the below-ground compartments, is far from complete. For the construction of this "first approximation" model, changes in distribution of energy will have to be described as well as possible without full knowledge of the various processes involved, i.e. a "black box" approach is required. Because of this, the resolution of the first approximation model will not be great. The main function of this model is not highly accurate prediction but the identification of compartments and processes that are particularly important in the functioning of the system so that research effort may be directed to the most critical areas. As our knowledge in these areas advances, the "black boxes" will be replaced by more exact, mechanistic descriptions of processes in later versions of the system model. The first approximation model will be constructed using data collected in 1970 and prior seasons. It will be completed by early 1971, so that it may be used to modify the 1971 research.

Some processes of the system have been studied in such detail that accurate mechanistic submodels can now be attempted. Detailed submodels have been constructed for primary production (Miller), depth of thaw and soil temperature (Nakano and Brown), and gross near-surface meteorology (Lord and Pandolfo). The status of each of these is discussed elsewhere in this report. Eventually, these and other submodels will be brought together in a final system model. It is in the final model that accuracy of prediction will be stressed, so that the model may be used for system simulation and problem solving.

UNDISTURBED ECOSYSTEM RESEARCH

Abiotic

Snow cover and summer climate

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During the 1969-1970 winter, the snowpack of arctic Alaska was significantly less than normal. The maximum snow depth recorded by the U.S. Weather Bureau at Barrow was only 39% of the mean value over the 9-year period beginning with the 1961-62 winter (Table III). This light snow cover was particularly evident at site 1. By the first few days of June the area was more than 50% snow free. Figure 7 is an oblique aerial photo taken on 4 June showing the snow-free character of site 1 and the accumulation in the polygon troughs and in the Footprint Creek channel.

The snowpack can generally be subdivided into two distinct layers. The upper layer consists of hard, fine-grained (0.5- to 1.0-mm diam) wind-packed snow with density between 0.35 and 0.45 g/cm^3. The lower layer consists of loosely consolidated depth-hoar crystals (up to 1 cm diam) with density of 0.25 to 0.35 g/cm^3. There frequently is a gradation from the hardest part of the

Figure 7. Aerial oblique photograph of sites 1 and 2 and Footprint Creek channel showing the snow cover on 4 June 1970.

*Principal authors.

Table III. Snow depth on the ground (cm).

(ESSA climatological data.)

	1961/62	62/63	63/64	64/65	65/66	66/67	67/68	68/69	69/70	MEAN
SEP.	2.5	5.1	2.5	T	2.5	2.5	7.6	7.6	T	2.5
OCT.	25.4	22.9	27.9	30.5	10.2	15.2	12.7	12.7	10.2	17.8
NOV.	30.5	22.9	33.0	27.9	27.9	22.9	22.9	27.9	10.2	25.4
DEC.	35.6	22.9	20.3	30.5	40.6	25.4	38.1	20.3	10.2	27.9
JAN.	55.9	22.9	15.2	30.5	43.2	30.5	40.6	22.9	12.7	30.5
FEB.	73.7	20.3	30.5	30.5	40.6	30.5	40.6	27.9	15.2	35.6
MAR.	76.2	58.4	27.9	30.5	43.2	35.6	43.2	27.9	15.2	43.2
APR.	76.2	73.7	25.4	40.6	48.3	35.6	45.7	33.0	15.2	43.2
MAY	40.6	63.5	20.3	27.9	45.7	10.2	43.2	43.2	17.8	35.6
JUNE	10.2	5.1	2.5	7.6	17.8	5.1	10.2	7.6	5.1	7.6
MAX.	76.2	76.7	33.0	40.6	48.3	35.6	45.7	43.2	17.8	46.0

upper layer to softer snow below; but the contact between these harder layers and the depth hoar crystals of the lower layer is always sharp, with an abrupt and easily measured difference in snow density.

Ordinarily the snowpack on the tundra is about 40 cm thick between microrelief such as hummocks and tussocks and 20 cm thick or less over their tops. A 40-cm snowpack typically has hard wind slab for the top 20 cm, moderately hard snow for the next 10 cm, and depth hoar with negligible hardness for the bottom 10 cm.

During the 1970-71 winter, detailed investigations of the snowpack formation and metamorphism are planned. These began as the fall snow cover accumulated. Temperature measurements within the snow cover and in the plant canopy are being made in typical lemming habitats.

The 1970 Barrow summer climate was cooler and drier than usual. The average monthly air temperatures were below normal for all three months. The summer was extremely dry with only one storm exceeding 2.5 mm of precipitation in a 24-hour period. The monthly averages, totals and departures from the normal are as follows:

Month	*Avg temp (°C)*	*Departure*	*Precip (mm)*	*Departure*
May	–7.2	+0.4	2.3	–0.8
June	+0.5	–0.1	0.5	–8.6
July	+3.2	–0.7	4.8	–15.7
Aug	+1.7	–1.6	8.9	–14.0

Although air temperatures rose above freezing during the last week in May, daily average temperatures did not remain above freezing until 15 June. The daily mean, maximum and minimum air temperatures are shown in Figure 8. Spring runoff began through Footprint Creek on 14 June, although many snow-free tundra areas were in evidence by that date. Due to the light snow cover and the lack of June or early July precipitation, sustained runoff ceased during the first days in

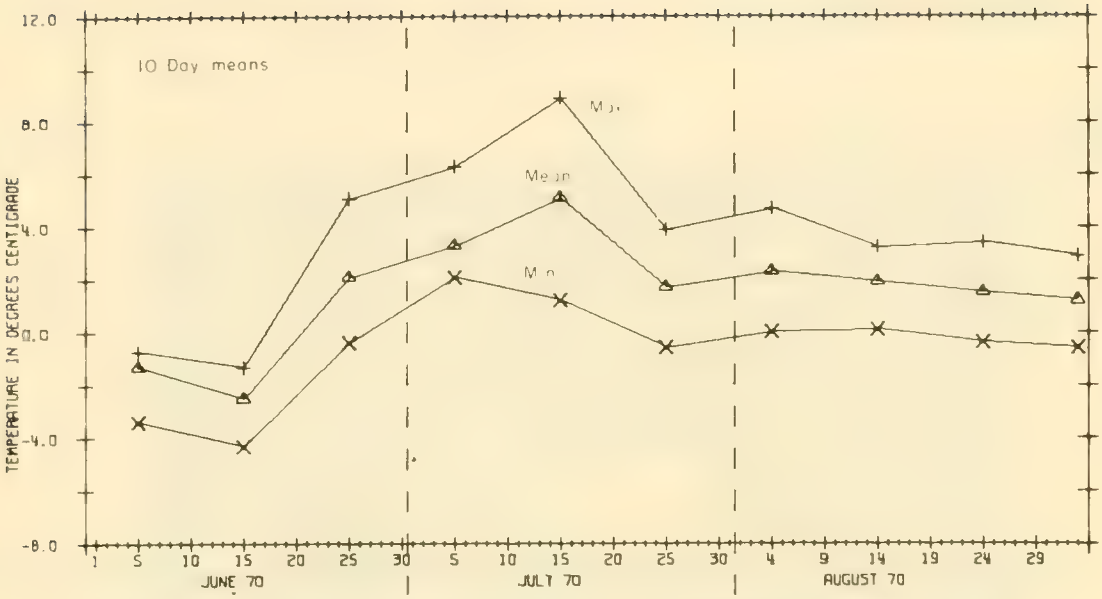

Figure 8. Daily minimum, maximum and mean air temperatures, Barrow, Alaska.

July. Continuous gaging of runoff in the east fork of Footprint Creek was available through a dam and a Pascal flume. This nearly total lack of runoff during the summer compared with the summer of 1964 which was also extremely dry and cool and during which runoff was nil.

Micrometeorology

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The 1970 micrometeorology program began with the summer season. Therefore, the objectives were to determine the energy fluxes and the distribution of energy within the three-layer system: air/vegetation/soil. This program was extended to a four-layer system to include snow beginning in the fall 1970. Three vertical levels of measurements were made to evaluate radiative, conductive and convective transfer processes in the near-surface tundra environment:

1) Near-surface atmosphere: A 16-m tower was installed at site 2 in early June. Values of wind speed and direction and ventilated air temperatures were measured at 1, 2, 4, 8 and 16 m above the surface. The sensors were provided by the USA Natick Laboratories.

2) Plant canopy: Ventilated thermocouple sensors installed in copper tubes placed at 0, 2.5, 5, 10 and 15 cm above the soil surface and within the canopy were placed in several control plots and manipulated treatments. Figure 9 illustrates one of these units, which employ a small d-c blower motor. Radiation extinction was monitored at similar vertical intervals through the use of photocells.

3) Soil temperatures: Temperatures were measured with thermocouples to a depth of 1 m.

At site 2, micrometeorological data acquisition was on a paper tape data logger at hourly intervals. During periods of malfunction, data were collected on multipoint strip chart recorders.

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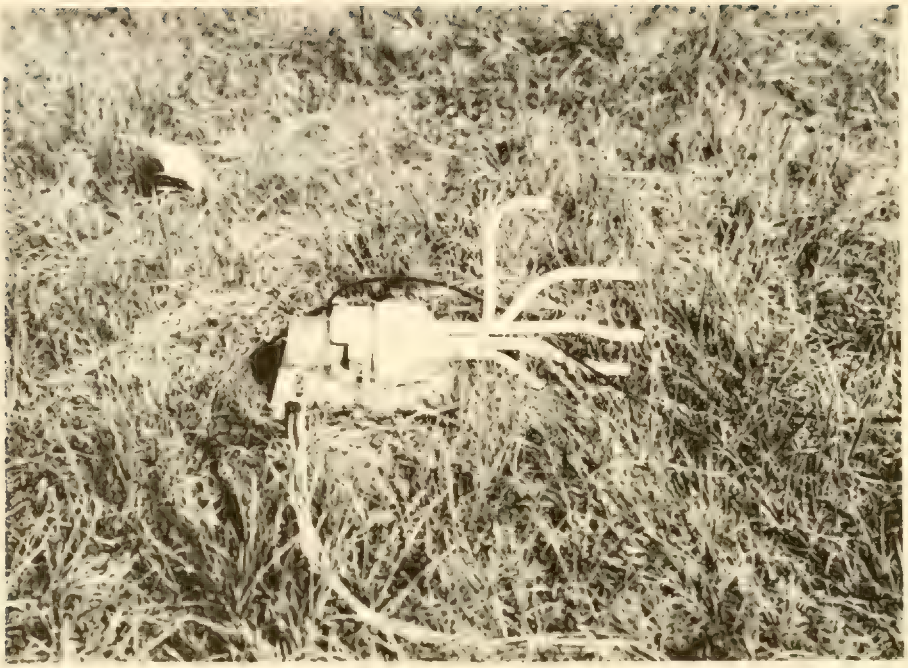

Figure 9. Close-up of air canopy probes.

Several typical results from the micrometeorological tower data are given in Table IV. Throughout the summer, temperature profiles were nearly isothermal or showed slight inversions. Stabilities were therefore neutral or slightly stable. Wind profiles were close to logarithmic and yielded roughness parameters between 1 and 2 cm. The roughness parameters enter the computations of the eddy heat flux, as an important terrain type specification.

Canopy temperatures for various manipulations provided interesting data on the effects of the vegetation upon the thermal regime of the tundra surface. Temperature profiles were measured within clip and cleared and mulched vegetative canopies as well as within a natural (control) canopy (Table V). Temperatures within the mulched canopy are generally 1-2°C higher in the top layers of the 15-cm-high canopy, where material has been added artificially, but are about the same as in the other plots in the lower layers. The vertical temperature profile in the mulched layer is therefore close to isothermal, whereas the clip and cleared plot shows temperature increases in the layer up to 2°C, with higher temperatures at the soil surface. The control plot also shows temperature increase with depth in the vegetation, but direct heating of the surface by radiation is not as pronounced, owing to higher leaf area indices. The vertical wind structure in the natural and disturbed canopies remains to be measured with hot-wire anemometers now available to the project.

Radiative energy inputs and outputs by reflection and thermal emission were measured at several sites. Table VI gives the mean incoming short-wave radiation for 10-day periods obtained from the Barrow Weather Bureau. The radiative flux divergences within the vegetation layer were computed from these values and the mean measured extinction profiles. Extinction profiles as a function of seasonal changes of the leaf area index will be computed.

Table IV. Typical wind and temperature profile data, micrometeorological tower.

DATE TIME	HEIGHT (M)	SPEED (M SEC-1)	DIRECTION (DEG.)	TEMPERATURE (DEG.C)	REMARKS
2200	16	0.97	303	0.85	LOW WIND SPEED, ISOTHERMAL
30 AUG.	8	0.87	304	0.95	TEMPERATURE STRATIFICATION
	4	0.76	284	0.90	Z(0)=2 CM
	2	0.64	292	0.85	
	1	0.57	297	0.85	
2400	16	4.55	242	-2.00	MODERATE WIND SPEED, AMBIENT
29 AUG.	8	4.15	244	-1.90	TEMPERATURES BELOW FREEZING,
	4	3.60	248	-2.05	NEAR-ISOTHERMAL TEMPERATURE
	2	3.15	239	-2.15	STRATIFICATION
	1	2.76	238	-2.15	Z(0)=2 CM
2400	16	5.39	120	5.90	MODERATE WIND SPEED, AMBIENT
27 AUG.	8	4.85	130	6.00	TEMPERATURES ABOVE FREEZING,
	4	4.30	136	5.90	NEAR-ISOTHERMAL TEMPERATURE
	2	3.78	120	5.85	STRATIFICATION
	1	3.37	132	5.85	Z(0)=1 CM
1200	16	5.47	222	7.35	MODERATE WIND SPEED, SMALL
27 AUG.	8	4.88	226	7.50	TEMPERATURE INVERSION
	4	4.33	229	7.60	Z(0)=1 CM
	2	4.13	227	7.75	
	1	3.48	229	7.90	
1200	16	7.22	234	2.20	HIGHER WIND SPEED, SMALL
29 AUG.	8	6.57	243	2.30	TEMPERATURE INVERSION
	4	5.76	233	2.45	Z(0)=1 CM
	2	5.28	214	2.60	
	1	4.37	227	2.75	

Table V. Temperature in the vegetative canopy, 10-day means (°C*).

HEIGHT (CM)	11 JULY TO 20 JULY	21 JULY TO 30 JULY	31 JULY TO 9 AUG.	10 AUG. TO 19 AUG.
CLIP AND CLEAR PLOT				
15	5.2	4.0	3.1	2.8
10	5.1	3.9	3.1	2.9
5	-	4.5	3.9	3.1
2.5	-	-	-	3.9
SURFACE	6.1	5.7	5.0	3.8
-5	-	-	-	-
MULCHED PLOT				
15	6.6	4.5	4.5	-
10	6.9	4.7	4.7	-
5	-	5.9	5.2	-
2.5	-	-	-	-
SURFACE	6.9	5.5	5.1	-
-5	4.8	3.0	3.6	-

* ALL TEMPERATURES WERE MEASURED WITH 30 A.W.G. VENTILATED THERMOCOUPLES

Table VI. Incoming short-wave radiation, 10-day means (cal/cm² day).

HEIGHT ABOVE SOIL (CM) *	RADIATION INTENSITY **	1 JULY TO 10 JULY	11 JULY TO 20 JULY	21 JULY TO 30 JULY	31 JULY TO 9 AUG.	10 AUG. TO 19 AUG.	20 AUG. TO 29 AUG.
15	100	552	509	495	284	233	212
10	74	408	376	366	210	172	157
5	52	287	264	257	148	121	110
2.5	35	193	178	173	99	81	74
SOIL SURFACE	11	61	56	55	31	26	23

* TOP OF VEGETATION
** PERCENT OF INCIDENT AT TOP OF VEGETATION

The reflectivities of typical man-disturbed and undisturbed surfaces within the Barrow ecosystem are shown in Table VII. The reflectivities of natural dry-ground vegetation (24% reflectivity) and wet-ground vegetation (16%) are reduced to as low as 10% by various kinds of surface manipulations.

Table VII. Albedo measurements over undisturbed and disturbed tundra surfaces, Barrow, Alaska.

	Albedo (%)
Dry ground	
1. Dead grass, tall	26
2. Top of high polygons, low vegetation	24
3. Low vegetation (brownish, willow leaves)	23
4. Cotton grass	23
Wet ground	
5. Green grass and moss, low	20
6. Green vegetation, high	16
7. Dead vegetation	15
8. Bottom of high polygons, wet moss	11
Bare natural ground	
9. Mud flats of wet creek bed	15
Water surfaces	
10. Cat track, water-filled	11
11. Weasel track, water-filled	10
12. Water puddle in Ski-doo track	10

Table VII (Cont'd).

Mechanically manipulated surfaces	*Albedo (%)*
13. Ski-doo track, compacted vegetation	21
14. Weasel track, wet	15
15. Cat track, wet soil, bare	13
16. Road, gravel pad, wet	11
Oil spills on dry ground	
17. Oil plot, ground-soaked	22
18. Fertilized oil plot	20
19. Oil plot, oil-soaked plants	17
Representative albedo value for total area	20

Soil thaw and model validation

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The seasonal thaw of arctic soils is a sensitive indicator of near-surface energy exchange and seasonal climate. The structure and composition of the vegetative and litter layers significantly modify the soil thermal regime, thaw, and plant growth responses. For example, the hypothesis has been offered that accumulation in litter reduces soil thaw and soil temperatures to the degree that nutrient availability may be limited. In terms of summer climate, soil thaw can be characterized in terms of air temperature and precipitation. During dry cool summers thaw is at a minimum and conversely during warm wet summers thaw is at a maximum.

Soil thaw has been measured at site 8 since 1962. During this period, extremes in the secular thaw pattern have probably been observed; 1968, the deepest thaw and 1964, the shallowest thaw. The following values were averages of the same 200 points measured at site 8 since 1962: 1962 - 40 cm, 1963 - 38 cm, 1964 - 29 cm, 1965 - 37 cm, 1966 - 36 cm, 1968 - 41 cm, and 1970 - 36 cm. The 1970 season produced about an average thaw at Barrow.

The objectives of the current program were twofold:

1. Determine the initial response or sensitivity of soil thaw to a variety of man-made and natural perturbations. These studies were done in cooperation with the several biological and pedologic projects.

2. Validate a soil thaw-temperature model by measuring soil temperatures and actual thaw under a range of surface and soil variables.

In order to accomplish these objectives soil thaw was measured by probing on all plots at sites 1 and 2 at 10-day intervals. Site 1 plots and adjacent sites covering the complete range in soil variability were instrumented with stacks of thermocouples. Thermocouple spacings were at every 2 cm in the upper 10 cm and 5- to 10-cm intervals below. Temperatures were automatically recorded half-hourly on a paper punch tape data logger. Approximately 200 sensors were monitored throughout the season. Temperatures were also recorded for other subprojects including leaf and canopy temperatures.

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*Principal authors.

†Not at Barrow during 1970.

Table VIII. Sample computer output for canopy, leaf and soil temperatures.

MC 7 DAY 18 1970

CHAN NO	DEPTH CM	HOUR 12.0	12.5	13.0	13.5	14.0	14.5	15.0	15.5	16.0	16.5	17.0	17.5	AVE	AVE*
78	.0	17.0	19.6	16.9	20.2	20.4	17.1	17.6	18.8	18.9	17.5	17.3	12.8	17.8	12.0
79	.0	16.4	18.7	17.1	19.6	19.8	16.9	17.2	18.4	18.4	17.3	17.0	13.0	17.5	11.9
80	2.0	12.9	14.7	14.7	15.4	15.6	14.6	14.2	15.4	15.3	15.0	14.7	12.1	14.5	10.0
81	4.0	9.7	10.1	10.6	10.8	11.2	11.3	11.1	11.3	11.5	11.5	11.3	11.0	10.9	8.1
83	8.0	6.8	6.9	7.0	7.3	7.5	7.7	7.8	7.9	8.0	8.1	8.2	8.2	7.6	6.4
84	10.0	6.4	6.6	6.7	6.9	7.0	7.2	7.4	7.4	7.5	7.7	7.7	7.8	7.2	6.4
85	20.0	1.0	1.0	1.1	.9	1.0	1.0	1.0	1.0	1.1	1.1	1.2	1.3	1.1	1.2
86	30.0	-.1	-.3	-.3	-.2	-.2	-.2	-.2	-.1	-.2	-.2	-.1	-.2	-.2	-.1
87	40.0	-.8	-.8	-.8	-.8	-.8	-.8	-.7	-.8	-.8	-.8	-.7	-.8	-.8	-.8
88	50.0	-1.5	-1.5	-1.4	-1.5	-1.5	-1.5	-1.5	-1.5	-1.5	-1.5	-1.5	-1.5	-1.5	-1.4
89	60.0	-1.6	-1.7	-1.7	-1.6	-1.6	-1.6	-1.7	-1.7	-1.6	-1.7	-1.6	-1.7	-1.7	-1.6
90	70.0	-2.4	-2.1	-2.3	-2.4	-2.5	-2.3	-2.1	-2.4	-2.4	-2.3	-2.4	-2.3	-2.3	-2.2
91	80.0	-2.5	-2.5	-2.5	-2.6	-2.6	-2.5	-2.6	-2.6	-2.5	-2.6	-2.6	-2.5	-2.5	-2.5
92	90.0	-2.8	-2.9	-2.8	-2.9	-2.8	-2.9	-2.9	-2.8	-2.9	-2.9	-2.8	-2.9	-2.9	-2.8
93	100.0	-3.2	-3.1	-3.1	-3.1	-3.2	-3.2	-3.2	-3.2	-3.2	-3.2	-3.1	-3.2	-3.2	-3.1
126	.0	15.7	18.1	14.3	19.7	20.1	15.4	16.7	18.9	19.2	17.3	16.6	10.7	16.9	10.8
127	-2.5	16.2	17.8	13.4	20.0	20.5	15.5	17.0	18.7	19.6	17.3	16.7	10.8	17.0	10.7
128	-5.0	15.1	16.3	12.1	18.9	19.3	14.1	15.1	16.8	17.7	15.5	15.2	10.4	15.5	9.7
129	-10.0	13.0	14.0	10.4	16.1	17.8	11.6	13.3	13.6	14.4	12.7	12.7	8.9	13.2	8.4
130	-15.0	12.3	14.7	10.7	16.6	15.6	10.6	12.3	13.1	14.0	12.8	12.1	9.0	12.8	8.1
131	CAREX	15.3	17.1	12.2	19.7	19.8	13.9	16.4	17.6	17.2	15.5	15.2	10.6	15.9	10.6
132	DUPONTI	19.2	18.5	14.3	23.4	23.2	15.4	19.8	22.4	23.2	18.5	20.2	10.0	19.0	11.9
133	RANUNCU	15.9	17.0	13.1	19.0	19.9	14.9	17.2	18.8	19.3	17.4	17.3	11.0	16.7	10.7

AVE = PAGE AVE
AVE* = CUMULATIVE DAY AVE
- DEPTH INDICATES SENS ABOVE GROUND

Data tapes were air mailed to USA CRREL, Hanover, New Hampshire, every several days. These tapes were run through a standard computer program, the data for each temperature level per core printed and summarized for every 6 hours and for every 24 hours, and the print-out returned to Barrow usually within 5 days after the data were recorded in the field. A sample 6-hour output for soil, plant canopy and leaf temperatures is given in Table VIII. The thaw adjacent to each core was probed on a regular basis so that measured degrees Centigrade could be compared with physically probed thaw. Both values were then compared with the thaw model that will be discussed later in this section.

The results of soil thaw under the various manipulations will be discussed more fully in a later section of this report. The seasonal progressions of thaw for site 1 and site 2 plots are presented in Figures 10 and 11. Soil thaw is most rapid in the initial 2 to 3 weeks of thaw. At site 1, 50% or more of the thaw occurred by 4 July. Site 1 with its more dense canopy had a considerably shallower thaw than site 2 control plots: approximately 20 cm for site 1 vs 26 cm for site 2. Both these values are significantly less than those for site 8, which averaged 36 cm in 1970. The site 1 and site 2 soils were on the more shallow end of the thaw gradient.

Heat and mass transports are two important physical processes in the arctic tundra soils. Understanding of the mechanisms of the transport phenomena is the basis upon which a sound mathematical model is built. Despite extensive research on the exchange of heat and mass at the air/soil interface, the degree of accuracy in the determination of exchanged quantities is less than adequate. In order to concentrate on the transport phenomena in the soil, the air/soil interface was chosen as the upper boundary condition. Variables such as temperature and moisture content at and below the interface were measured in the field. Although from the microscopic viewpoint the mechanism of heat transfer in soils is not by conduction alone, it is possible and practical to define the effective conductivity of soils and to formulate the problem as one of pure conductive heat transfer with phase changes. This is the basic assumption adopted in the thaw-temperature model.

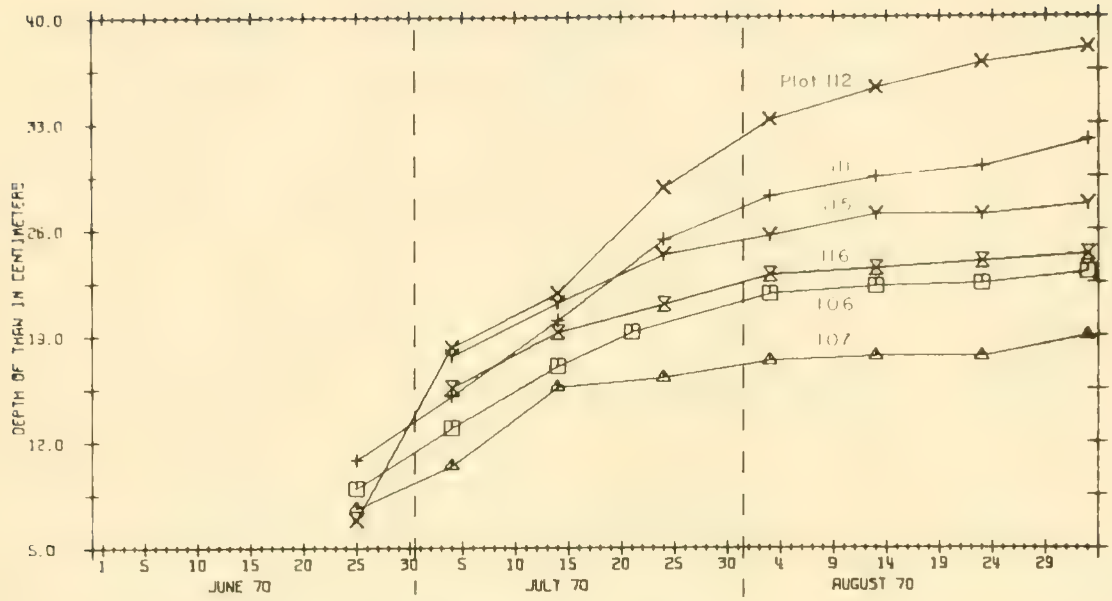

Figure 10. Progression of soil thaw on site 1 plots.

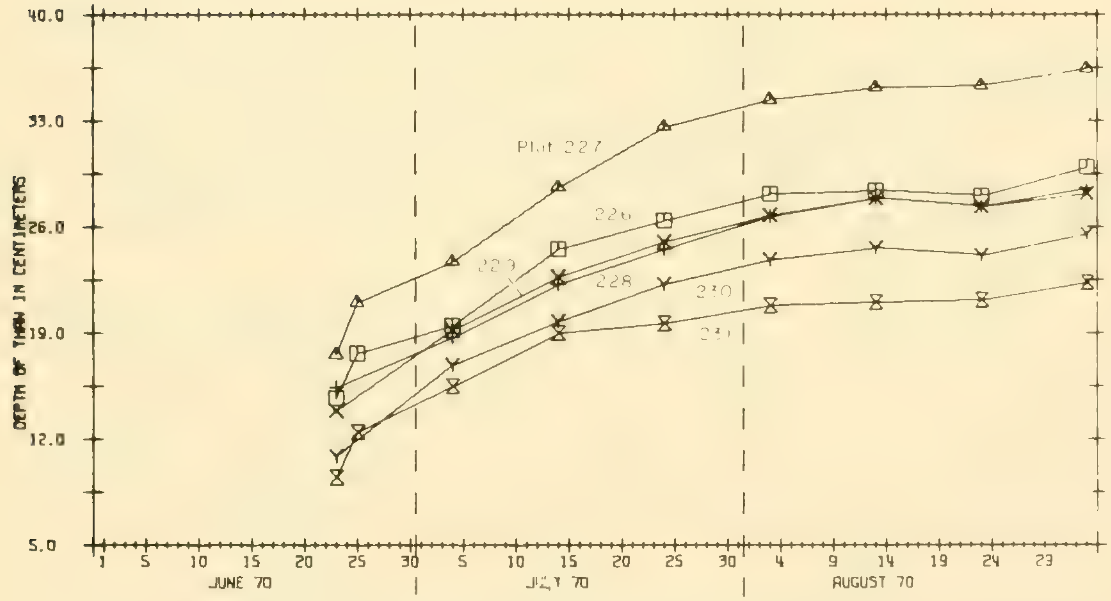

Figure 11. Progression of soil thaw on site 2 plots.

The effect of mass transfer, especially water transport, on heat transfer is also an important factor to be considered. It is anticipated that the change of thermal properties of soil with water content and convective heat transport associated with water transport are major contributions to the thermal regime. Efforts have been initiated to determine the effect of mass transport on heat transport. Besides water transport, the quantities and migration of organic and inorganic chemicals through tundra soils are particularly important during periods of freezing and thawing.

The thaw-temperature model involves a program in which an implicit finite difference scheme is adopted to solve the one-dimensional heat conduction problem as soil water undergoes phase changes.

Table IX. Space increments for mesh points.

Depth, x (m)	*Increment, x (m)*
$0 < x \leq 0.4$	0.002
$0.4 < x \leq 1.0$	0.010
$1.0 < x \leq 2.0$	0.05
$2.0 < x \leq 5.0$	0.25
$5.0 < x \leq 10$	0.50
$10 < x \leq 20$	1.00

Table X. Thermal properties of soils.

		Thermal conductivity (kcal/m hr °C)	*Volumetric heat capacity (kcal/m^3 °C)*	*Moisture content (kg/m^3)*
Organic layer	frozen	0.1	600	800
	unfrozen	0.08	500	800
Soil layer	frozen	0.8	600	750
	unfrozen	0.6	600	750

In order to include the effect of moisture transport, thermal properties of soils are considered to be a function of location as well as time. The upper boundary is the surface of the soil at the base of the plant canopy. The measured surface temperatures are used in terms of specified mean values, such as mean daily temperatures, 6-hourly mean temperatures, etc. The lower boundary is a horizontal surface located 20 m below the surface where the temperature is presumably constant. The space between these two boundaries is dissected into about 300 mesh points with variable space increments as shown in Table IX.

The initial condition is introduced into the program in such a way that the measured temperature profile available down to 70 cm below the ground surface is directly fed into the program by the use of polynomial interpolation. The temperatures at the rest of the mesh points are extrapolated by the use of polynomial approximation. The time increment is chosen according to the temperature difference between two successive surface temperatures, so that a sudden large change of surface temperature does not introduce error in the finite difference scheme. The criterion of selecting proper time increment was made through error analysis of the present scheme for the Neumann type of problem for which an exact solution is known.

As an example, the results of computation for temperature core 7 on control plot 106 will be presented. This core has a 4-cm-thick organic layer and we assumed the two-layered system for which estimated thermal properties are tabulated in Table X. The predicted mean daily temperature profiles as well as observed profiles are shown in Figure 12 and the thaw depths are plotted in Figure 13. The accuracy of prediction is quite satisfactory. It is obvious from these graphs that soil temperature can be accurately predicted any time during the summer based upon known surface temperatures and soil physical properties. Thermal properties of soils, especially in the organic layer, and the moisture contents in frozen soils are two major factors influencing the thaw depth. The moisture contents of frozen soils were measured gravimetrically on samples adjacent to this core, but the thermal properties were estimated based on available literature. Therefore, the ultimate validation of the model still requires the accurate determination of thermal properties of the soils.

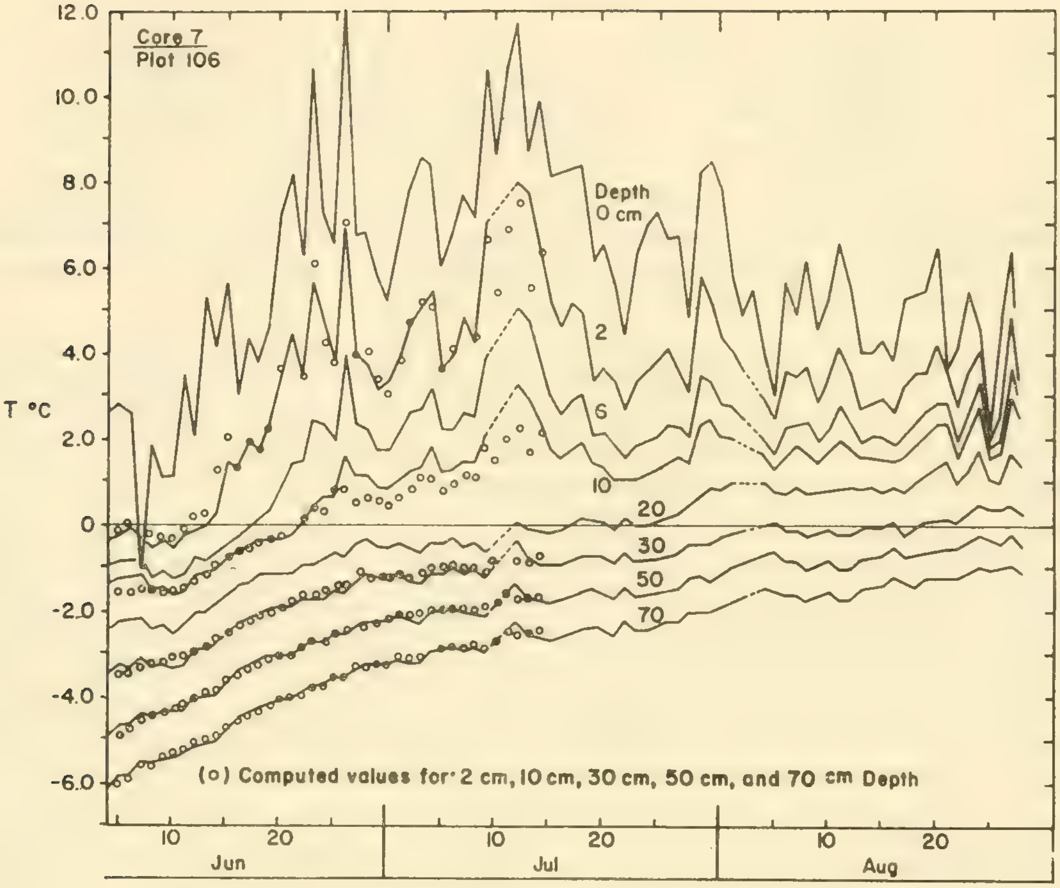

Figure 12. Plots of measured and computed soil temperature.

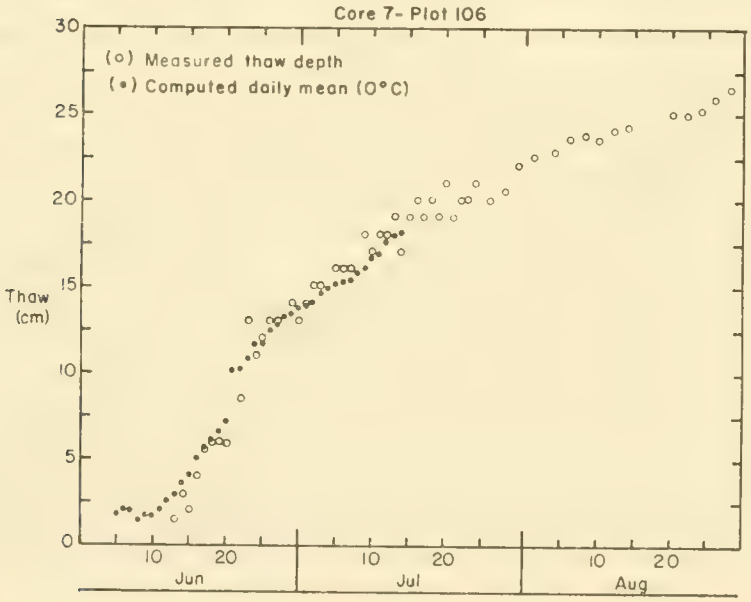

Figure 13. Plots of measured depth of thaw and computed thaw depth.

Simulation of meteorological variations

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Joseph Pandolfo	The Center for the Environment and Man
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This study aims to model numerically the spatial and temporal variations in the meteorological properties of the coastal tundra ecosystem. A first-phase goal is to determine the most important natural variations of the weather and how these would probably be modified by artificial perturbation of the vegetative covers.

Originally, four terrain units were to be simulated: ridge and slope, lowland polygonal ground, meadows, and thaw lakes. It was hypothesized that each type would be broad enough to permit its local variation to be represented in terms of dependence on a vertical coordinate ranging from the permafrost boundary to the upper atmosphere. Details of this project were contained in the original proposal. The following is a summary of initial results.

Of the four categories of environment comprising the entire abiotic ambience of the tundra biosphere, lowland polygonal ground most closely corresponds to the simplifying assumptions of the boundary-layer model being used to simulate the ambient physical variations. The Center for the Environment and Man sea-air model was therefore modified to fit this case first and applied to a time interval for the Barrow area that were available from the University of Washington, July 1966 data.

The boundary layer model, modified for soil and air, starts from initial values and predicts primarily the variations in the following physical characteristics observable for a period of several days:

1) Wind-height profile

2) Temperature-height profile in air and extending below ground surface

3) Moisture-height profile in air but ending at ground surface

4) Vertical component of energy flux at ground surface and at a lower reference level.

As part of the boundary conditions, the reflectivity to solar radiation (i.e. albedo), thermal conductivity below the surface, and a constant temperature at a carefully chosen reference depth must be specified. Existing soil temperatures showed a fairly constant temperature at the 16-cm depth and a rough judgement was made so that at 20 cm below the surface, temperatures would be constant at 274.5°K. Since both albedo and thermal conductivity were not directly measured in 1966, the principal interest in applying the model was to find the particular albedo and thermal conductivity which produce simulated results in agreement with those observations. If such albedo and thermal conductivity conformed approximately to values derived from 1970 field and laboratory observations, the model might then be applied with confidence to a wide variety of situations. Of particular interest would be disturbances leading to changes in vegetation.

Initial profiles of wind, temperature, and moisture were derived from monthly average data collected by the World Meteorological Organization for Point Barrow, Alaska, July 1966. Subsurface monthly average temperatures were derived from 1966 data. Then, keeping their profiles constant, a matrix of different albedo and assumed depth, invariant thermal conductivities were specified for a set of 22 experiments. The range of thermal conductivity was judged by a rough measure of phase lag in the estimated diurnal component of temperature variation between surface and the 16-cm depth.

Results of the numerical experiments are given in Table XI wherein thermal conductivities are stated in cgs units, temperatures in degrees Kelvin, and time lags in units of 5 minutes. These data may now be compared with their counterparts in the 1966 data base which may be stated as follows:

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*Principal author.

†Not at Barrow during 1970.

1) Temperature excursion

   a. at surface
      272°K to 292.5°K.

   b. at –4 cm
      274.8°K to 278°K.

   c. at –16 cm
      275.2°K to 276°K.

2) Time lags of temperature minima from surface minimum:

   a. at –4 cm
      80 minutes or 16 time steps.

   b. at –16 cm
      5 hours or 60 time steps.

From Tables XIa and XIb it is clear that the simulated results on temperature extremes indicate wider excursions throughout the ranges of albedo and thermal conductivities covered. At the surface, the maxima and minima decline with increasing albedo while with increasing conductivity the maxima decline and the minima increase. Roughly extrapolating, the model would behave like the observations for an albedo of 0.5 and a thermal conductivity of 0.003. At the 4-cm depth the model temperature extremes behave somewhat differently and it is clear that to agree with observations, we would have to go much further outside the albedo-thermal conductivity range.

On the other hand, Tables XIc and XId show substantial agreement for thermal conductivity between 0.0026 and 0.0034 and appropriately no dependence of the time lag upon the albedo.

The principal driving force of the physical variations is the diurnal variation of solar radiation intensity incident upon the ground surface. However, both in reality and in the model there are two additional driving forces of different spectral content. First, there is the wind vector which rotates with an inertial period of 12 hours. Second, there is a nonlinear relation between turbulent thermal transport in the atmosphere and the local vertical temperature gradient which generates high harmonics of the diurnal frequency. Finally, there is the problem of real random cloud cover variation which is not represented by the constant cloud cover assumption in the model and which may introduce into observations a strong stochastic spectral contribution.

In an effort to eliminate diurnal harmonic spectral contribution, the temperature minima were followed. Below the ground surface thermal conductivity may not vary with depth to judge simply by the fact that the –16 cm lag is 4 times the -4 cm lag. The reference level later may be chosen more rigorously according to the thaw depth which is diurnally invariant during July and the temperature gradient at the –16 cm depth.

Disagreement of the model results in surface temperature excursion is probably due to greater cloud cover prevalent for the specific day of the 1966 observations. More cloud cover can easily be introduced into the model to try to bring temperature excursion at both surface and 4-cm depth into agreement for overall thermal conductivity between 0.0026 and 0.0034. Next, the 1966 data and the model data can be processed so as to extract a nearly pure diurnal component and with this information to solve the thermal conductivity as depth-dependent in two layers (0-8 cm and 8-16 cm depths). At that point, an approximate representation of the physical parameters required by the numerical model will have been constructed.

Using the 1970 summer data, it will be possible to solve more closely the depth-dependent thermal conductivity parameter. There are also better atmospheric data available for input data and more comprehensive comparisons including those for wind and moisture. For both 1970 and 1966 seasons, we will then have a model that works well enough to calculate the downward energy flux at the thaw level. As further comparison data become available, the model will be applied to thaw lakes in summer and winter, and lowland polygonal ground in other summer months and under snow during the winter.

Table XI. Alaskan tundra environment simulation (mid-July 1966).

a. Temperature extremes (max and min) at surface (°K).

Albedo	.0010	.0018	.0020	.0026	.0030	.0034	.0040
	Kinetic thermal conductivity (cm^2/sec)						
.1	304.0		302.7		301.8		301.0
	270.7		273.1		274.0		275.0
.2	301.5		300.3		299.4		298.6
	270.5		272.6		273.3		273.4
.25	300.1	299.2		298.3		297.4	
	271.0	273.0		273.5		273.0	
.30	298.6	297.4	297.2	296.8	297.6	296.4	
	269.1	272.9	271.4	272.8	272.2	272.7	
.35	295.9	295.0		294.4		293.9	
	269.8	271.3		272.0		272.6	

b. Temperature extremes (max and min) 4 cm below surface (°K).

Albedo	.0010	.0018	.0020	.0026	.0030	.0034	.0040
	Kinetic thermal conductivity (cm^2/sec)						
.1	291.0		292.8		293.5		293.7
	278.0		276.4		276.1		275.7
.2	289.7		291.4		291.9		292.1
	276.7		276.2		275.8		275.4
.25	289.5	290.4		291.0		291.2	
	275.8	275.9		275.6		275.3	
.30	288.2	289.6	289.7	290.1	290.3	290.4	
	274.8	275.5	275.4	275.2	275.0	274.9	
.35	287.5	288.9		288.9		288.6	
	275.4	275.1		274.8		274.0	

c. Relative time lags of temperature minima from surface to 4 cm below (units of 5 minutes).

Albedo	.0010	.0018	.0020	.0026	.0030	.0034	.0040
	Kinetic thermal conductivity (cm^2/sec)						
.1	29		21		17		19
.2	29		21		17		14
.25	31	23		18		17	
.30	31	23	21	20	18	16	
.35	31	23		19		17	

d. Relative time lags of temperature minima from surface to 16 cm below (units of 5 minutes).

Albedo	.0010	.0018	.0020	.0026	.0030	.0034	.0040
	Kinetic thermal conductivity (cm^2/sec)						
.1	116		75		56		45
.2	102		75		57		45
.25	115	81		63		52	
.30	116	81	75	65	58	52	
.35	118	30		64		53	

Primary Producers

Primary terrestrial production and photosynthesis

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Sharon Tieszen	Augustana College	Bob Vaughn	University of Alaska
Ken Olson	Augustana College	Frank Bogardus	University of Alaska
John Ahrendt	Augustana College	Martyn Caldwell	Utah State University
Doug Johnson	Augustana College	John Dennis*	University of Calgary
Dave Harrison	Augustana College		

The central role of producers in determining the amount of available energy for the entire system necessitated that a thorough study of primary production and its interrelationships with environmental factors, energy flow through the various compartments, and nutrient cycling be undertaken at Barrow. Thus, the subprojects which concentrated on aspects of primary production generally focused on three integrated objectives.

The principal objective was a determination of the efficiency of energy incorporation and its dependence upon both the physical factors of the above-ground environment and individual species responses. These studies included a detailed examination of micrometeorological factors (especially temperature and light intensity) both above and through the canopy, a thorough analysis of community composition and canopy structure, and a rather complete characterization of photosynthetic responses and limiting factors in most of the predominant plants.

The second objective concerned more directly the flow of nutrients and energy. These studies involved primary production related to nutrient availability, nutrient uptake and retention, and nutrient release. In a similar manner, the distribution of matter and energy from the primary producer compartment via herbivory, accumulation and loss of litter, decomposition, and saprovore activity were studied.

The third objective was to attempt to determine the causal factors associated with the range of production values found in the various community types at Barrow and to compare production values and canopy structures from the coastal plain of Alaska and the latitudinal transect and between the intensive sites of the Arctic and the Alpine at Colorado.

Plant production was estimated by clipping 0.1-m^2 quadrats at the base of the moss layer, separating all higher plants by species, and subsampling for dry weight, caloric determinations, nutrients, chlorophyll, lipids, and carbohydrates. Net above-ground production attained a maximal value of about 100 g dry wt/m^2 shortly after 1 August, which is approximately 6 weeks after snowmelt. Thus, most of the above-ground production occurs in a six-week period or less (Fig. 14). In this early part of the growing season production appears to be linear with time and is associated with an apparent increase in caloric content from a mean of around 4300 cal/g at the beginning of the season to a maximum of 4500 cal/g at the peak. This trend is present in each of the species, and preliminary data indicate that it is correlated with a similar increase in lipid content.

Comparison of primary production with sample years dating back to 1960 at the Gasline site of Schultz† (Fig. 2, site 12),shows that 1970 was an exceptionally good year for growth. Both *Eriophorum angustifolium* and *Dupontia fischeri* production exceeded that of previous peak years. The unusually large production was apparently the result of low lemming numbers coincident with a favorably long growing season.

Subsurface standing crops of vascular plants were measured at peak season in early August on two plots. Total standing crop of all living material present in the top 20 cm of soil ranged from 1075 to 1600 g/m^2. Subsurface-to-shoot ratios ranged from 11:1 to 14:1. In the organic mat,

* Principal authors

† Observations provided by Schultz's subproject

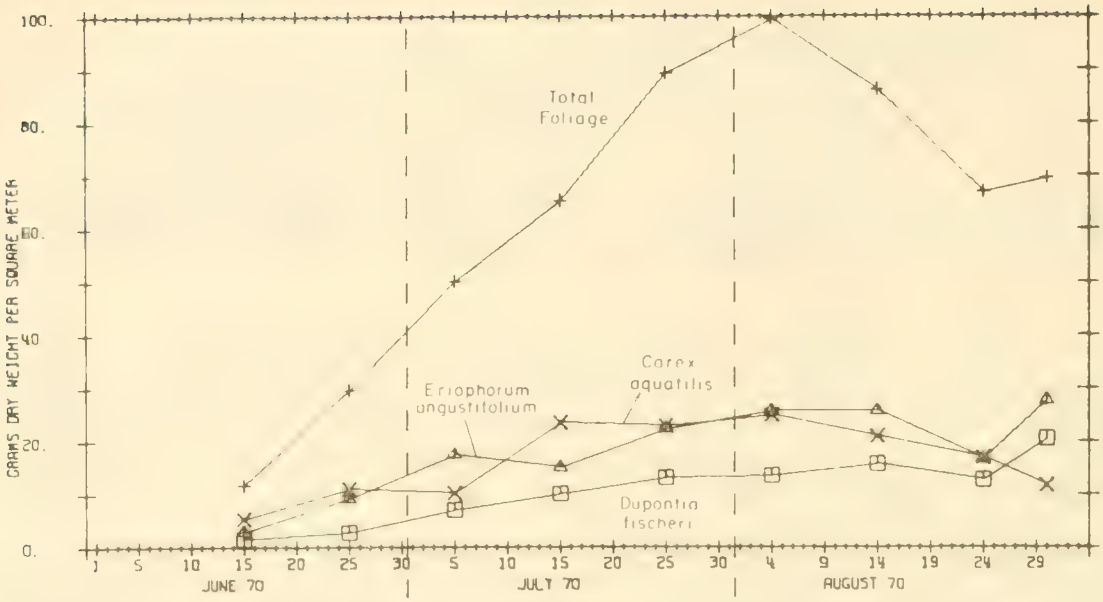

Figure 14. Seasonal primary production values, site 2 control plots, Barrow, Alaska.

≤2 cm thick, between 60 and 85% of the living material consisted of rhizomes and stem bases. Rhizome material in the top 5 cm of mineral soil constituted from 20 to 60% of the total living phytomass. Up to 77% of the living material in the second 5 cm increment of mineral soil consisted of rhizomes. There were no rhizomes in deeper increments. Between 80 and 99% of the total living subsurface phytomass occurred in the top 12 cm of soil (includes the organic mat). These data indicate that subsurface vascular plant activity primarily occurs in the upper part of the active layer, in that part of the soil having early and rapid thaw, warmer temperatures, and higher oxygen contents. Maintenance of a large subsurface standing crop requires either long-lived structures or rapid turnover with high annual input of photosynthate.

The absence of high numbers of lemmings for several years has resulted in an accumulation of standing dead material. Careful physical observations allowed a separation of this material into age classes by year of production. In this material, caloric content was distinctly lower as the age of the material increased. Thus, there is an apparent leaching or decomposition of organic materials in the standing dead compartment. The extent and mechanism of the removal of materials from this compartment by these means remains to be determined.

Of the species found on site 2, *Dupontia fischeri*, *Eriophorum angustifolium*, and *Carex aquatilis* were the most abundant and accounted for the majority of the production. In contrast to these species, in which growth was continuous during the season, some of the producers revealed distinct seasonality in production. Seasonal production in the cryptogams could not be followed due to methodological problems. However, the total standing crop of live portions of cryptogams at the peak of the season was measured in one plot. A foliose lichen provided an average of 2 g/m^2, polytrichum-type moss an average of 3 g/m^2, and all other mosses an average of 40 g/m^2. Thus, production in this layer is quite substantial and significant.

Chlorophyll determinations were made as an indication of the amount of photosynthetic tissue in the community, as a unit for comparison with laboratory photosynthesis studies, and as an indication of onset and degree of senescence. Chlorophyll content in the community decreased rapidly after 15 July, suggesting a rapid loss of photosynthetic capacity and an onset of senescence in some leaves (Fig. 15). This was also indicated by the detailed growth studies on *Dupontia fischeri*, *Alopecurus alpinus*, and other grasses where the first leaf of the season was decreasing in photosynthetic activity by 15 July. Chlorophyll varied by a factor of 2 among the species; its distri-

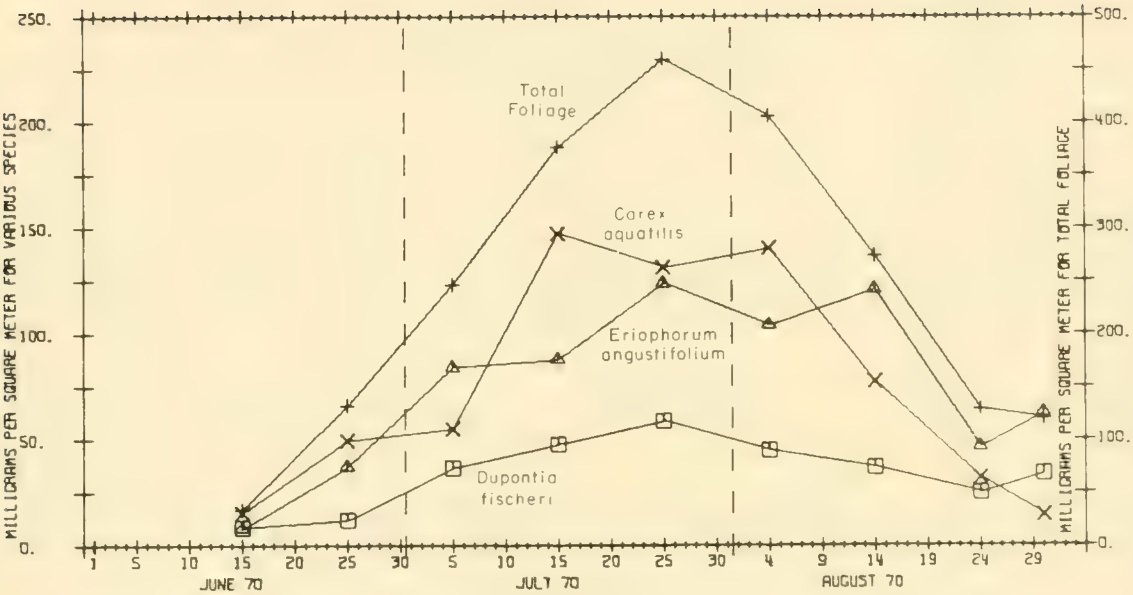

Figure 15. Seasonal chlorophyll contents, site 2 control plots, Barrow, Alaska.

bution in blade and non-blade material also varied. For example, at the peak of the season *Eriophorum angustifolium* possessed 20 times more chlorophyll in the blades than in the remainder of the plant while in *Carex aquatilis* nearly a third of the chlorophyll was in non-blade material. Field photosynthesis determinations with a portable $^{14}CO_2$ technique indicated that these stems and green flowering structures were active in the uptake of CO_2.

Table XII contains the seasonal data for these above ground production parameters. The plant nutrient data for the three principal species show several distinct seasonal trends, particularly for the more mobile elements: phosphorus, nitrogen and potassium. Phosphorus showed an initial increase followed by a leveling off, a gradual decline and late season increase (Fig. 16). The phosphorus values from site 2 were lower than those reported from other previously sampled Barrow sites. The low values compare favorably with other low lemming years. Nitrogen showed a more consistent increase, followed by a late season decline and subsequent rise (Fig. 17). Other elements (Ca, Mg, Fe, Mn, Zn) showed no clear trends. Late summer values for nitrogen and phosphorus were higher than the spring's standing dead. Again this suggests nutrient leaching prior to initiation of the following growing season.

The mechanistic approach to an understanding and modeling of primary production requires a thorough knowledge of leaf position and orientation in the canopy. These considerations are necessary to calculate and predict energy exchange and photosynthesis in individual leaves, intact plants, and entire stands through one entire growing season. The 1970 plant studies utilized an inclined point frame system to estimate for each species leaf area indices (LAI) as a function of position in the canopy.

The leaf area index is a measure of the amount of leaf cover, and may be thought of as the ratio of the area of leaf surface to the area of ground. Thus a leaf area index of 0.8 means that 80% of the surface is covered by leaves. These indices were determined at six sampling periods through the growing season with a frame consisting of 39 pins at 2.5 cm intervals. Usually the contacts of at least 500 pins were recorded upon pushing the pins through the entire depth of the canopy. Slight changes in microrelief resulted in a few contacts below mean ground level, and in this report these contacts are grouped in the increment "-X to -0.1."

Table XII. Above ground production.

		15 JUNE	25 JUNE	5 JULY	15 JULY	25 JULY	4 AUG.	14 AUG.	24 AUG.	30 AUG.
ERIOPHORUM ANGUSTIFOLIUM										
PRIMARY PROD	*1	2.99	9.19	17.41	14.99	22.25	25.70	25.53	16.55	27.60
CHLOROPHYLL/SQ.M.	*2	8.2	37.1	84.0	87.7	123.5	120.5	103.7	45.9	62.1
CHLOROPHYLL/G	*3	2.42	4.69	4.96	5.89	5.52	4.11	3.98	2.45	1.93
CALORIC VALUE	*4	**	4409	4441	4423	4530	**	**	**	**
LEAF AREA INDEX		**	0.11	0.20	0.25	0.18	0.33	**	0.28	**
CAREX AQUATILIS										
PRIMARY PROD		5.36	10.98	10.15	23.33	22.89	24.89	20.82	16.89	11.60
CHLOROPHYLL/SQ.M.		15.6	49.3	55.1	147.2	131.1	140.2	77.2	31.7	14.2
CHLOROPHYLL/G.		2.91	4.65	5.22	6.22	5.74	4.50	3.66	1.80	1.21
CALORIC VALUE		4357	4432	4418	4490	4456	**	**	**	**
LEAF AREA INDEX		**	0.07	0.11	0.18	0.15	0.22	**	0.17	**
DUPONTIA FISCHERI										
PRIMARY PROD		1.58	2.78	7.08	9.93	13.06	13.47	15.62	12.65	20.40
CHLOROPHYLL/SQ.M.		8.5	12.2	36.3	47.5	58.7	44.4	36.6	24.6	33.4
CHLOROPHYLL/G.		5.39	3.74	4.39	4.61	4.19	2.84	2.32	2.28	1.74
CALORIC VALUE		**	4196	4316	4413	4338	**	**	**	**
LEAF AREA INDEX		**	0.04	0.14	0.22	0.26	0.37	**	0.26	**
ALL FOLIAGE										
PRIMARY PROD		11.73	29.64	50.08	65.13	89.13	99.49	86.03	66.90	69.50
CHLOROPHYLL/SQ.M.		33.6	131.6	245.6	375.7	458.7	404.9	272.8	127.8	118.6
CHLOROPHYLL/G.		2.81	3.93	4.86	6.24	5.15	3.85	3.29	1.89	1.50
CALORIC VALUE		4357	4402	4386	4461	4414	**	**	**	**
LEAF AREA INDEX		**	0.26	0.60	0.83	0.76	1.20	**	0.93	**

*1 PRIMARY PRODUCTION - GRAMS/SQUARE METER
*2 CHLOROPHYLL CONTENT - MILLIGRAMS/SQUARE METER
*3 CHLOROPHYLL CONTENT - MILLIGRAMS/GRAM DRY WEIGHT
*4 CALORIC VALUE - CALORIES/GRAM
** DATA NOT AVAILABLE

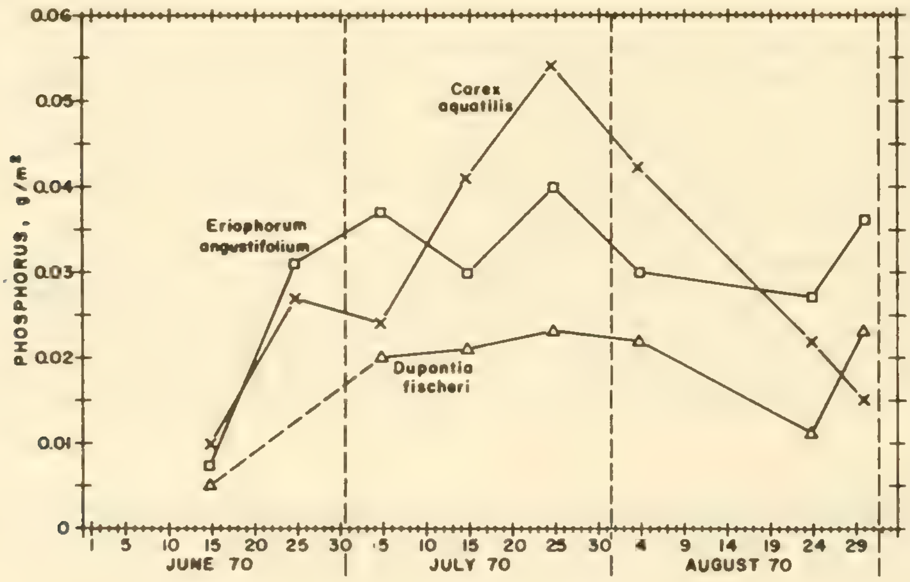

Figure 16. Seasonal phosphorus contents, site 2 control plots, Barrow, Alaska.

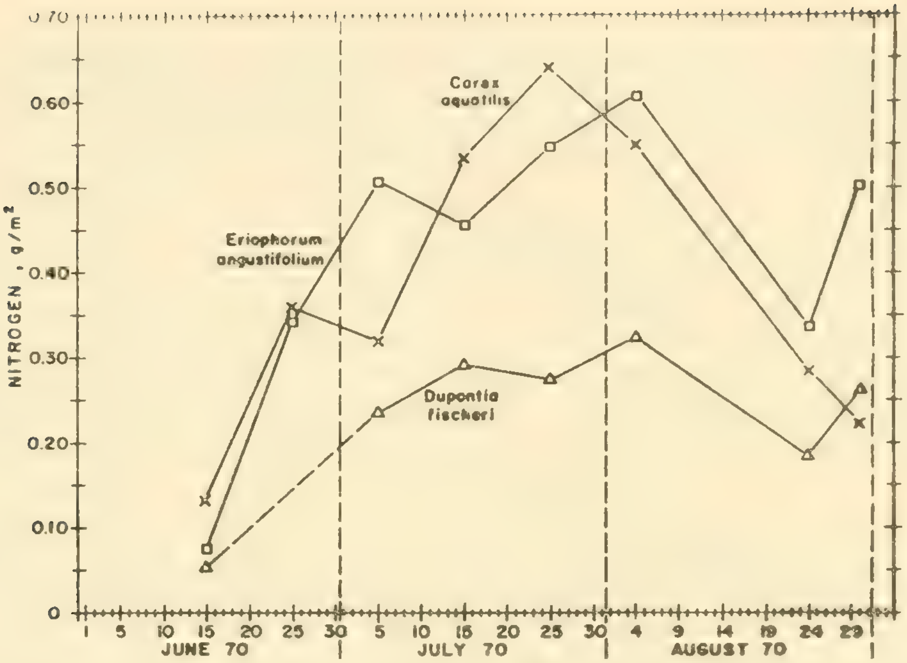

Figure 17. Seasonal nitrogen contents, site 2 control plots, Barrow, Alaska.

The maximum leaf area supported by the community, LAI = 1.2, was contained within a zone 20 cm high and was greater in the 0-5 cm increment than any other. However, a greater amount of leaf material of *D. fischeri* and *C. aquatilis* was in the 5-10 cm increment than was the case in *E. angustifolium*. The standing dead (attached growth from previous years) also accounted for a LAI of 1.2 at this time. This material is very significant in the canopy as a non-functional absorber of radiation, and the consequent effect of the shading of photosynthetic leaves must be known. These dead leaves were distributed mainly in the bottom of the canopy where their influence on the vascular plants is probably reduced. Leaf angles varied greatly from predominantly horizontal in some of the forbs to quite erect in the three major producers. The functional significance of this will be tested in the primary production model and should be validated next summer.

Leaf area indices varied widely from one community to another as did the total primary production values. The highest indices were obtained in very wet habitats and were found in pure stands of *Dupontia fischeri* and *Arctophila fúlva* where the leaf area indices (5.1 and 7.5 respectively) were associated with equally high values for total production (734 and 541 g/m^2). Presumably the erect nature and marked stratification of the leaves in these species are related to the high potential leaf area and production values. Figure 18 contains plots of seasonal LAI values for the three principal species and the total foliage.

Requirements for stand photosynthesis and production predictions require a knowledge of air temperature in the canopy and its relationship to radiation intensity and wind. In conjunction with the micromet program, aspirated thermocouples were placed in control, mulch, clip and clear, and the greenhouse plots at heights of 0, 2.5, 5, 10 and 15 cm. Air temperatures in the control canopy showed some profile development, with highest temperatures near ground level. Temperature in instrumented leaves was usually tightly coupled to air temperature, although occasionally, under clear conditions, leaf temperatures were considerably above air temperature. Much more significant are the differences in both leaf and air temperatures associated with seemingly minor changes in microrelief.

Efficient utilization of the 24 hours of radiation near the summer solstice demands that leaf production and expansion be attained as soon in the growing season as possible, since the light available around midnight decreases rapidly after about 15 July. Accompanying this limited radia-

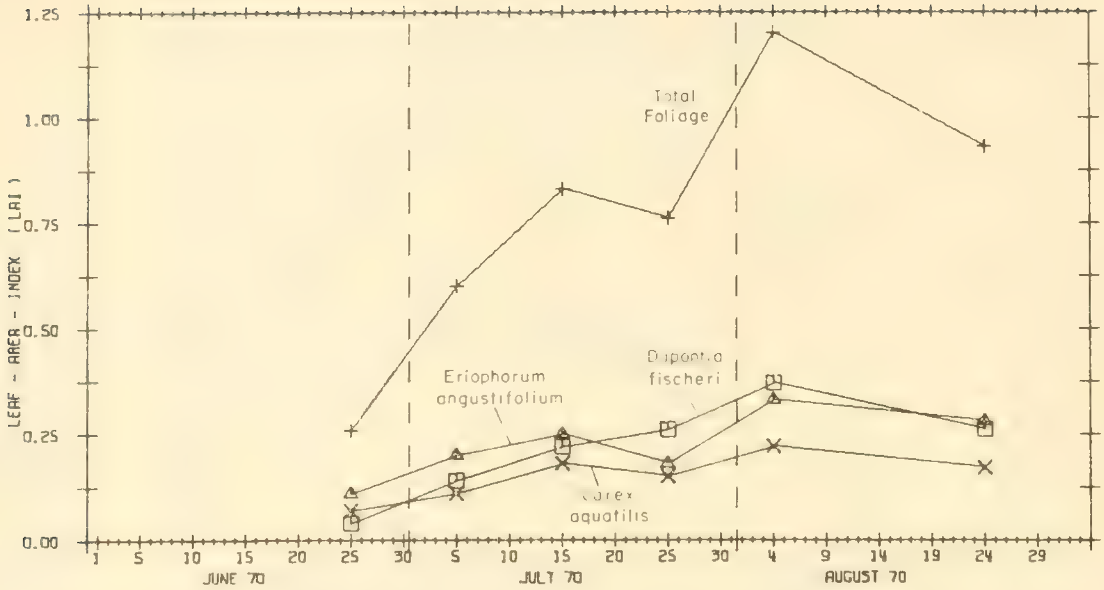

Figure 18. Seasonal LAI values, site 2 control plots, Barrow, Alaska.

tion supply is the effect of leaf shading in the canopy, a factor which is substantially increased by the standing dead material accumulated in the absence of a lemming high. Again in cooperation with the micromet program, photocell systems were positioned in the canopy to record seasonal changes in light extinction through the canopy. Light intensity in the canopy was reduced substantially below 15 cm, and at ground level was generally less than 10% of incoming visible radiation. Light intensity differed markedly between noon and midnight and was reduced by the end of the season to about half the amount available at the beginning of the growing season. As is indicated by the photosynthesis studies, leaves are frequently light-limited.

The approach of the subproject in modeling primary production is based on a prediction of stand production from a knowledge of species responses under various environmental conditions. Thus, detailed photosynthetic characterization of many of the main species was necessitated. In addition, aspects of the project attempted to determine unique adaptations or responses in these plants. Therefore, mechanistic aspects of photosynthesis were investigated.

The photosynthesis studies included a survey of carboxylation systems in all native vascular plants. From the standpoint of photosynthetic efficiency in CO_2 uptake, one might expect some phosphoenol-pyruvate carboxylation plants. The fact that this system is usually associated with tropical plants and taxonomic groups, however, would suggest its absence from this region. In all cases carboxylation activity was higher with ribulose, 1-5, diphosphate than with phosphoenol-pyruvic acid as substrate, although often there was considerable PEP activity. Associated with the high RUDP activity were high CO_2 compensation concentrations (range – 35-80 ppm). Associated with these biochemical and physiological comparisons were more detailed studies of the grasses at Barrow; and, in addition to the above features, all showed a marked stimulation of photosynthesis in the absence of oxygen. This stimulation was not accompanied by an increase in transpiration or a decrease in stomatal diffusion resistance. All grasses possessed a CO_2 dependency at and below ambient concentrations, thus indicating that ambient CO_2 concentrations were limiting photosynthesis at high intensities.

The photosynthesis characterizations showed that all responses were similar to those generally associated with grasses possessing high RUDP activity. Thus maximal (light saturated) rates were low and in these grasses usually averaged less than 10 mg $CO_2/dm^2/hr$. These low values, however, are considerably below those characteristic of similar grasses from temperate latitudes.

Two grasses (*Arctophila fulva* and *Elymus arenarius*) had distinctly higher rates and also possessed very high growth rates. The light intensity curves for photosynthesis indicate that saturation is approached between 2500 and 5000 ftc but in most cases is not attained at 1000 ftc. Light intensities required for compensation are somewhat high due probably to the high respiration rates which characterized all grasses.

Temperature optima for net photosynthesis were usually around 15°C. The CO_2 uptake decreased at lower temperatures but at 0°C there was still substantial photosynthesis. At the higher temperatures net photosynthesis decreased rapidly. This was associated with a marked stimulation of the generally high respiration rates by temperature. The temperature optima for the isolated carboxylation enzymes were higher than those for leaf photosynthesis, indicating that the decrease in CO_2 uptake at high temperatures must be due to other factors. It should be noted, however, that there were species differences in the temperature stability of RUDP carboxylase.

Major components of the production studies were the detailed growth rate and phenology of photosynthesis determinations on five species. Growth and photosynthesis were initiated about 15 June with the production of the first leaves. This leaf in *Dupontia*, for example, was the most efficient leaf in CO_2 uptake until around 1 July at which time senescence and a decrease in CO_2 uptake ensued. During this time, however, leaves number 2 and 3 emerged and began replacing leaf number 1 as the most important photosynthetic structure. Interestingly, growth as measured by increase in plant height or leaf number attained its optimum between 15 July and 1 August which agrees with the period of maximum production in the entire community. It must be stressed that the last leaves to emerge and develop did so after "maximal production" had occurred. Thus, since they are still actively incorporating CO_2, it must be at this time that large proportions of photosynthate are being allocated to reproductive and/or storage tissue. In still other species, e.g. *Ranunculus nivalis* and *Saxifraga cernua*, there were distinct differences between the activities of the basal leaves and those attached to the flowering stems. Basal leaves were usually considerably more important in CO_2 uptake. In all cases, however, the actual CO_2 uptake rates were dependent upon light intensity. Thus, time of day, position in the canopy, and the canopy structure were very important factors affecting CO_2 uptake.

Although the emphasis in the above discussion is on the effect of available light intensity, it must be mentioned that other factors also control production on this and other sites. Some of these comparisons are made in the report on the activities at Prudhoe Bay. At Barrow, observations on the community gradient site (4) reveal additional differences. This site included 6 study plots which encompass a moisture and topographic gradient from low, wet meadow and polygon through to raised, dry polygon top. Peak-of-season leaf area indices varied from 1.50 (wet meadow) to 0.56 (eroded polygon top), and were associated with similar changes in above-ground production of from 71.6 to 16.6 g/m^2. Similarly, the extent of vertical development of the canopy could be related to this moisture gradient. At the alpine site on Niwot Ridge, Colorado, where radiation is considerably more intense, the maximal production of above-ground material in Kobresia meadow averaged 120 g/m^2, a value only slightly higher than those obtained from site 2 at Barrow. Thus, factors other than light intensity and temperature are extremely important in determining the magnitude of the production at different sites. These factors will need to be taken into account as we attempt to generalize from the Barrow site to other tundra areas.

Primary production model

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Each of the previously discussed studies was designed to provide input into a model to predict community photosynthesis in tundra regions. The model simulates the physiological mech-

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anisms which control photosynthetic rates in an attempt to identify the ways in which tundra conditions may limit physiological processes. The present model was expanded and modified from an earlier physiological model, so as to take advantage of the existing arctic tundra data base. Because of this, the model is ready for first order validation of predictions of tundra photosynthesis using 1970 and earlier data.

The model first calculates vertical profiles of temperatures of sunlit and shaded leaves by setting the leaf temperature equal to air temperature and repeatedly calculating the leaf temperature with corrected infrared radiation profiles until the leaf temperatures do not change more than 0.1°C. After these leaf temperatures are calculated the energy budgets for sunlit and shaded leaves at each level are calculated. The increment of water deficit is calculated from the transpiration rate and a rate of water uptake. At present, water uptake is assumed to be constant. Then gross photosynthesis is calculated from absorbed solar radiation and leaf resistance. The lower rate of gross photosynthesis is selected and reduced proportionally to the temperature departures from the reference temperatures if absorbed solar radiation is not limiting photosynthesis. Respiration is calculated in relation to leaf temperatures and net photosynthesis is calculated. The effects of standing dead vegetation on the radiation and wind regimes in the canopy were not included; these are being added to the model. Since no data on air temperatures were available, prior to 1970 air temperatures within the canopy were set equal to the air temperatures above it.

The stand photosynthesis model calculates the net production of leaves. This net production is assumed to be allocated to roots for storage or growth and to leaves for new leaf area. The allocation process defined by the model is constrained by optimum leaf/root ratio and by the energy economy of leaf production. Allocation to seed storage is not yet included in the model. Leaf area expands at a given level depending upon net photosynthesis and an arbitrary maximum leaf area for each level. Surplus in excess of the requirements for already established canopy levels results in a growth of a new level at the top of the canopy. Species position and light utilization characteristics are to be considered in expansion of the model.

For the purpose of validation, the year 1965 was selected as the most complete set of data for the Barrow area. Numerous transformations of the published and unpublished data were necessary for production of a consistent set of units.

Several conclusions may be drawn from the analysis of the 1965 data (recently supplemented by 1970 data):

1. Even with a low canopy and small leaf area indices, light extinction in the canopy is high because of low solar altitudes.

2. Production is limited primarily by light and temperature. Warming the area should increase production.

3. Infrared radiation and ground surface temperatures do not affect transpiration or net production greatly, because their influence on leaf temperature is slight due to high convectional exchange. Ground temperatures will affect root respiration and the accumulation of root mass in the growing season.

4. Evaporation rates calculated with a small leaf area index are similar to those measured in 1965 by Dennis.

5. Primary production increases with leaf area index up to a leaf index of about 0.5 then decreases, using photosynthesis-light curves representative of average tundra species measured in 1969 and a leaf slope of 15°. Evaporation continues to increase with leaf area index.

6. Leaf temperatures are consistently about 0.5°C below air temperature because of the low intensity of solar radiation, the relatively large negative infrared radiation balance, and the high convectional exchange potential of the leaves.

7. The model could be used to generate a surface of net production as a function of solar radiation and air temperature, which could be used to fit a less elegant and less expensive model of production.

Aquatic production and photosynthesis

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Production in arctic lakes and ponds is extremely low, even compared to oligotrophic lakes in temperate latitudes. Although the phosphorus levels in tundra ponds are not extremely low according to standards of temperate latitudes, nutrient limitations (particularly of phosphorus) in combination with the effects of light and temperature have been held responsible for the low rates of primary productivity in this environment. Thus it seems likely that changes in the rate of phosphorus input into the pond environment will have a marked influence on plankton productivity. In addition, perturbations of the aquatic phosphate levels may affect microfloral regeneration rates and the flux of phosphorus and other nutrients back to the terrestrial environment through the emergence of the adult forms of the abundant invertebrate fauna and other pathways.

The main objectives of these studies were to determine the importance of phosphorus in small pond ecology and to assess the sensitivity of the system to variations of the incoming flux of phosphorus. The primary concern is to determine:

1. the relationships between the rate of supply of dissolved inorganic phosphorus and the standing stock and rates of plankton primary productivity, and

2. the rate of uptake and regeneration of phosphorus from detritus and suspended particulates as a function of phosphorus concentration.

These studies will provide flux rates and residence times for phosphorus and will provide some indication of changes in the nature of the phosphorus cycle resulting from various levels of incoming phosphorus flux. In addition they should indicate to what extent the rate of primary productivity in these ponds is controlled by the supply of phosphorus. These investigations will hopefully result in a sufficient understanding of this aquatic environment so that predictions concerning perturbations resulting from land surface disturbances or fertilization can be made more usefully than is now possible. For these reasons, the scope was expanded to include several perturbations and observations of previously stressed aquatic ecosystems.

A series of small ponds (site 7) adjacent to site 2 were selected and subjected to detailed observation and experimental manipulation during the summer. A group of these small ponds, designated B, C, D, and E, are similar in size and general appearance (Fig. 3). These basins are shallow, permanent ponds located in an area of poorly drained low-centered polygons. Samples were taken throughout the summer for baseline primary productivity determinations, estimates of biomass, nutrient chemistry, and kinetics, and certain routine physical and chemical determinations. Ponds B and C were used as control ponds, and manipulations carried out on these were confined within polyethylene containers. Pond D was the site of two manipulative studies of the effects of phosphorus addition. Pond E was also used for baseline studies until mid-July, when an oil spill was introduced. Ponds F, G, H, and I are different from each other, and from the ponds mentioned above. They were included to broaden the scope of the pond types represented. Pond F is small and shallow, and is probably ephemeral in dry years. Ponds G, H, and I are located in a drier terrain on an area of high-centered polygons about 500 m west of the control ponds.

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This section of the report presents results from the control plots, the phosphorus experiments and the interactions of nitrogen nutrition with primary production. The field program started on 18 May and was terminated 14 September 1970.

The quantitative phosphorus analyses consist of the determination of dissolved reactive, dissolved unreactive (organic), particulate reactive, and particulate unreactive phosphorus. This elaborate scheme was in part necessitated by the presence of dissolved organic acids and particulate iron-rich suspensions in tundra waters, as both of these fractions may contain substantial quantities of phosphorus not intimately involved in the biological phosphorus cycling in the ponds. Phytoplankton uptake, microbial regeneration, and physicochemical transports were assessed by ^{32}P tracer techniques in combination with the addition of antibiotics and metabolic poisons.

Primary productivity was measured using ^{14}C labeled bicarbonate, with incubation under natural light. Only phytoplankton productivity was routinely determined, and the quantitative contribution of benthic plants is not known. Chlorophyll a, pH and alkalinity data were obtained for each productivity measurement. Light, dark and net productivities are all reported since 1) dark uptake tends to represent a substantial proportion of the total uptake and 2) dark uptake data may be used independently to estimate heterotrophic activity in the water.

In conjunction with the biological and chemical aquatic work a number of routine physical measurements were made at the study ponds. East-west transects were established across ponds C and E, and depth of thaw profiles were obtained at intervals across these transects by the frost probe technique. Vertical profiles of air, water and sediment temperatures were obtained from thermocouple strings placed near the centers of ponds C and E. Additional air temperatures, mid-depth water temperatures, and sediment surface temperatures for ponds B, C, E, and F together with water levels for ponds B, C, and E were measured.

Pond D, which had a surface area of 750 m^2, a mean depth of 20 cm, and a volume of 150 m^3, was subjected to enrichment with phosphate, and the effects on primary production, phosphorus cycling, and nitrogen cycling were monitored. The first addition, on 25 July, involved the addition of 46 g phosphorus, designed to produce a final concentration of about 300 μg P per liter of pond water. A second addition of phosphorus was made on 28 July, this time designed to produce a somewhat higher final concentration of phosphorus.

The initial phosphorus addition appeared to result in a slow increase in primary productivity. The second, somewhat excessive, addition had the initial effect of depressing photosynthesis to some extent immediately and totally on the day following treatment. This was followed by a rapid recovery, with a steady increase in photosynthetic rate to higher levels than otherwise had occurred in the ponds throughout the summer. The persistence of these high rates will be determined upon completion of sample processing.

The first addition of phosphorus to pond D resulted in a concentration of 174 μg/liter of dissolved reactive phosphorus one day after the enrichment, compared with a value of 2.6 prior to the treatment. The second addition resulted in a phosphorus concentration of 780 μg/liter. The rate of decline from this high level was rapid. Dissolved unreactive phosphorus appeared to decline during treatment and then to slowly decrease.

There were no apparent changes in organic nitrogen nutrient levels in the pond following manipulation. Measurements of nitrogen fixation using acetylene reduction did not indicate nitrogenase activity before or after treatment. The behavior of the particulate nitrogen fraction was of interest. There appeared to be a clear positive response to the original phosphorus addition, which was further augmented by the second phosphorus addition. The peak in particulate nitrogen lasted only a short time and was followed by a rapid decline to pretreatment levels. This presumably was due to limitation by a different nutrient. Addition of ammonia at this point resulted in a second particulate nitrogen increase. The maximum particulate nitrogen level was 400 μg/liter, compared with a baseline level between 60 and 85 μg/liter.

Sub-ponds created within ponds B (B_1, B_2, B_3) and C (C_1, C_2, C_3) also were subjected to phosphorus manipulation. These sub-ponds consisted of containers constructed of clear polyethylene sheeting, each containing an area of about 2 m^2 and open at the top and bottom. Syringe pumps were set up to deliver phosphate solution at a steady rate over a long period of time. In each pond one sub-pond was not subject to manipulation but was used as a control for the enclosures. Sub-ponds B_2 and C_2 were supplied with phosphorus at a rate of 0.5 mg P/day (about 2μg P/liter-day) and B_3 and C_3 at a rate of 2.5 mg P/day (about 10μg P/liter-day) starting at 2200 hours, 29 July 1970. Only two sets of primary productivity data are available at present, one for before and one for after treatment. The data are somewhat variable but do appear to have a general trend for increased productivity in the treated ponds, especially marked in the case of pond C_3. In pond C_3 the productivity rose from a net rate of 0.02 μg C/liter-hour to 2.45 μgC/liter-hour. A slight increase in pH was also evident. Quantitative phosphorus determination and ^{32}P kinetic studies were done (nominally at 5-day intervals) through mid-September. By 11 August the phosphate concentration had increased tenfold in the high level treatment subponds.

The treated sub-ponds were tested for nitrogen fixation before and during phosphorus infusion. No evidence of nitrogen fixation was found by the acetylene reduction technique. Some ^{15}N nitrogen fixation determinations were also made; the results of these are not available as yet. There was no consistent increase in particulate nitrogen within these sub-ponds during treatment.

The rate of ammonia production within the pond area was measured using an isotope dilution technique. A quantity of ^{15}N ammonia was added to a water sample, the initial ^{15}N enrichment of the ammonia fraction in the water determined, and then the enrichment determined again following 24 hours of incubation. This yields the rate of supply of ammonia from other nitrogen fractions in the water (dissolved and particulate organic, animal excretion, plant excretion, etc.) but does not take into account any supply from the sediments to the pond waters. The information is an indication of the metabolic activity of the microorganisms responsible for nitrogen regeneration, and gives a good idea of the amount of nutrient available for plant growth as a result of such *in situ* regeneration.

Due to mass spectrometer problems, not all the samples have been analyzed. The few currently available results are given here:

	Ammonia supply (μg-at/liter-day)
Pond C	
July 22	0.86
July 28	1.52
Pond D	
July 25	0.99
July 27	1.74

These rates are extremely low compared with measurements carried out in other waters. Upon completion of nutrient analyses, it will be possible to calculate turnover times from this information. From the limited data available here, turnover times would appear to be on the order of several days.

Tables XIII-XVI contain selected data that are currently available for ponds B, C, and D.

Table XIII. Primary productivity, phosphorus concentrations and related factors, pond B, 1970.

DATE	PH	ALK. (MEQ/L)	PRIMARY PRODUCTIVITY (UG C/LITER-HR) LIGHT	DARK	NET	CHL.A (UG/LITER)	PHOSPHORUS (UG/LITER)* DRP	DUP	PRP	PUP	TP
20 MAY	6.27	0.340	0.311	0.015	0.296	–	3.7	1.6	–	–	13.0
7 JUNE	6.62	0.229	–	–	–	–	–	–	–	–	–
11 JUNE	6.98	0.242	0.204	0.009	0.194	LT 0.4	5.6	2.8	2.5	2.8	13.7
15 JUNE	6.86	0.199	0.577	0.0329	0.544	LT 0.4	1.5	4.6	3.2	4.6	14.0
18 JUNE	6.43	0.100	0.038	0.010	0.029	1.3	1.5	7.7	2.0	9.3	20.6
21 JUNE	6.40	0.132	0.135	0.015	0.119	1.0	0.5	8.3	1.0	8.1	17.9
23 JUNE	6.41	0.166	0.178	0.012	0.167	LT 0.4	1.4	9.7	1.2	5.8	18.1
26 JUNE	6.96	0.22	0.121	0.008	0.113	LT 0.4	0.8	7.2	1.4	6.0	15.4
28 JUNE	7.03	0.24	–	0.005	–	1.0	0.4	7.7	1.7	4.7	14.5
30 JUNE	7.19	0.26	0.046	0.003	0.043	0.3	3.7	4.7	3.7	5.7	17.8
5 JULY	7.17	0.28	0.130	0.001	0.129	1.4	2.2	3.7	1.0	5.8	12.7
10 JULY	7.17	0.34	0.083	0.005	0.078	0.5	2.6	4.5	0.6	5.3	13.0
15 JULY	7.11	0.44	0.097	0.0103	0.087	1.0	1.4	10.9	LT 0.1	6.1	18.4
20 JULY	7.05	0.41	0.091	0.0135	0.070	–	1.7	9.3	LT 0.1	4.3	15.3
28 JULY	7.23	0.42	0.14	0.03	0.11	0.5	3.8	6.4	0.2	5.7	16.1
1 AUG.	7.41	0.45	0.17	0.01	0.16	LT 0.4	4.0	8.1	0.4	3.5	16.0

* DRP – DISSOLVED REACTIVE PHOSPHORUS
DUP – DISSOLVED UNREACTIVE PHOSPHORUS
PRP – PARTICULATE REACTIVE PHOSPHORUS
PUP – PARTICULATE UNREACTIVE PHOSPHORUS

Table XIV. Primary productivity, phosphorus concentrations and related factors, pond C, 1970.

DATE	PH	ALK. (MEQ/L)	PRIMARY PRODUCTIVITY (UG C/LITER-HR) LIGHT	DARK	NET	CHL.A (UG/LITER)	PHOSPHORUS (UG/LITER)* DRP	DUP	PRP	PUP	TP
20 MAY	6.27	0.180	1.582	0.129	1.453	–	4.2	11.3	–	–	76.8
7 JUNE	6.68	0.194	–	–	–	–	–	–	–	–	–
11 JUNE	6.56	0.126	0.120	0.009	0.110	1.2	2.5	1.2	1.0	9.0	13.7
15 JUNE	6.67	0.178	0.775	0.024	0.751	LT 0.7	1.5	4.6	3.7	9.0	18.9
18 JUNE	6.66	0.138	0.155	0.019	0.136	0.5	4.6	4.6	2.4	9.0	20.7
21 JUNE	6.59	0.156	0.189	0.016	0.173	LT 0.4	2.6	8.2	4.2	4.3	19.3
23 JUNE	6.53	0.168	0.143	0.009	0.134	–	0.4	7.0	3.6	5.2	16.2
26 JUNE	6.90	0.22	0.123	0.009	0.114	LT 0.4	1.0	8.2	3.7	7.0	19.9
28 JUNE	6.83	0.26	0.096	0.007	0.087	LT 0.4	0.4	34.5	2.3	6.0	43.2
30 JUNE	7.02	0.23	0.0006	0.0017	–	1.8	2.0	4.6	1.9	6.5	15.0
5 JULY	7.04	0.29	0.1093	0.009	0.100	0.8	2.0	3.9	1.8	7.0	14.7
10 JULY	6.98	0.36	0.638	0.010	0.628	LT 0.4	1.6	10.4	1.2	8.8	22.0
15 JULY	7.10	0.41	0.116	0.008	0.108	1.1	1.8	13.7	LT 0.1	9.5	25.0
20 JULY	7.27	0.40	0.148	0.049	0.099	1.0	2.2	11.8	LT 0.1	18.5	32.5
28 JULY	–	–	–	–	–	–	3.5	12.4	0.3	8.5	24.7
1 AUG.	7.19	0.45	0.31	0.06	0.25	1.0	3.8	12.8	0.6	33.6	50.8

* DRP – DISSOLVED REACTIVE PHOSPHORUS
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PUP – PARTICULATE UNREACTIVE PHOSPHORUS

Table XV. Primary productivity, phosphorus and nitrogen concentrations and related factors, pond D, 1970.*

			C14 PRIMARY PROD (UG C/LITER-HR)			PHOSPHORUS (UG/LITER)**					NITROGEN (UG-AT/LITER)			PARTICULATE NITROGEN
DATE	PH	ALK. (MEC/L)	LIGHT	CARK	NET	DRP	DUP	PRP	PUP	TP	NH3-N	NO2 -N	NO3 -N	(UG/LITER)
20 MAY	6.2	0.360	0.04	0.01	0.03	2.3	4.4			16.9				
18 JUNE														57.5
24 JULY	7.1	0.304	0.34	0.01	0.34	2.6		0.2	10.3					
25 JULY														85.17
26 JULY	6.7	0.308	0.83	0.07	0.76	174.0		0.3	32.0					130.65
27 JULY	7.2	0.317	0.88	0.09	0.79	46.1	19.4	2.6	39.2	107	2	0.04	0.1	243.56
28 JULY	7.2	0.318	0.39	0.10	0.29	22.6	19.6	2.4	17.6	62	2	0.07	0.1	216.98
29 JULY	7.3	0.369	0.02	0.04	NEG	780.0	0	23.0	21.0	824	3	0.07	0.1	403.95
30 JULY	7.2	0.382	0.21	0.27	NEG	572.0	10.0	15.6	32.6	630	2	0.04	0.1	93.11
31 JULY	7.7	0.340	2.35	0.43	1.92	265.0	14.0	11.8	33.1	324	2	0.06	0.1	88.27
1 AUG.	7.2	0.370	3.61	0.12	3.49	174.0	20.0	9.4	36.5	240	2	0.06	0.1	105.43
3 AUG.	6.9	0.324	3.27	0.64	2.63	57.0	22.4	4.0	39.9	123	2	0.04	0.1	137.67
6 AUG.	7.0	0.300	5.39	1.57	3.82	33.6								
7 AUG.	6.9	0.304				18.1								
9 AUG.	7.0	0.310				29.6								
13 AUG.	7.0	0.316												
15 AUG.														79.38
16 AUG.														162.9
17 AUG.														125.31
18 AUG.														108.64
19 AUG.														55.07
20 AUG.														173.01
21 AUG.														224.19
22 AUG.														260.72

* MISSING VALUES ARE NOT AVAILABLE AT THIS TIME

** DRP - DISSOLVED REACTIVE PHOSPHORUS
DUP - DISSOLVED UNREACTIVE PHOSPHORUS
PRP - PARTICULATE REACTIVE PHOSPHORUS
PUP - PARTICULATE UNREACTIVE PHOSPHORUS
TP - TOTAL PHOSPHORUS

Table XVI. Primary productivity, phosphorus concentrations and related factors, subponds B and C, 1970.

				PRIMARY PRODUCTIVITY (UG C/LITER-HR)			PHOSPHORUS (UG/LITER) *				
DATE	PH ALK	PH	ALK. (MEC/L)	LIGHT	DARK	NET	DRP	DUP	PRP	PUP	TP
28 JULY	B1	6.89	0.328	1.32	0.12	1.20	2.9	11.5	0.2	6.4	21.0
	B2	6.80	0.334	0.43	0.07	0.36	2.1	11.5	0.2	5.6	19.4
	B3	6.83	0.336	0.35	0.05	0.30	2.0	14.4	0.5	10.9	27.8
1 AUG.	B1	7.12	0.370	0.39	0.08	0.31	3.2	11.6	0.3	4.3	19.4
	B2	7.09	0.322	0.67	0.03	0.64	3.1	15.3	0.5	11.3	30.2
	B3	7.08	0.369	1.26	0.05	1.21	5.7	20.4	1.0	25.2	52.3
28 JULY	C1	6.81	0.295	0.67	0.12	0.55	3.1	21.3	0.5	21.5	46.4
	C2	6.75	0.278	0.17	0.05	0.12	2.0	17.1	0.2	11.6	30.9
	C3	6.60	0.270	0.20	0.18	0.02	3.4	15.6	0.6	14.0	33.6
1 AUG.	C1	6.88	0.295	1.19	0.09	1.10	4.0	22.4	0.5	21.7	46.6
	C2	6.79	0.264	1.08	0.06	1.03	4.4	17.4	0.6	25.4	47.8
	C3	6.81	0.300	2.55	0.10	2.45	6.2	23.4	0.9	29.9	60.4

* DRP - DISSOLVED REACTIVE PHOSPHORUS
DUP - DISSOLVED UNREACTIVE PHOSPHORUS
PRP - PARTICULATE REACTIVE PHOSPHORUS
PUP - PARTICULATE UNREACTIVE PHOSPHORUS

Herbivore populations and grazing effects

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One of the conspicuous features of the coastal tundra ecosystem is the dominance of a single grazing species, the brown lemming, *Lemmus trimucronatus*. Population density of this species varies in a cycle of large amplitude over a 3 to 5-year period. In the absence of other significant grazers, this results in a cyclic grazing process.

In 1970 lemming density was very low. The results of standard kill-trap lines, which have been run at Barrow by Pitelka since 1955 (Fig. 2) allow us to compare lemming abundance with that recorded in previous seasons. The 1970 results are given below:

	22 June-8 July	*24 July-6 Aug*	*25 Aug-4 Sept*	*Total*
Lemmus trimucronatus	1	3	2	6
Dicrostonyx groenlandicus	16	8	9	33

The totals for *Lemmus trimucronatus* are among the lowest ever recorded. The total for the normally rare collared lemming, *Dicrostonyx groenlandicus*, is higher than in previous seasons and includes a number of captures in habitats in which this species has never previously been trapped at Barrow. Most significant of these is the low, very wet habitat of central marsh. However, the combined numbers of both species are quite low and indicate negligible grazing pressure in 1970.

Vegetational dominance, cover, and height were observed for all trap lines. Observations were made at 6-m intervals along each trap line. The results will be used to correlate trapping success (hence habitat use) with cover characteristics throughout the cycle.

The objective of quantitative modeling of the tundra ecosystem requires that an estimate be made of consumer populations in terms of number (and biomass) per unit area of tundra. Attempts were made to produce such data for lemmings by mark and release techniques on live-trap grids. Estimates of actual population densities made by such means could then be used to calibrate the kill-trap lines, so that kill-trap results could be used to estimate population density. Two plots were established (each 61 × 61 m) to accomplish this calibration. One was laid out near site 2 (Fig. 3), the other between trap lines indicated as T_1 (Fig. 2). Each consisted of 100 live traps placed within a meter of the grid intersections at 6-m intervals; in addition, 20 live traps were placed outside the live-trap plot along a midline which bisected the plot and extended 61 m beyond both boundaries. This line was to be snap-trapped following the live-trapping program.

Each plot was live-trapped once during the summer, for a period of 6 days, with three checks each day. The plot near trap line T_1 was live-trapped between 28 July and 3 August; no lemmings were captured. Immediately following this a snap-trap calibration line, consisting of 30 stations at 6-m intervals, with three traps per station, was run through the plot. One-third of this line was located within the live-trap plot, while two-thirds of the line extended beyond the plot on either side. The snap-trap line was run for three days (4-6 August), with two checks each day; no lemmings were captured.

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The live-trap plot near the intensive site was run between 16 and 21 August; no lemmings were captured here, either. Brown lemmings were occasionally seen in this area during the summer; however, this area was repeatedly visited by a large number of alert observers and the observations may have been of transient lemmings, or of individuals in a population so sparse as to make detection by trapping unlikely. Thus, while the primary objective in trapping was not accomplished, the results emphasized that, at low points in the cycle, lemming abundance approached zero.

While few data were acquired directly, this was, perhaps, an ideal season to begin an intensive study of the effects of lemming grazing on other ecosystem components. The tundra vegetation was last subjected to heavy grazing in 1965; since then considerable recovery has occurred. This is particularly evident in the large amount of standing dead material in the vegetative canopy. A study of the feeding ecology of *Lemmus trimucronatus*, emphasizing food selection by lemmings and its influence on the vegetation, was begun by Melchior.

In a pilot study, the food preferences of six hand-captured brown lemmings were tested in individual experimental enclosures. Each lemming was permitted to graze a ½-m^2 area containing four plant species. Each plant species was presented as a homogeneous 625-cm^2 block of sod with its natural standing crop. At the end of a 4-hour period, the lemmings were removed from the test enclosures. The wet and oven-dry biomass of standing crop remaining was determined and compared with the wet and oven-dry biomass of standing crop on ungrazed (control) blocks of sod. The food preference of each lemming was ranked from 1 (greatest biomass consumed) to 4 (least biomass consumed). The mean rank of each of the four plant species was: 1 for *Eriophorum scheuchzeri*, 2.3 for *Dupontia fischeri*, 2.7 for *Carex aquatilis*, and 3.6 for *Arctophila fulva*. As indicated by these data, all of the lemmings showed a preference for *Eriophorum scheuchzeri*; however, lemmings must be tested on many additional combinations of grasses and sedges and the preferences among these then related to lemming densities and the distribution of plant species. In anticipation of further work on the feeding ecology of *Lemmus trimucronatus*, a large lemming enclosure was constructed and a point frame (see section on primary production) was used to characterize the pretreatment (ungrazed) condition of the vegetation within the enclosure. Several areas within the enclosures were protected from grazing; these served as controls. A live-trap grid was established near the enclosure to monitor the unconfined lemming populations.

An additional study, which although not conducted primarily at Barrow is critical to an understanding of the role of lemmings in the ecosystem, is being made by Coady and West on the energetics of the brown lemming. This study is investigating the relationship of lemming metabolism to ambient temperature, time of season, phase of cycle, and other relevant factors and will provide estimates of digestive efficiency of lemmings consuming their natural diet. The results will allow us to convert estimates of lemming density to estimates of energy utilization. When this is combined with data on feeding behavior, the intensity of grazing on the vegetation throughout the population cycle can be estimated.

Metabolic rates of lemmings have been measured in each season of the year. A sample result, which shows the oxygen consumption of spring-acclimatized lemmings measured at constant temperature over a 24-hour period, is given in Figure 19. Animals used for these measurements were supplied with food and water and had sufficient space to move around freely. Average daily metabolic rates can be calculated from such records and will indicate at least minimum values for animals in their natural habitat at the same time of year.

When a series of measurements is made of oxygen consumption over a range of temperatures the relationship between ambient temperature and metabolic rate may be calculated. For example, using animals captured at Barrow during the summer season, the following relationship was found:

$$O_2 \text{ consumption (cc/g hr)} = 2.89 - (0.074 \times \text{temp in } ^\circ\text{C}).$$

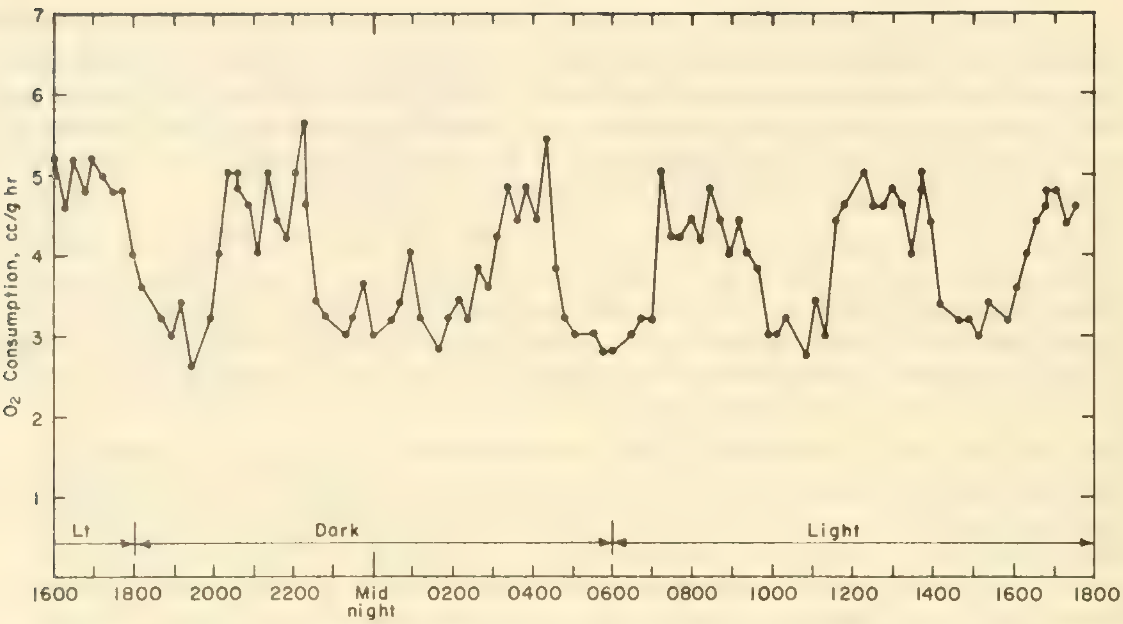

Figure 19. The diurnal oxygen consumption rate for a lemming.

Arthropod populations

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The objectives of the study on tundra arthropods were 1) to estimate seasonal changes in numbers of the more abundant arthropod groups and 2) to investigate in greater detail population phenomena and energy flow in one conspicuous and important group, the crane flies (Diptera: Tipulidae).

Samples for the determination of arthropod abundance at site 2 were taken from the same study plots and quadrats sampled by other subprojects (Tables XVII and XVIII). The sampling unit was a 15.2-cm-diam sod core taken to a depth of approximately 10 cm or to the mineral soil. Previous sampling had revealed that very few arthropods were found at greater depth or in the mineral soil. Two cores were taken from each of two sample quadrats from the five destructively-sampled control plots. Thus, the results may be analyzed by sample, or according to nested quadrat, plot, and study site. In this report only summary figures are given. The intensive site control plots were sampled at 10-day intervals, beginning 16 June. Three of the natural manipulations (clip and clear, clip and uncleared, and light-intensity mulch), and the artificial manipulation site control plots were sampled at 10-day intervals, beginning 19 June. The community gradient site was sampled on 22 June and at 10-day intervals thereafter. Sod cores were placed in berlese funnels for three days to remove the arthropods. The partially dried samples were then sorted by hand and any additional arthropods were removed.

The number of arthropods removed per square meter from the site 2 control plots is given in Table XVII. The biomass estimates given for the two crane fly larvae are based on recorded size distributions of extracted larvae and known length: weight regressions.

The most abundant arthropods were the Collembola. The recorded densities of 40,000-65,000/m^2 are at the upper end of the range of densities reported for a wide variety of the world's habitats, and

Table XVII. Soil arthropods, site 2 control plots.

	15 JUNE	25 JUNE	5 JULY	15 JULY	25 JULY	4 AUG.	14 AUG.	24 AUG.
TIPULIDAE								
TIPULA CARINIFRONS								
N/SQ.M.	22	19	19	16	16	19	38	
GRAMS/SQ.M.	0.045	0.127	0.285	0.135	0.216	0.301	0.600	**
PEDICIA HANNAI								
N/SQ.M.	263	183	169	230	116	175	125	
GRAMS/SQ.M.	0.438	0.352	0.316	0.498	0.228	0.352	0.227	**
MITES								
N/SQ.M.	13001	9967	9389	11767	13345	17823	15234	5545
COLLEMBOLA								
N/SQ.M.	47637	40636	40636	59638	57782	65127	45903	29179
NEMATOCERA LARVAE								
N/SQ.M.	561	630	425	336	330	442	416	408
CARABIDAE LARVAE								
N/SQ.M.	27	0	13	5	11	8	22	19
CARABIDAE ADULTS								
N/SQ.M.	2	0	8	5	2	2	0	0

** VALUE NOT AVAILABLE

Table XVIII. Soil arthropods, site 1.

	19 JUNE	29 JUNE	9 JULY	19 JULY	29 JULY	8 AUG.	18 AUG.	28 AUG.
TIPULIDAE								
TIPULA CARINIFRONS								
N/SQ.M.	48	27	20	20	34	20	41	0
GRAMS/SQ.M.	0.659	0.145	0.123	0.424	0.900	0.436	1.175	0
PEDICIA HANNAI								
N/SQ.M.	62	41	13	13	20	48	0	34
GRAMS/SQ.M.	0.041	0.038	0.018	0.010	0.031	0.032	0	**
MITES								
N/SQ.M.	11834	12223	11889	21779	23557	26474	39082	6500
COLLEMBOLA								
N/SQ.M.	48614	61560	43031	62671	84090	86729	95563	34390
NEMATOCERA LARVAE								
N/SQ.M.	1007	1923	833	840	2694	527	2349	444
CARABIDAE LARVAE								
N/SQ.M.	13	6	0	27	13	20	55	21
CARABIDAE ADULTS								
N/SQ.M.	0	0	0	0	0	6	0	0

** VALUE NOT AVAILABLE

attest to the significance of Collembola in the tundra ecosystem. Arctic Collembola weigh approximately 1.25×10^{-5} g (dry weight) each. The biomass of Collembola thus exceeded 0.5 g/m². This value is similar to that observed for the two Tipulidae species which are much less abundant but many times larger than the Collembola. Biomass turnover, however, is probably much more rapid in the Collembola than in the Tipulidae, so that the Collembola are of greater significance in the movement of energy in the ecosystem. Biomass estimates are not available for the soil mites. The numbers of these arthropods are also quite high, and the mites may rival the Collembola in energetic importance.

The next most abundant arthropods recorded were larvae of the various species of Diptera, suborder Nematocera. These weigh approximately 2×10^{-4} g each, and the densities recorded represent about 0.1 g dry weight/m².

The most important species of arthropods on the study area are the two species of Tipulidae. All of the other values given in Table XVII represent taxonomic groupings of several to many species. On the intensive study area the smaller, carnivorous crane fly larva, *Pedicia hannai*, was more abundant than the larger, saprovorus species, *Tipula carinifrons*.

All of these arthropods showed similar seasonal changes in abundance, with greater abundance recorded in the early and late periods of the season than in mid-season. In the Diptera, pupation, emergence of adults, and breeding all occur in July; recruitment of new larvae into the population occurs soon thereafter. Larvae lost due to predation or other mortality, or due to emergence, are replaced at that time. The annual cycle of abundance results from highly seasonal recruitment combined with mortality distributed over the entire season. If recruitment is insufficient to replace animals lost to mortality, the population shows a net decline over the season. This was the case for Nematocera larvae and for *Pedicia hannai* in 1970.

Even with a highly synchronous period of adult emergence the number of dipteran larvae in the soil never approaches zero. In fact, the lowest numbers were approximately 50% of the greatest. These data indicate life cycles of more than one season, with larvae of several generations co-existing in the soil at any time. This is confirmed by data on size distribution of larvae; for example, the early season size distribution of *Pedicia hannai* showed a clear bimodality with the peaks representing larvae of different ages:

Size distribution of *Pedicia hannai* larvae – 16 June 1970.

length-mm	6-7	8-9	10-11	12-13	14-15	16-17	18-19	20→
N/m^2	2	18	40	16	55	85	27	12

The numbers of mites and Collembola showed similar seasonal changes. Although the life cycles of these groups have not been studied in arctic regions, it is unlikely that they have cycles of longer than one year. The most common pattern for north temperate species of Collembola is two generations per year. Perhaps the simplest interpretation of these data would be that these are annual species, with some reproduction occurring throughout the season but the peak of reproduction occurring at mid-season, and peak recruitment following thereafter. The abrupt decline in abundance of mites and Collembola between mid- and late August corresponds to the onset of nightly freezing of the ground surface.

The control plots at site 1 differed from site 2 in a number of ways (Table XVIII). *Pedicia hannai* was far less abundant, and those present were small so the biomass of this species was negligible. Larvae of other nematoceran species, on the other hand, were more abundant than they were on the intensive sites. Early and late in the season mites and Collembola were present at densities similar to those at the intensive site; however, the magnitude of variation seen during the season was very large. Early and mid-August values were two to three times above those of early June, and the late August decline was very steep.

The Diptera complete larval development and pupation in the organic-rich, near-surface layers of the soil. The adults emerge from the soil to complete the life cycle above ground. The timing and extent of emergence of adult Tipulidae was measured using emergence traps and sticky-boards. Two emergence traps, each covering $0.76\ m^2$, were placed on each of the control and manipulated plots. These gave a quantitative assessment of emergence, but sampled a limited area. The sticky-boards (one board, $1\ m \times 10\ cm$, on each control plot) sampled a larger but undetermined area, and gave an index of emergence. Thus, the two sampling methods yielded complementary results.

At site 2, the first *Pedicia hannai* was detected on a sticky-board on 3 July, and in an emergence trap on 6 July. The median dates of those captured in emergence traps were 9 July (males) and 10 July (females). This sexual difference in timing of emergence has been observed in prior years as well. The dates encompassing the central 75% of the emergence were 6-12 July (males) and 8-15 July (females). Thus, emergence of adults is quite synchronous. A total of 8.3 *Pedicia hannai* emerged/m^2 on the control plots. The male:female ratio (22:41) significantly favored females. This was in contradiction to the community gradient site, where significantly more males than females were captured in emergence traps. The distribution of the catch revealed a surprising degree of within-plot, as well as between-plot, heterogeneity. The two traps on control plot 208 captured 21 and 1 *Pedicia hannai*, respectively, and the total catch per plot ranged from 3 to 25 individuals. The heterogeneity in adult emergence may be greater than the heterogeneity in larval numbers and biomass if there is a negative association between larvae of different age (year) classes. This could produce dominant age class phenomena that are out of phase on different areas. This possibility was suggested by the data on size distribution of larvae, but has not yet been subjected to statistical test.

The emergence of 8.3 *Pedicia hannai*/m^2 removed 0.013 g (dry weight) of biomass from the soil. This is, of course, only a small part of the annual production of *Pedicia hannai*. Fourth instar larvae, prior to pupation, weigh three to four times as much as adults; the difference is biomass metabolized in pupation or cast as the final exuvium. In addition, the majority of larvae do not complete pupation to emerge as adults. The biomass produced by these larvae must be considered as well. A more accurate estimate of production based on changes in numbers and size distribution of larvae throughout the season will be made. This will be compared with estimates based on metabolic rates measured at various temperatures in the laboratory. These data have yet to be analyzed; however, it can be said that significant respiration occurred even at +0.5°C, and respiration rate increased sharply with increase in temperature.

Sticky-board trapping was also used at study site 6 at which adult arthropod abundance has been followed since 1967. This enables us to compare 1970 with preceding seasons. July of 1969 was quite cold, and emergence of both *Pedicia hannai* and *Tipula carinifrons* was less than that recorded in 1967 and 1968. In 1970 the emergence of *Tipula carinifrons* increased somewhat over that of 1969, but was still below the values of 1967 and 1968. Emergence of *Pedicia hannai* was below even the 1969 value, and was the lowest recorded in the four years of observation. Thus, the estimate of 8.3 adults/m^2 may represent a minimum figure for this species. The timing and synchrony of emergence did not differ from those of previous seasons.

Soil arthropods were sampled on the community gradient site 4 at 10-day intervals, beginning on 22 June. Surface active arthropods were censused at 3-day intervals. The emergence of adult Tipulidae was recorded daily throughout the period of emergence. Because of the wide range of habitat conditions at this site, the sampling effort was more dispersed, and the results more subject to chance variation, than on the intensive site. Still, basic patterns of distribution and abundance emerged.

Larvae of *Pedicia hannai* were most abundant on the wet and mesic plots, and were never found on either of the two polygon top plots (5 and 6). The wettest plot (plot 1) was also the most productive for this species; more than 500 larvae/m^2 occurred there on 22 June. On the community gradient site, as on the intensive site, the density of *Pedicia hannai* showed a net decline over the season. Apparently, 1970 was not a favorable year for reproduction and/or survival of first instar larvae.

Larvae of *Tipula carinifrons* were found on all six of the study plots, although they were uncommon on the two wet tundra plots. The maximum density recorded was 180/m^2; this was recorded on one of the mesic plots on 22 June.

Mites were more abundant on the two mesic plots, which resemble the plots on the intensive site 2, than on the wetter or drier plots. Collembola were most numerous on the wet plots and least numerous on the dry plots. In this, they resembled *Pedicia hannai* larvae, which prey upon Collembola. However, when the numbers of *Pedicia hannai* and Collembola from individual samples were analyzed negative correlations were found throughout the season. Thus, abundance of *Pedicia hannai* is not directly associated with abundance of its principal prey. It is possible, though, that the negative correlations result from increased predation on Collembola where *Pedicia hanni* are abundant.

Nematocera larvae occurred in greatest numbers on the dry polygon top plots, and showed a strong negative correlation with *Pedicia hannai* larvae, which may prey upon them. This agrees with results obtained from the artificial manipulation site, which differed from the intensive site 2 in having fewer *Pedicia hannai* but more Nematocera larvae. On the community gradient site Nematocera larvae resembled *Pedicia hannai* larvae in showing a net decline over the season. A similar decline, although of less magnitude, was also seen on the intensive site.

Ground beetles (Carabidae) occurred with equal frequency on the mesic and dry plots, but quite rarely on the wet plots. Abundance of larvae varied from $18/m^2$ on 2 and 12 July to $60/m^2$ on 11 August. Adults were found in all three summer months; however, they were never common. The overall ratio of larvae to adults (108:8) could be interpreted as indicating life cycles of several years, short adult life spans, or high mortality of larvae and pupae. All of these factors may be involved.

Rove beetles (Staphylinidae) were found most frequently on the polygon plots and least frequently on the wetter plots. Their density was about one-third that of the Carabidae. Larvae of leaf beetles (Chrysomelidae) were found infrequently in all habitats.

The emergence of adult crane flies was followed using two emergence traps, each covering 1 m^2, on each of the six study plots. *Tipula carinifrons* was captured in 10 of the 12 traps; the empty traps for this species were on a polygon top and in the polygon trough. The greatest number of captures in one trap was 11; the other traps captured 1 (4 traps), 2 (4 traps), or 3 (1 trap) individuals. Thus, *Tipula carinifrons* is able to complete its life cycle in a wide range of habitats but is not exceedingly abundant in any of these. With the wide range of habitats involved, the emergence was not highly synchronous. For instance, 17 males emerged between 3 and 27 July, with the median emergence on 18 July and the central 75% of the emergence falling in a 13-day period between 12 and 25 July. Sticky-board traps on the same plots gave somewhat different results. The median capture of 125 male *Tipula carinifrons* occurred on 11 July, with the central 75% captured between 7 and 17 July. The difference is probably due to the small number of captures in the emergence sample.

Pedicia hannai emerged into 7 of the twelve traps. None emerged into the polygon top traps, and no larvae were encountered in these habitats. The other traps captured from 1 (3 traps) to 33 individuals. The two traps in the wet meadow produced a mean of 26 adult *Pedicia hannai*/m^2. In both crane fly species the emergence of adults was not sufficient to account for the large decline in larval populations which occurred from early to mid-season.

The emergence of *Pedicia hannai* was more synchronous than that of *Tipula carinifrons*. The median emergence of 56 males occurred on 13 July, and the median of 31 females on 14 July. In both sexes 75% of the adults emerged in a 4-day period between 12 and 16 July. Similar results were obtained by sticky-board trapping.

The median dates of emergence on the community gradient site 4 were several days later than the medians for site 2. This correlates with a later snowmelt on the community gradient site, and supports the hypothesis that timing and synchrony of emergence are controlled by a system of time or temperature summation rather than by some seasonally varying environmental stimulus.

Avian populations and production

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Populations of breeding birds and the production of these populations were estimated by sampling within a 700 × 500-m rectangular plot encompassing sites 1 and 2 at Barrow, Alaska. In

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Table XIX. Incidence and actual or potential breeding status of adult birds on study plot at Barrow, Alaska, 1970.

Species	18 June F	18 June M	29 June F	29 June M	9 July F	9 July M	19 July F	19 July M	Attempts	Success
Snow bunting *Plectrophenax nivalis*	2	2	2	2	2	2	1	1	3	1
Lapland longspur *Calcarius lapponicus*	16	11	9	6	12	6	5	2	8*	4*
Red phalarope *Phalaropus fulicarius*		(10)	2	2	1	1	0	0	2	1
Pectoral sandpiper *Calidris melanotos*	7	6	6	4	0	3	0	1	3	3
Semipalmated sandpiper *Calidris puslilla*	2	2	2	2	0	0	0	0	2	2
Baird's sandpiper *Calidris bairdii*	3	1	2	2	1	1	0	0	3	1
Dunlin *Calidris alpina*	3	3	7	7	2	2	1	1	7	6
Golden plover *Pluvialis dominica*	1	1	2	2	2	2	1	1	2	2
Long-billed dowitcher *Limnodromus scolopaceus*	0	0	1	1	0	0	0	0	1	0
								Totals:	31	20

*Estimates; not all nests found.
M - Male
F - Female

the absence of brown lemmings there was no attempted breeding by predatory birds in the Barrow area in 1970. Snowy owls were rarely seen, and jaegers occurred only as wandering individuals or small groups. Breeding activities of nesting birds were followed by a single observer at 2-day intervals, between 10 June and 28 July 1970, supplemented by synchronized intensive censusing by three observers on 18 and 29 June and 9 and 19 July. Nine species of birds made 35 nesting attempts, of which 20 were successful, at least to the point of one or more chicks being reared to a stage of independence from the nest and from resources within the study area. These data are summarized in Table XIX. These figures can be used to make at least a crude estimate of energetic significance of the bird species. Estimates indicate that the Lapland longspur was the single most important avian consumer on the study area, although the shorebirds as a group consumed more energy (sum = 1736 kcal/Ha) than the two passerine species (sum = 883 kcal/Ha).

Observations suggest that the proximity of a heavily traveled gravel road, an artificial impoundment of snowmelt water, and an unusually large snowdrift, all served to diversify the habitat over its natural state, making it attractive to more species and to greater numbers of birds, especially during the peak of snowmelt in mid-June.

Decomposers - Microbiology and Nutrient Cycling

Soil microbiology

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The quantity of the microbial biomass of the Barrow site is an order of magnitude less than, or under some conditions may approach, the microbial biomass of wet organic soils in the lower latitudes. However, the quality of the biomass and the quality of the microbial activities differ as a result of the factors of low maximum temperature, freeze-thaw cycles, acid pH, and long dormant periods when the organisms must utilize cell reserves to survive. At the end of winter (16 June was the first sample date), the bulk of the soil biomass consisted of bacteria which were largely gram negative short rods which were identified as members of *Pseudomonas, Cytophaga, Flavobacterium,* and *Vibrio* spp. A variety of green algae, yeasts, and molds were isolated but each group was present in quantities less than 10^3/g dry wt soils. The moss-litter layer contained the greatest quantity of microorganisms and the quantity decreased with soil depth.

The bacterial biomass reached a maximum in early July and declined in quantity in late August. At peak season an average of 1.3×10^4 fungal propagules were observed on the site 2 controls. Eighty-one species of micro-fungi were isolated from Barrow soils, while only 51 were recovered from Prudhoe Bay soils. The extremely high concentration of yeasts in Barrow soil (1.5×10^5/g soil) at peak season is one of the most unique aspects of the Barrow site. Most of microorganisms studied in pure culture were capable of growth at mesophilic (20°C) and psychrophilic (0°C) temperatures. Some thermophilic bacteria were isolated but they comprised a small part of the microbial biomass. Table XX contains average seasonal microbial counts for site 2.

Soil respiration was measured during July and August as an indication of *in situ* microbial activity. Respiration gradually decreased during this time period; this trend may be similar to the burst of activity observed in spring in temperate zone soils followed by a decline as substrate, nutrients, or moisture becomes limiting. The data obtained from soil on the site 3 control plot during four sample periods are shown in Table XXI. This technique was very useful in demonstrating how perturbations often increase the rate of organic matter oxidation. This will be discussed in another section of this report. A respiration rate of 10 μliter (μl) O_2/hr g dry soil was typical in the litter layer in early July. Substrate chambers which contained a known cellulose protein-soil mixture were inserted into different depths of the soil. The chambers were removed at the end of the season and caloric determinations are being conducted.

Gas exchange chambers were constructed and inserted into the soil at site 2. Time and equipment did not permit an extensive examination of this aspect during the field season but these chambers are now in place and can be used in the next field season. Preliminary evidence indicates that the levels of carbon dioxide, oxygen and methane vary considerably in the tundra profile.

A portable polarograph and a specially designed miniature O_2 electrode were used to measure *in situ* O_2 concentration at the intensive site. The saturation of oxygen in the litter layer of the drier plots (at 5 cm) varied between 30 and 60%. The concentration decreased sharply below 10 cm (saturation was 10-15% at 15 cm) and it was zero below 20 cm in the soil profile. The O_2 concentration in soil over ice wedges and in low polygon centers was frequently anaerobic at the 10-cm soil depth. These data appear to correlate with plant root biomass. This electrode will be very useful in future investigations where it is important to know what oxygen is available for microbial and plant processes in soil. The electrode is inexpensive; therefore, it will be possible to place a number of units in soil and follow oxygen levels in soils with different moisture levels throughout the season.

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Table XX. Average seasonal microbial plate counts of Barrow site 2, 1970*.

Date	Soil depth (cm)	Bacteria† colonies/g dry wt soil	Fungal** propagules /g dry wt soil	Algae/g dry wt soil
16 June	Litter	2.4×10^7	2.1×10^3	10^3
	0-2	1.8×10^7	6.5×10^3	10^2
26 June	Litter	1.4×10^7	1.7×10^4	10^3
	0-5	2.0×10^6	1.4×10^3	10^2
6 July	Litter	4.5×10^7	7.5×10^4	10^4
	0-5	6.7×10^6	5.2×10^3	10^2
	5-10	5.5×10^5	5.0×10^3	$<10^2$
16 July	Litter	6.1×10^7	7.2×10^4	10^4
	0-5	1.7×10^6	2.7×10^3	10^3
	5-10	3.4×10^5	8.0×10^2	10^2
	10-15	3.1×10^5	$<10^2$	$<10^2$
26 July	Litter	3.9×10^7	2.7×10^5	10^4
	0-5	2.5×10^6	3.3×10^3	10^3
	5-10	2.1×10^5	3.4×10^2	$<10^2$
	10-15	4.3×10^5	$<10^2$	
3 Aug	Litter	2.8×10^7	6.0×10^5	10^3
	0-5	1.1×10^6	3.8×10^3	10^2
	5-10	1.4×10^5	<40	$<10^2$
	10-15	2.5×10^5	<40	$<10^2$
15 Aug	Litter	7.6×10^6	1.8×10^4	10^3
	0-5	2.1×10^5	5×10^2	10^2
	5-10	6.6×10^3	<40	$<10^2$
	10-15	9.7×10^4	<40	$<10^2$

* Each plate count represents the average of plots 206, 207, and 208.

† Each figure represents the average of two media, i.e., Thornton's Mannitol-Asparagine mineral salts medium and soil extract medium.

** Each figure represents the average of two media, i.e., Rose Bengal streptomycin media and acid agar.

Table XXI. Respiration rates of Barrow soils, 1970.

Date	Plot no.	Depth soil (cm)	µl O_2/hr g soil
8 July	301	Litter	10.1
	301	2-4	1.7
	303	Litter	11.1
	303	2-4	26.6
	307	Litter	20.0
	307	2-4	22.8
18 July	301	Litter	5.0
	301	2-10	4.5
	301	10-15	19.1
	301	15-20	10.9
	311	Litter	17.3
	311	5-10	18.2
	311	15-20	24.5
3 Aug	301	Litter	3.4
	301	0-5	2.7
	301	10-15	1.9
	301	15-20	13.4
20 Aug	301	Litter	2.7
	301	0-5	2.3
	301	5-10	1.4
	301	10-15	1.9
	301	15-20	4.6

No attempt was made during 1970 to isolate and identify anaerobic microorganisms; however, in the buried organic layers of site 2 the anaerobic organisms appear to play a significant role in the cycling of nutrients and the formation of organic matter. This observation was based upon direct microscopic counts using aeridine orange. High numbers of viable bacteria were observed but we were unable to culture them under aerobic conditions. Significant quantities of methane may be produced by anaerobic bacteria which are decomposing organic matter at the bottom of the thawed portion of the soil profile.

Subsamples of soil were collected for caloric examination of the soil from many of the samples which were used for microbial examination and respiration determinations. These values will be useful in determining the total potential energy available to soil organisms. In the litter layer of the intensive site 4015 cal/g dry wt soil were observed.

Special emphasis was placed on that portion of the decomposer microflora which is capable of decomposing cellulose, lignin, and water-soluble polyphenols. A large portion of the organic matter consists of cellulose; therefore, many bacteria and fungi which are capable of decomposing cellulose were isolated from site 2. The size of this population varied from 10^2 to 10^4 organisms/g dry wt of soil. Other selective media were used to isolate microorganisms which degrade lignin or tannin; a variety of fungi were isolated which have that potential. The quantity and activities of these organisms at the Barrow site are not known.

One hundred selected bacterial cultures are being examined using a factor analytical approach. These cultures will be compared at Uppsala with cultures gathered from the various IBP sites.

Soil nutrients

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Rod Arkley*	University of California	Alex Simmon	University of California
Hans Jenny	University of California	Karen Fuller	University of California
Arnold Schultz†	University of California	R.E. Hughes, Sr and Jr	Nature Conservancy, Bangor, U.K.
Fred Bunnel	University of California		

Little is known of the dynamics of soils in tundra ecosystems. Considerable changes undoubtedly occur in the concentration of available nutrients in the soil solution as a result of fluctuations in soil temperature, moisture, and biological activity which occur during the active season in arctic soils. The importance of soil dynamics in the tundra ecosystem, particularly fluctuations of nutrient concentrations in the soil solution, is germain to our understanding of the total ecosystem. The soil solution is the intermediary between the decomposers and the primary producers and functions as an important, but complex, link between these two ecosystem components. Activities of decomposers and primary producers have direct, dynamic effects on the properties of the soil solution while fluctuations in properties of the soil solution have direct effects on the decomposers and producers.

The primary purpose of the soil nutrient studies was to determine the magnitudes and directions of nutrient concentration changes in the soil solution and to determine quantitatively the relationship between the soil solution and soil, decomposers, primary producers, and below-ground and above-ground microenvironments.

Studies of soil dynamics and nutrient cycling consisted of several coordinated parts: 1) chemical, physical, and morphological measurements of soil cores (15-cm diameter by 5-cm depth intervals); 2) chemical measurements of soil solution extracted from each soil core segment; 3) monitoring of soil moisture and temperature fluctuations from buried sensors; 4) chemical, physical, and morphological measurements of 7.5-cm and 15-cm diam soil-vegetation tesseras, by 5-cm depth intervals; and 5) chemical analysis of soil core (15-cm diameter by 2.5-cm depth intervals) samples from Schultz's gasline plots.

* Principal authors

† Not at Barrow during 1970

Part 1) measurements consisted of redox potentials, pH (1:1 paste), temperatures, moisture contents, bulk densities, depth to free water, and estimations of root and coarse skeleton contents, texture, and color on each 15-cm by 5-cm core segment collected.

Part 2) measurements consisted of electrical conductivities, pH, and concentrations of Al, total Fe, ferrous Fe, Mn, NH_3-N, NO_3-N, NO_2-N, PO_4, Si, SO_4, Ca Mg, Na, and K in the soil solution extracted fromeach core segment. Measurements of electrical conductivity,pH, and concentrations of Ca, Mg, Na and K in soil solution are completed.

The tesseras will provide base-line soil data to be used for coordination of all project studies and for evaluation of soil variability at the study site. Measurements conducted on these samples were total C, total N, extractable P, pH, exchangeable acidity, exchangeable bases (Ca, Mg, Na, K), bulk density, particle-size distribution, texture and colors. At this time, total C and N determinations have been completed on all 249 samples collected.

Part 5) of the studies consisted of collecting soil core samples from Schultz's gasline plots for chemical analyses (Fig. 2 location 12). The main purpose of this part of the study was to provide comparability between previous years' studies and the present studies with regard to nutrient cycling. Sampling procedures there were similar to those of the IBP intensively studied sites to insure maximum comparability between all sites. Samples were collected in late June, early August, and late August.

Much remains to be done on laboratory analyses,data reduction, and processing. A comprehensive program of factor analysis has been initiated on the data. In the meantime, some results of the studies can be discussed, although precautions must be taken to ensure that initial interpretations are not construed to be final or, for that matter, even necessarily correct.

No Mn, H_2S, or NO_2-N was detected in any of the soil solution extracts. Only in an occasional extract was any NO_3-N or SO_4 detected; and at this time the significance, if any, of these findings is not apparent. The absence of Mn, H_2S, and NO_2-N and the occasional occurrence of NO_3-N and SO_4 in the soil solution, if true,pose some interesting questions that will hopefully be answered in the near future. It is a certainty that microbiological populations and activities, as well as reduction potentials of the soil solution, will have important bearings on answers to these questions.

Concentrations of Al, Fe^{+2}, Fe^{+3}, NH_3-N, PO_4, Ca, Mg, K, Na and Si inthe soil solution generally increased with depth (Table XXII). This was also true of soil pH. The pH of the soil solution, on the other hand, decreased with depth; this was also the case for moisture percentage, redox potential, and temperature. Differences between these two parameters was 0.8 pH units in the 0-5 cm interval, 0.5 units in the 5-10 cm interval, and only 0.3 units in the 10-15 cm interval. The reasons for these differences are not apparent at the present time.

The relative concentrations of elements and ions detected in the soil solution were, on the average, Na>Ca = Si>Fe^{+3} = NH_3-N>Mg>Al>K>Fe^{+2}>PO_4. As a first approximation, it does not appear that any of these elements or ions are at levels low enough to cause deficiencies in the primary producers, although P concentrations are probably marginal.

There were very definite seasonal fluctuations in concentrations of elements and ions in the soil solution. For some, such as Al, Fe^{+2}, Fe^{+3}, NH_3-N, and Si, the fluctuations were comparatively large whereas for PO_4, Na, K, Ca, and Mg the fluctuations were smaller in amplitude. Fluctuations were not parallel although data analysis will be required before details of this can be discussed. Between 26 July and 6 August the concentrations of most of the elements and ions in solutions in the upper 10 cm of soil decreased to a low and then increased between 6 August and 15 August. This may be related to the transition through the growth peak of the vegetation which was considered to be sometime in early August. Fluctuations in concentration were not parallel between depth intervals. For example, between 26 July and 6 August, when the concentrations of many of the elements and ions in solution were decreasing in the upper 10 cm of soil, they were increasing in solution at the 10-15 cm depth.

Table XXII. Average values of parameters from five site 2 control plots by sampling dates (PPM in soil solution).

PARAMETER	DEPTH (CM)	6/18	6/26	7/6	7/16	7/26	8/6	8/15	8/25
SOIL PH	0-5	5.4	5.3	5.5	5.2	5.4	5.1	5.2	5.3
	5-10	*	5.3	5.6	5.4	5.5	5.4	5.4	5.5
	10-15	*	*	5.4	5.6	5.6	5.5	5.4	5.5
SOIL SOLUTION PH	0-5	6.3	6.1	5.9	6.0	5.9	6.1	6.0	6.1
	5-10	*	5.9	5.5	6.0	6.0	6.1	6.0	6.0
	10-15	*	*	5.7	5.7	5.8	6.0	5.8	5.7
AL	0-5	1.1	1.2	1.9	1.8	3.9	0.9	1.8	1.3
	5-10	*	2.1	1.7	2.9	1.8	1.1	3.8	2.9
	10-15	*	*	1.5	3.9	2.4	2.2	3.6	3.1
FE+2	0-5	0.20	0.26	0.28	0.63	0.48	0.30	0.20	0.29
	5-10	*	0.52	0.27	0.64	0.44	0.41	0.49	0.41
	10-15	*	*	0.21	0.94	0.75	1.02	0.45	0.55
FE+3	0-5	2.9	5.1	7.2	7.1	7.2	4.5	7.1	5.0
	5-10	*	6.7	4.1	6.0	4.1	3.3	12.0	4.8
	10-15	*	*	3.4	7.5	5.2	4.4	9.1	8.3
NH3-N	0-5	3.0	2.8	4.4	4.8	5.2	2.4	5.1	3.7
	5-10	*	3.6	4.5	6.6	4.0	3.9	8.1	6.2
	10-15	*	*	5.6	14.7	5.9	6.4	8.6	7.6
PO4	0-5	0.31	0.28	0.28	0.23	0.38	0.16	0.22	0.23
	5-10	*	0.60	0.23	0.21	0.39	0.27	0.24	0.21
	10-15	*	*	0.24	0.26	0.25	0.37	0.48	0.33
SI	0-5	3.7	5.2	7.1	7.1	6.8	5.8	5.4	6.5
	5-10	*	9.1	9.9	9.7	9.4	9.2	8.6	9.9
	10-15	*	*	10.3	12.3	9.4	10.1	12.0	11.8
ORTHO-PO4	0-5	*	0.10	0.11	0.14	*	0.05	0.10	0.11
	5-10	*	0.10	*	0.16	*	0.08	0.09	0.13
	10-15	*	*	*	0.20	*	0.08	0.32	0.10
NA	0-5	10.5	10.7	10.7	9.0	13.9	11.5	10.8	10.7
	5-10	*	17.7	12.5	10.8	14.5	12.3	12.5	11.6
	10-15	*	*	15.6	12.7	15.3	15.3	13.7	12.0
K	0-5	1.1	0.8	1.3	1.5	0.7	0.6	0.7	0.4
	5-10	*	1.3	2.5	0.9	0.8	0.5	0.5	0.4
	10-15	*	*	1.9	1.3	1.0	1.0	0.5	0.5
CA	0-5	8.1	8.8	7.1	8.6	8.3	7.2	8.1	6.5
	5-10	*	10.9	8.9	10.0	8.0	8.0	8.6	9.3
	10-15	*	*	7.8	10.0	10.7	13.6	10.2	10.3
MG	0-5	4.1	4.3	3.7	3.4	5.1	3.8	4.6	3.5
	5-10	*	5.7	4.2	4.4	3.9	3.7	4.9	4.8
	10-15	*	*	4.2	5.6	5.3	5.8	4.9	5.1
MOISTURE AT 70 DEG.C (G H2O/100 G SOIL)	0-5	611	429	375	364	298	282	288	332
	5-10	*	214	142	136	121	106	116	123
	10-15	*	*	121	151	135	110	117	137
REDOX (MV)	0-5	*	149	279	263	320	299	318	287
	5-10	*	137	294	234	253	252	301	259
	10-15	*	*	263	224	248	236	298	238
TEMPERATURE (DEGREES C)	0-5	2.2	7.0	4.4	5.6	4.5	3.6	3.8	2.9
	5-10	*	2.4	2.2	4.0	2.3	2.2	2.5	2.3
	10-15	*	*	1.0	2.6	1.4	1.4	1.6	2.3
BULK DENSITY (G/CC)	0-5	0.17	0.31	0.35	0.18	0.23	0.26	0.21	0.32
	5-10	*	0.47	0.69	0.31	0.38	0.41	0.32	0.60
	10-15	*	*	0.67	0.28	0.28	0.37	0.31	0.57

* DATA NOT AVAILABLE

There were definite differences between the five control plots at site 2. Plot 207 consistently had lower concentrations of Al, Fe^{+2}, Fe^{+3}, NH_3-N, and Si in the soil solution than the other plots, particularly in the upper 10 cm. It also had the highest soil moisture percentages. Further, plot 210 appeared to be more similar to plot 207 than to the other three plots with respect to most parameters. These differences will have to be considered, in the final analysis, when attempting to measure responses to the various natural perturbations at this site.

Analysis of the tessera samples to provide base-line soil data is still in progress. The only data available at this time are percentages of C and N (Table XXIII). At this time, values are based on a 30°C dry soil weight instead of the conventional 70°C or 105°C weight. Percentages of C and N are very high at both site 1 and 2 but they are both very definitely higher at site 2. This is a reflection of more mesic conditions at the latter site. At both sites the C and N values were high throughout the profiles and there was a tendency toward a decrease and then an increase with depth. This is mainly a reflection of buried organic matter at both sites. The C/N ratios are the most revealing part of the data at this time. Even though there were rather large differences between the two sites in percentages of C and N, the C/N ratios in comparable depth intervals were amazingly similar. This seems to indicate that state factors and processes, although differing in magnitude, are very similar at both sites. If this is true the C/N ratio may well prove to be one of the more important measures of the ecosystem.

Table XXIII. Average carbon, nitrogen, and C/N ratios in tesseras, sites 1 and 2*.

SITE	DEPTH	N	AVE.PCT CARBON	AVE.PCT NITROGEN	AVE.PCT C /AVE.PCT N	AVERAGE C/N
1	VEGETATION	6	26.8	1.04	25.8	27.7
1	0-5 CM	6	15.6	0.75	20.8	21.2
1	5-10 CM	6	15.4	0.80	19.3	19.4
1	10-15 CM	6	12.6	0.64	19.7	18.6
1	15-20 CM	6	12.7	0.73	17.4	18.0
1	20-25 CM	6	12.6	0.65	19.4	19.7
1	25-30 CM	5	11.6	0.69	16.8	17.5
1	30-35 CM	4	13.3	0.69	19.3	19.7
2	VEGETATION	22	35.0	1.36	25.7	26.1
2	0-5 CM	22	29.4	1.43	20.6	21.0
2	5-10 CM	22	19.0	0.97	19.6	20.1
2	10-15 CM	22	14.7	0.70	21.0	21.5
2	15-20 CM	22	17.2	0.88	19.5	19.6
2	20-25 CM	21	19.5	0.90	21.7	21.7
2	25-30 CM	15	19.0	0.82	23.2	24.0
2	30-35 CM		17.7	0.89	19.9	20.0

* BASED ON SAMPLES DRIED AT 30 DEG. C.
VALUES WILL BE ADJUSTED TO A 70 DEG C OR 105 DEG C DRY WEIGHT
WHEN THESE DATA BECOME AVAILABLE.

Nitrogen fixation - Arctic tundra

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The purpose of this study was to determine the significance of nitrogen fixation as a nitrogen input into the tundra ecosystem. Since the rate of decomposition of organic material is believed slow, nitrogen limitation can reasonably be expected. If this is the case, a large proportion of nitrogen fixers should occur. Many tundra plants belong to groups known to fix nitrogen, including those lichens having blue-green algae as the algal component, the blue-green algae that occur in moist areas on the tundra surface, the legumes, and nonlegume nodulated plants such as *Dryas*. The actual contribution of these to the tundra nitrogen budget is not known.

This study was divided into two main phases. First, a survey of plants in the arctic tundra IBP site area and in an alpine tundra site was made, testing as many species as possible for nitrogen fixation. Second, nitrogen input through fixation was estimated on a surface area basis for some of the plots at the Barrow site.

Nitrogen fixation measurements were carried out using the acetylene-reduction method, with confirmation of positive results using ^{15}N. Details of the methodologies will be presented in subsequent reports.

Two distinct types of experiments were carried out in Barrow. Selected plants were tested for nitrogen fixation and segments of soil with associated vegetation from the plots used for the other terrestrial work in this area were measured. In addition, numerous nitrogen fixation determinations were made on the ponds used for the aquatic Barrow work, including water samples, concentrated organisms from the water, and pond sediments.

Cores, 0.01 m^2, were removed from a small number of control and manipulated plots to test for nitrogen fixation. From each core, squares were cut with 3-cm-long sides; these were subjected to testing using acetylene-reduction and nitrogen-15, with duplicate acetylene reduction experiments for some cores. Blanks were also run; in these no acetylene was added, so that any ethylene production by the tundra vegetation or soils could be detected and subtracted from the nitrogen fixation values.

For the site 2 plots, all the control plots showed nitrogen fixing activity, with rates of about $0.2 \cdot 10^{-3}$ μg-at/cm^2 hr. This is equivalent to 2μg-at/m^2 hr, which would account for a major nitrogen input into this system. The conversion of ethylene production rates to equivalent nitrogen fixation was done according to established procedures, but the value obtained should be considered an approximate value only. No ethylene production in the absence of acetylene was detected at any time. The manipulated plots showed a reduction of nitrogen fixation rate in the case of the clip and clear plot, and a complete absence of fixation in the two fertilized plots tested (Table XXIV).

Plants present at site 2 and vicinity were collected and subjected to acetylene reduction, and in some cases nitrogen-15, tests for nitrogen fixing activity. The plants and lichens which yielded negative results are listed below:

Salix pulchra	*Astralagus alpinus* L.
Petasites frigidus	*Dryas integrifolia*
Saxifraga flagellaris	*Alectoria bicolor* (Ehrh.) Nyl.
Saxifraga cernua	*Dactylina arctica* (Hook.) Nyl.

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Saxifraga caespitosa	*Cochlearia officionalis arctica*
Saxifraga punctata	*Cetraria nivalis*
Ranunculus nivalis	*Cetraria simmonsii* Krog.
Salix sp.	*Cetraria richardsonii* (Hook.)
Ranunculus pygaeus	*Polygonum acutiflora*
Saxifraga hieracifolia	Moss from Nuwuk Pond

Table XXIV. The results of acetylene reduction nitrogen fixation measurements for the terrestrial Barrow tundra.

	Ethylene produced/hr *(μ mole $\times 10^{-3}$)*	*Equivalent N fixed/hr* *(μg-at $\times 10^{-3}$)*
Site 2		
Control plots and quadrats 24 July		
20857	3.5	2.33
20857	3.1	2.05
20684	2.58	1.72
21098	2.85	1.90
21098	1.65	1.09
Manipulated plots 3 Aug		
22612 (clip and clear)	0.14	0.09
23263 (20-10-10)	0.00	0.00
23368 (8-32-16)	0.00	0.00
Site 1 (3 Aug)		
10673 (control)	0.00	0.00
11102 (heated air)	0.00	0.00

Note: All experiments were carried out on 3-cm $\times$ 3-cm squares taken from 0.01 m^2 core. Blank samples (without added acetylene) were run for each core, with negative results. ^{15}N confirmation for these results will be available for selected samples.

Table XXV shows plants which yielded positive results, including three species of lichens, two of which still await identification. Blue-green algae, where present, appeared to be important contributors to the tundra nitrogen budget, and fixation was also associated with several other plants. It is important to realize that no claim is made here for nitrogen fixation by the plants themselves, but only that active nitrogen fixation was associated with these plants. The organisms responsible may be bacteria associated with root or leaf nodules, bacteria or blue-green algae in physical association with the plants, or even such organisms inadvertently introduced with the plant into the experimental vessels. The nitrogen-15 results, which will involve separate analyses of enrichment in the roots, leaves and stems, may yield further information. From the ecological point of view, it is significant to know that there is nitrogen input from the atmosphere in association with these plants.

Based on the information obtained on the intensive site plots, nitrogen fixation would appear to be a major input into the tundra nitrogen cycle in this area. A rate of approximately 2 μg-at/m^2 hr may account for a large proportion of the total nitrogen assimilated by the photosynthetic organisms. Further information on seasonal variations and more intensive work on the variability of such fixation rates on the tundra surface would now be desirable.

Table XXV. Results of nitrogen fixation determinations on plants at site 2, 22 July - 3 Aug, 1970.

	Ethylene produced (μmoles/hr $\times$ 10^{-3})	*Equivalent N fixed (μg-at N/hr $\times$ 10^{-3})*
Draba lactea	1.96	1.30
Poa arctica	0.77	0.51
Ranunculus pallasii	0.77	0.51
Cardamine pratensis	5.95	3.96
Rumex arcticus	0.58	0.38
Thamnolia vermicularis or *Thamnolia subuliformis*	0.41	0.27
Nostoc sp.	0.26	0.17
Red algal mat from shallow pond	0.51	0.33
Unidentified moss	0.58	0.38
Unidentified lichen*	5.8	38.2
Lichen*	88.6	59.0

* Currently being identified

In addition to the terrestrial sites, several aquatic environments were sampled for nitrogen fixation. Nitrogen fixation assays were done on the water and sediment of ponds B and C during the first week of June. No positive results were obtained, indicating that nitrogen fixation was not an important input into these ponds at this time. Similar experiments during July and August did not show any nitrogen fixing activity. Several ponds and waters with algal mats were sampled in order to make nitrogen fixation assays. The only positive results in the aquatic environment for nitrogen fixation were for algal mats collected from Footprint Creek. The Footprint Creek results were:

Sample	*Ethylene produced (μmoles/hr $\times$ 10^{-3})*	*Equivalent N fixed (μg-at N/hr $\times$ 10^{-3})*
Footprint Creek No. 1 - 1 Aug	0.64	0.42
Footprint Creek No. 2 - 1 Aug	1.28	0.85

STRESSED ECOSYSTEM RESEARCH

Barrow Terrestrial Manipulations*

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The objective of the manipulation experiments and the description of the treatments at sites 1 and 2 are presented in the section on research design. Some of the effects of the manipulations can be observed in the data presented in Table XXVI. The results of the oil treatments are discussed in a later section. Figure 20 shows one of the plots (clip and clear) with the insect emergence traps on opposite corners of the plot.

Abiotic

Depths of thaw measurements in late summer reflect cumulative seasonal influences of the surface manipulations. At site 2, the five control plots all produced similar average thaw depths, indicating satisfactory replication for at least the physical soil properties among the control plots. The most apparent effect of the natural manipulations was the reduction in thaw by varying amounts of mulch, and the increased thaw on the clip and cleared plots. A trend towards increased thaw is suggested on the clip and uncleared plots. For the artificial manipulations, the intensive physical disturbance produced a substantial increase in thaw; however, the light intensity treatment had minimal effect. The heated air of the greenhouse produced an increase in thaw of 6 cm over the adjacent control by early August. Figures 10 and 11 show the seasonal progression of thaw for different manipulations on the two sites. The July mean air temperatures for the greenhouse and control were:

	Surface	*15-cm height*
Control	6.2°C	6.1°C
Warm air	9.6°C	7.4°C

Figure 21 is a view into the partly opened greenhouse.

The heated soil experiment was initiated in early summer at site 1 to provide an *in situ* year-round facility to test the effects of warm soil on the biological and thermal regimes of the tundra. The experiment was designed and installed as a cooperative effort between USA CRREL and the Institute of Arctic Environmental Engineering, University of Alaska. It was originally designed to simulate the heat flow at the ground/air interface from a buried, hot oil pipeline under arctic coastal conditions. The immediate objectives were 1) to determine the physical and thermal response of the wet tundra soils and ice-rich permafrost to a continuous above-freezing heat input and 2) to evaluate seasonal biological responses under the imposed vertical and horizontal thermal gradients. Figure 22 is a photograph of the experimental setup. The strings indicate the location of the buried 1.25-cm-diam copper tubing.

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*Essentially all project participants named in preceding sections of the report were involved in this integrated program. Only the project leaders or new personnel are listed.

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Table XXVI. Early August seasonal parameters on control and manipulated plots.

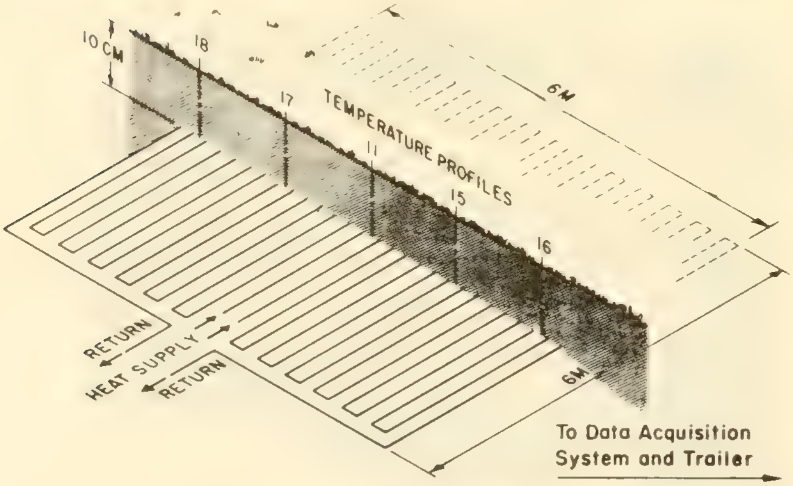
	Abiotic				Primary producers				Consumers		Decomposers (0-5 cm)	
Treatment	Plot	Thaw	Moisture		Primary production	Chlorophyll	LAI		Emergence-Tipulidae		Bacteria	Fungi yeast
		(cm)	(0-5 cm) % Dry wt (70°C)	(5-10 cm) % Dry wt (70°C)	(g/m^2)	(mg/m^2)	Live	Dead	Tipula (N/m^2)	Pedicia (N/m^2)	Colonies/g dry wt soil	Colonies/g dry wt soil
											· (10^7)	× (10^4)
Control	206	26	262	129	91	364	0.9	1.2	0	16.7	3.0	15
Control	207	25	607	136	90	358	1.2	0.9	0.7	2.0	2.5	60
Control	207	25	163	94	133	424	1.3	2.0	0.7	14.7	5.4	54
Control	209	26	171	126	98	519			0	2.7		
Control	210	26	209	47	84	357			1.3	6.0		
Clip and clear	226	28	662	164	63	268			2.7	1.3		
Clip and clear	227	34										
Clip and uncleared	228	27							3.3	1.3		
Clip and uncleared	229	27										
Mulch (light)	230	24							2.7	1.3		
Mulch (heavy)	231	21	446	101	73	324						
Fert (20-10-10)	232	28	585	376	110						9.7	50
Fert (8-32-16)	233	23	312	95								
Control	106	22	93	71	120	452	2.0	2.1			2.1	37
Control	107	17										
Heated air	111	28	111	77	123	539	2.1	2.5				
Heated soil	112	33										
Oil	114	22			99	338					9.2	8
Disturb (light)	116	24	108	80	84	438	1.3	1.5				
Disturb (heavy)	115	21										

Figure 20. View of a site 2 clip and clear plot with emergence traps in opposite corners.

Figure 21. View into partly opened greenhouse on site 1.

The gradual heating of the soil began in mid-July. Within several weeks, a clearly defined zone of warmer soils appeared at 10-cm depth and thickened downward as heating continued. Input temperatures into the 200-m loop were generally about 10 to 12°C. Temperatures in the alcohol-water mixture at the outlet were in the 8 to 9°C range. Increased soil thaw became evident in August as ice-rich permafrost began to melt and differential subsidence began. By the end of the summer, average thaw due to artificial heating was 15-20 cm greater than on adjacent control plots. A distinct thaw bulb had developed beneath the center of the plot where input pipe temperatures are greatest (Fig. 23b). At this time, one-half of the pipe was shut off and the soil in it permitted to refreeze. Figures 23c and 23d show the temperature conditions in the plot for early September

Figure 22. Close up of heated soil experiment. Pipes are buried beneath strings.



a. Plot 112

Figure 23. Idealized section of heated soil experiment and plot of temperature fields at selected sample periods. Diagrams c and d illustrate the freezing of half the section after heating was terminated in it.

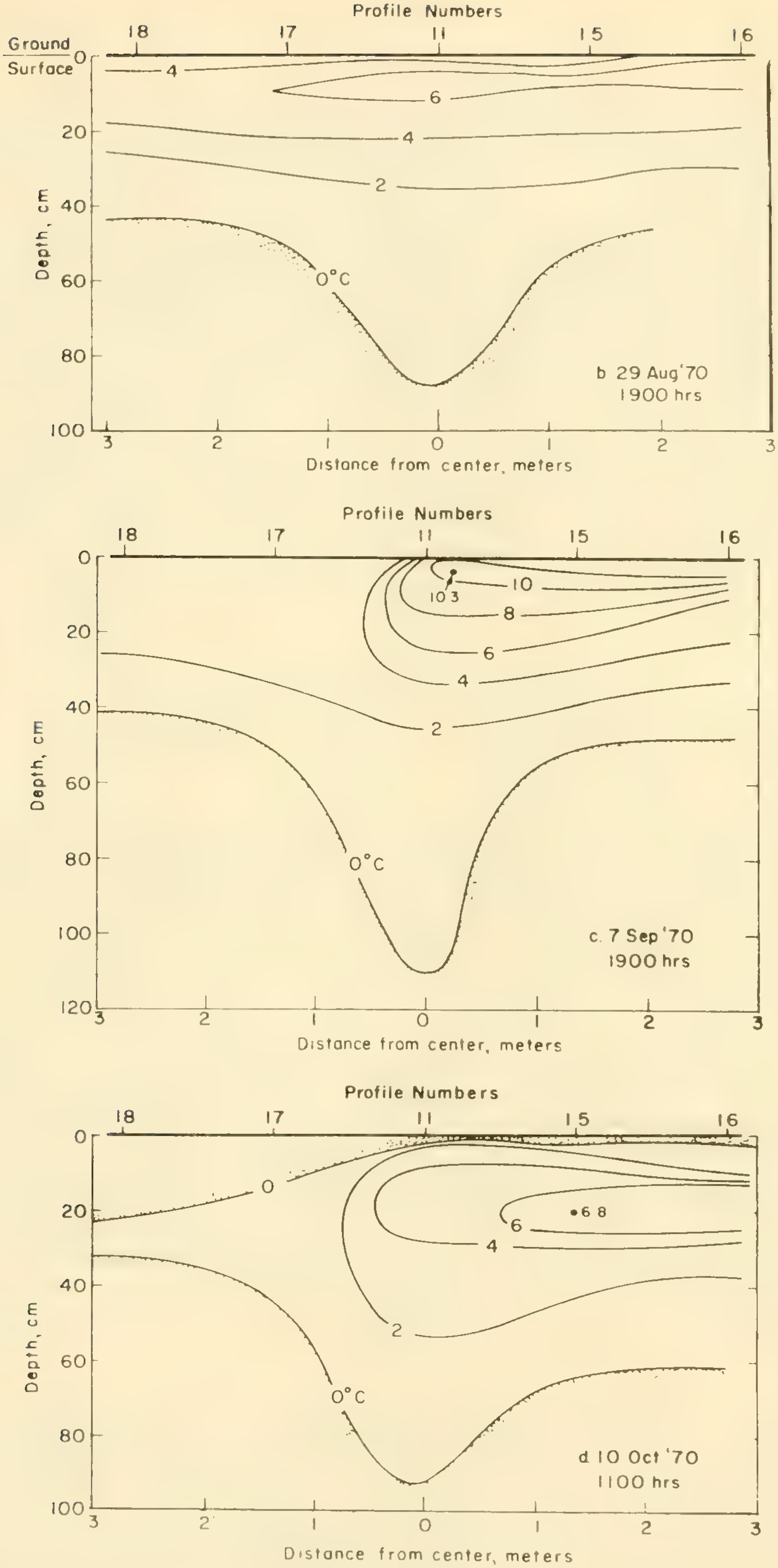


Figure 23 (Cont'd).

and October respectively. As of early November the soil in the heated section remained essentially unfrozen to the surface and was under 0.5 m of drifted snow. Biological sampling of this heated experimental plot began in the fall and will continue throughout 1971.

Primary producers

The total above-ground production was reduced on the clip and clear plot, even though the active layer depth was somewhat greater than that on the controls. Apparently the physical effects of removing vegetation inhibit production, possibly by removing the insulating and protecting features of the standing dead canopy. Reduced production has been observed by previous investigators in the growing season following heavy grazing by lemmings.

Reduced production was also seen on the plot subjected to heavy mulching. The effect on the canopy was to increase light extinction simultaneously with an increase in air temperature. Depth of thaw was reduced. The interaction of these factors resulted in a reduced production .

Rather surprisingly, fertilization produced no measurable increase in above-ground production in the year of application, although visible effects such as increased greenish color were discernible. This result contrasts sharply with results obtained at another Barrow site (Fig. 2, site 10) where fertilizer was applied between 1961 and 1964

	Site 10	
1970	*Fertilized*	*Control*
Production, g/m^2	109	28
Standing dead, g/m^2	109	47
Depth of thaw, cm	16	21

There, the residual effect of fertilization, six years after the last application, is still striking. The difference in depth of thaw is probably related to the very thick layer of sphagnum moss which has developed on the fertilized plot. The fact that high production is associated with a shallow depth of thaw and, most likely, low soil temperatures argues against the importance of these factors in inhibiting production on the mulched plot, discussed above. Results obtained on this previously fertilized plot suggest that effects of fertilization on the site 2 plots may become more evident in subsequent years. Alternately, the 1970 sampling intensity for the peak season sample may not have been large enough to account for plot variability.

Above-ground production was slightly greater on the site 1 control plots than on the site 2 control plots. At site 1 production was apparently reduced by oil treatment and by physical disturbance. Again limited sample size precludes definitive conclusions. On both sites chlorophyll m^2 and leaf area index were closely correlated with production. The major deviation was the relatively high chlorophyll value found in the greenhouse. This can probably be attributed to relatively greater proportions of photosynthetic tissue in the plants exposed to slightly higher air temperatures and slightly lower light intensity. Similarly, although peak season production was reduced in the clip and clear and mulched plots, senescence and deterioration of chlorophyll occurred much sooner on the cleared plots than on the mulched plots.

Consumers

The use of 6 × 6-m study plots was not suitable for the study of vertebrate consumers, since each individual ordinarily moves over areas larger than the manipulated plots. Soil arthropod populations were observed at 10-day intervals in the control plots and in the clip and clear, clip-and uncleared, and lightly mulched plots. There was no detectable difference between populations of the two species of Tipulidae on the control and manipulated plots. Because of the extended life cycles of arctic Tipulidae the density of larvae on these plots resulted from eggs laid in previous seasons, before the manipulations were imposed. The emergence of adult crane flies was also observed on these plots; however, both within-plot and between-plot heterogeneity on the control plots was very high, and obscured any possible treatment effect.

The three manipulated plots, when they were first sampled, had fewer mites and Collembola than the control plots. This is attributed to chance variation in the plots selected (randomly) for manipulation. This difference was maintained in the plot (clip and clear) from which organic matter was removed. However, in the two plots in which organic matter was made available to soil-dwelling animals this difference disappeared and by August the density of Collembola was greater than or equal to the density in the control plots. This finding should be confirmed by the use of replicated manipulation plots. If this is really a phenomenon, it could be due to the nutritive value of the litter added or to extension of the physical habitat, providing more living space. The physical and nutritive effects could be separated by the addition of non-nutritive litter to tundra plots. This possible increase in the number of Collembola was the only effect of natural manipulations on arthropod populations detected in the first season following manipulation. Additional effects might be expected in subsequent seasons, as saprovores and decomposers utilize the added litter, and are then fed on by carnivores.

Decomposers – microbiology and soil nutrient

The effect of manipulation on decomposer populations was examined for the fertilized (20-10-10), oil-treated, and track plots only. In the oil-treated plots at sites 1 and 3 there was a 10-fold increase in the bacterial plate count, and on the fertilized plot there was a twofold increase of the bacterial flora. However, at the site 3 track site there was a 15-fold decrease in the bacterial plate count as the result of compaction. It may be concluded that some of the manipulations used in this study altered the microbial biomass and may have had a greater effect on the activity of organisms in the soil at the start of the manipulation. No activity measurements were made of any plot at site 2, but the activity measurements at sites 1 and 3 are in agreement with this idea.

Complete soil nutrient analyses were performed on the manipulated plots at several sample intervals. The most conspicuous results were seen on the two fertilizer plots. The added nutrients were detectable in soil solution soon after fertilizer application. The added nitrogen (NH_3) was no longer evident at peak season, although the PO_4 level remained high. Other soil nutrients, however, were less concentrated in the soil solution of the fertilized plots than in the control plots. Thus, it appeared that fertilization stimulated biological activity to the point that nutrients (other than those added) in the soil solution were depleted relative to those in the control plots. Since fertilization did not lead to a demonstrable increase in above-ground production, the difference is attributed to nutrient content of the vegetation, storage by root systems, or nutrients bound by some groups other than primary producers. Samples for plant nutrient have been analyzed but data are not completely available at this writing.

In general, high soil moisture is related to the predominance of a moss layer. The difference between sites 1 and 2 is evident in the soil moisture values. All of the site 1 plots had lower soil moisture than the site 2 plots. The effects of treatment on soil moisture were not obvious at either site 1 or site 2.

The heated air manipulation appeared to have considerable effect on the soil and soil solution. Soil moisture was similar to that in the control plot; however, redox potential was lower, and soil temperature and pH were higher in the treated plot than in the control plot. Concentrations of Fe^{++}, NH_3, Si, Ca and Mg in the soil solutions were lower in the heated plot than in the control plot, and PO_4 concentration was much greater in the heated plot. The effects of physical disturbance were similar to those seen on the heated air plot. In all cases, the mechanisms relating the manipulation to observed effects on soil properties are not clear; and at this time in the analyses it is difficult to separate the treatment effects from the heterogeneity in soil properties encountered at both sites.

The effects of the various manipulations can be broadly categorized into those involving physical properties (temperature, structure of the vegetative canopy, etc.) and those involving nutrient availability. Effects in the first category should be evident soon after the manipulation is applied; however, effects related to nutrient availability may become evident only after several seasons. This is particularly true for bound nutrients in the form of litter or mulch. Thus, the lack of noticeable effect in the parameters measured should not be interpreted as proof that the manipulation did not influence the functioning of the system. For this reason, duplicate plots of several of the manipulations were reserved for sampling in future seasons. In addition, the high degree of variability encountered makes it difficult to draw conclusions from a single, peak-of-season, sampling. In cases where data from a single interval will suffice sampling should be more intensive than in this study.

Track Disturbance

Paul Gersper*	University of California	Bob Benoit*	Virginia Polytechnic Institute
Josephine Challinor*	Univeristy of California	Walt Campbell	Virginia Polytechnic Institute
Rod Arkley	University of California	Bob Breedlove	Yale University
Steve MacLean	University of Illinois	Larry Tieszen*	Augustana College
Jim Bumbarger	University of Montana	Doug Johnson	Augustana College
Don Smith	University of Montana	John Dennis	University of Calgary

The sensitivity of the wet tundra to visible damage is seen most dramatically following a disturbance caused by tracked or wheeled vehicles. The effects of these disturbances are apparent throughout the North Slope not only from current activity but, to a large extent, from events dating as far back as the 1940's. Thus, the consequences of the disturbance have short-term effects as well as long-term effects in that they persist for many years, indicating the slowness at which the tundra recovers from a given stress.

Increased human activity in recent years, and prospects of even more activity in the future, emphasize the need to examine critically the effects of vehicular disturbance on the tundra ecosystem. The objectives of this study were to measure and to evaluate the effects of past track disturbance on the tundra ecosystem with respect to dynamic interactions among ecosystem components.

Disturbances by surface vehicles are basically of two types. One type, less apparent than the other, is the passage over the tundra which causes the compression of the standing vegetation (live, and especially dead) to a layer a few centimeters thick directly above the wet moss and organic interface. Such areas are seen in subsequent years as "green belts" stretching over the tundra. They appear to be increased plant growth but this may be an illusion caused by the removal of contrasting brown and tan standing dead material due to increased rate of decomposition. The effects of these disturbances are certainly evident in the plant canopy where air, temperatures, wind, and light penetration are altered. This type of disturbance commonly results from traffic over a tundra with shallow snow cover. Even snowmobiles may produce this effect. As the number of passes increases over the snow-covered trail the effects can grade into those of the second type of track disturbance.

The second and more destructive type of disturbance results from physical disruption of the vegetative and soil organic layer. This drastically changes the thermal balance with the vegetation and soil, and increased soil thaw occurs. These tracks typically result in depressions over

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melting ice wedges and soils and tundra which are more wet. The degree of thawing and consequent subsidence depends upon the amount and type of ice contained in the permafrost beneath the track. Melting of ice wedges results in small ponds. If the track is on a slope or intercepts a drainage channel, it is susceptible to erosion, as is dramatically indicated by the effects seen on the research sites at Barrow.

The study of an old track at site 3 was undertaken in an attempt to determine some of the dynamic interactions which persist some time after the original disturbance. The track was occasionally used in summers during the mid 1960's. Its features varied depending upon the type of microrelief and substrate it crossed. Some places were completely barren of vegetation and others supported some of the most dense vegetative growth seen at Barrow. Characteristic of most of the track, however, was an absence of standing dead vegetation and litter. Thus, it appears that the turnover of nutrient in this situation must be high and presumably is unassociated with higher activities and/or populations of decomposing microorganisms.

Three plots were established across the track, each showing different degrees of erosion and wetness. Plot 306 was relatively dry and disturbance was least conspicuous. Plot 303 was intermediate in wetness and slightly depressed. Plot 305 had considerable subsidence due to ground ice melting and had surface water on it throughout the summer. Four points across the track were sampled in each plot: in the track depression, on the mound between the two tracks, on the outer edge of the track or bank, and at a control point several meters from the edge (Fig. 24, 25).

Microrelief, soil morphology, plant and soil nutrients, primary production, thaw, soil moisture, redox potentials and insect and microbial activities were measured at these plot points periodically throughout the summer. The following reports the differences encountered within and between each transect on the track.

Over the entire summer season, soil temperatures along the cross-sectional transects were, in decreasing order, mound $\geq$ depression $\geq$ bank $\geq$ control. The depth of thaw was more than double that of the control beneath the weasel tracks and the intervening mound where the track crossed a wet area (plot 305). Thaw differences in the drier plot 306 were neglibible and were intermediate across plot 303. On the average, thaw along cross-sectional transects was, in decreasing order, mound $\geq$ depression $\geq$ bank > control (Table XXVII).

The average pH of solution extracted from the upper 10 cm of soil on 2 July was 7.1 in the depressions, 7.0 in the mounds, 6.9 in the banks, and 6.5 in the controls. In general, soil solution pH of plot 305 control was about neutral (6.8 to 7.1) while those of plot 303 and 306 controls were slightly acid (5.8 to 6.7). Soil solution pH of the depressions and mounds of plots 303 and 306 was slightly less acid than that of the controls, but that of plot 305 had higher pH values in the depressions and mound (7.4 to 8.1). The reasons for the high pH values of the latter are not evident at this time. It is possible that bases were added to wetter depressed areas of the track by surface water moving in from the surrounding area.

Measurements of the redox potential corrected to pH 6.0 confirmed that plot 306 was the driest plot and 305 the wettest plot. Redox values (Eh at pH 6.0) at plot 306 ranged from +82 to +132; at plot 303, from −146 to +100; and at plot 305, from −181 to +89. Thus the soil of plot 305 had the greatest reducing conditions while that of plot 306 had the least. On the average, the greatest reducing conditions were in the track depressions with little difference between the other three locations.

The respiration rate of soil taken from the center of the track was approximately twice the rate of uncompacted soil on control areas at site 3. For example, the respiration rates of the 0 to 2-cm surface soil of the control and of the track were 10.5 and 23.8 μ liter O_2/hr g dry soil wt, respectively, on 3 July. There were fewer bacteria and fungi in the track soil than in the control. However, this may simply reflect the fact that these microorganisms were more actively decomposing a smaller

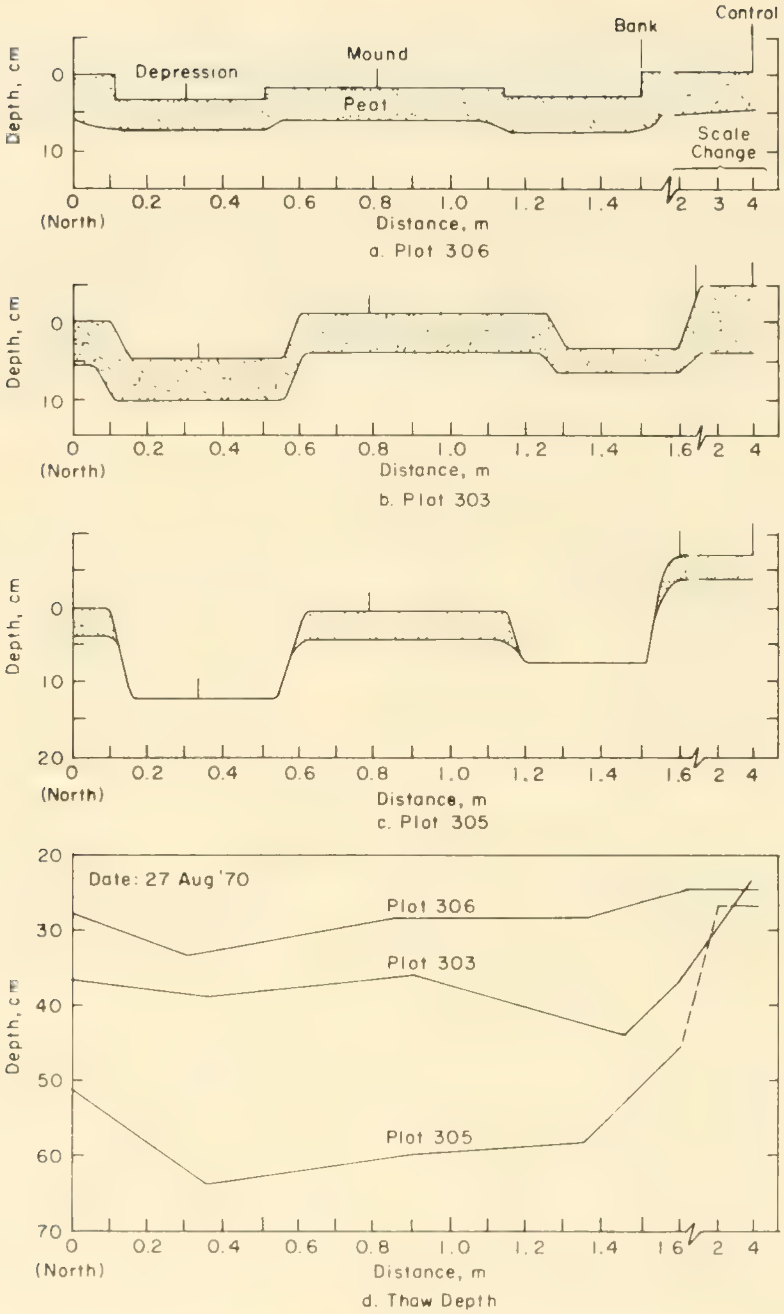

Figure 24. Cross sections and thaw profile under three sections of the weasel tracks.

quantity of the previous season's litter in a more favorable environment including neutral pH, higher temperature, more favorable moisture, maximum soil-substrate contact and/or higher concentrations of inorganic nutrients. Under such conditions less litter would accumulate on the soil surface at a slower rate. Oxygen saturation profiles of the track soil compared to those of the control plots indicate more anaerobic conditions in the track:

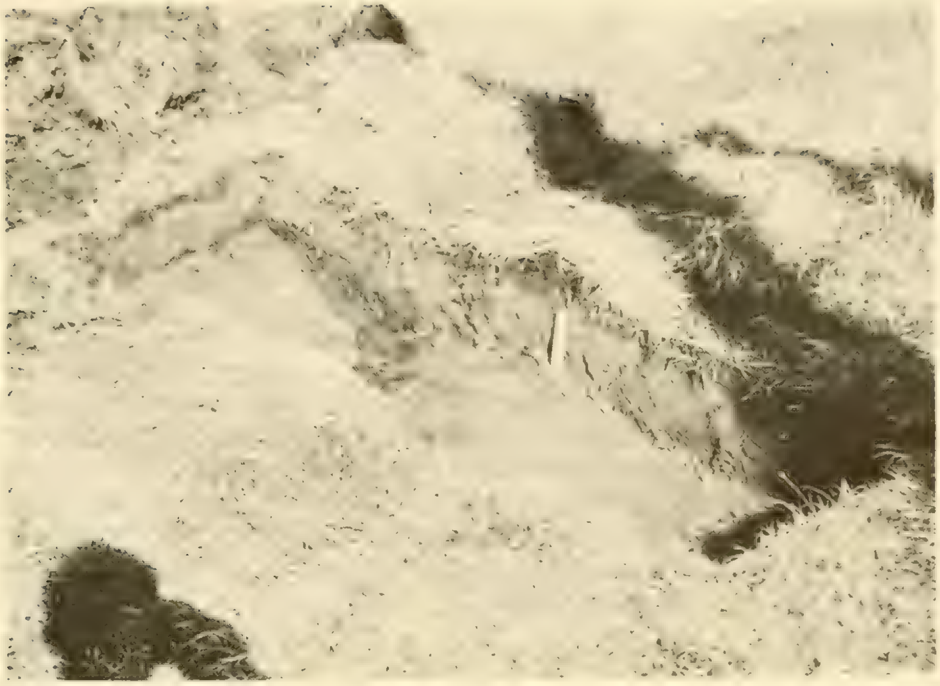

Figure 25. Soil trench across weasel track showing burned organic and undulation in frost table.

Table XXVII. Parameter means of three transects (plots 303, 305, 306).

Parameter	Date	Location: Depression	Mound	Bank	Control
Thaw depth, cm below surface	2 July	22.7	24.3	15.3	16.0
	29 July	35.0	39.0	33.7	24.3
	27 Aug	38.7	41.7	40.3	27.7
	Avg	32.1	35.0	29.8	22.7
Redox* (mV)	2 July	227	283	313**	272
	21 July	210	288	293**	332
	27 Aug	110	244	272**	271
	Avg	182	272	293	292
Moisture content* (gm/100 g wet soil)	2 July	45.1	49.8	51.9**	55.8
	29 July	41.8	57.8	48.6**	54.1
	27 Aug	45.1	57.1	50.5**	59.9
	Avg	44.0	54.9	50.3	56.6
Soil temperature*	2 July	2.7**	3.3	2.5††	1.6
	29 July	4.0	4.5	3.8**	3.7
	31 Aug	3.8**	3.4	2.4**	2.9**
	Avg	3.5	3.7	2.9	2.7
pH of soil solution†	2 July	7.1	7.0	6.9**	6.5
Live vegetation ($g/0.1\ m^2$)	2 July	4.0	10.0**	6.5**	5.0
	29 July	9.4	9.6	7.9**	8.1
	27 Aug	7.3	8.5	8.9	5.1
	Avg	6.9	9.4	7.8	6.1

* Average in upper 15 cm of soil.
† Average in upper 10 cm of soil.
** Plot 303 not sampled.
Plot 305 only.

O_2 saturation (%)		
Depth (cm)	*Control*	*Track*
5	40	16
10	38	6
15	26	0
20	6	
25	0	

This can be attributed to the combined effects of compaction, greater moisture content, and the increased O_2 demand of heterotrophic activity.

The production of plant material was measured by clipping as accumulated production over 2 July, 29 July, and 28 August sampling dates. In the track depression, production was greater than that of control on plot 306, less on plot 303, and about the same as that of control on plot 305. However, plant density was much less in the track than on the control locations, but the plants in the track appeared to be much larger. On the average, production was greatest on the mound and second greatest on the bank; and, in spite of lower plant densities, the track depressions had slightly greater primary production than the controls.

On 27 August 1970, four sod cores, each 15.2 cm in diameter, were removed for arthropod analysis from each of three stations along the weasel track but not in the plots. Station 1 corresponded to the depression of plot 305; the site was under standing water for the entire season and vegetation was sparse. Station 2, in an area of the track showing less subsidence, corresponded to the depression of plot 303. Station 3 was on the mound adjacent to station 2, and corresponded to the mound of plot 303.

Soil arthropod densities recorded at these stations are given in Table XXVIII.

Table XXVIII. Soil arthropod densities.

Sta.	*Pedicia hannai* *(N/m^2)*	*Tipula carinifrons* *(N/m^2)*	*Mites* *(N/m^2)*	*Collembola* *(N/m^2)*	*Nem. 1.* *(N/m^2)*
1	124	0	56	2,220	583
2	42	0	444	17,760	708
3	69	110	6,438	65,157	791
Site 2: Control (25 August)			5,545	29,179	408

These differences are striking and suggest that the flooded portion of the track was acting more like a small pond from the standpoint of the micro-arthropods. Station 2 resembled an ephemeral pond and was intermediate between an aquatic and terrestrial system.

Revegetation which occurs in the tracks is dependent on the types of species adjacent to the disturbed area. This is evidenced by an examination of the species which are found to inhabit these tracks and by a comparison with the adjacent available flora. Revegetation occurs primarily by vegetative reproduction as can be seen when the root systems are exposed. Rhizomes from the track can all be traced to "parent" plants alongside the track. Species which appear to be most successful in revegetating are *Dupontia fischeri* in wet areas (also *Arctophila fulva* if parent plants are available in the area), *Carex aquatilis* and, to a lesser extent, *Alopecurus alpinus* in somewhat drier situations. Occasionally, *Arctagrostis latifolia* invades the track although it as well as

Eriophorum angustifolium is most often found in abundance alongside the edge of the track. *Eriophorum angustifolium* is especially noticeable in this zone near the end of the season when the track is occasionally bordered by the white cotton-grass inflorescences. The frequent absence of mosses is conspicuous. Typically, growth is initiated somewhat sooner in the track than on adjacent tundra and occasionally a portion of the track is extremely lush as is indicated by the high production values and leaf area indices. Associated with these tall, lush areas, however, is the conspicuous absence of standing dead and litter.

Additional observations on the revegetation of tracks were made on two trails at site 8. One weasel trail examined was used intensively during the summer of 1962 and then closed to further traffic. On drier portions of this trail, which extends for 1.8 km, vegetation within the tracks had a similar appearance to that of the adjacent undisturbed areas. Regrowth had apparently been by vegetative means. The barer spots were revegetated only by cryptogams, mostly mosses less than 1 mm high. On the wetter portions of the trail, ponds had formed due to melting of the ground ice. These ponds were ½ m deep and more than 1 m across. There was no invasion by vascular plants along the edges or in the ponds but some mosses were present along the edges. On a second trail, which had been heavily used for 3 summers and abandoned in fall 1965, considerable thermal erosion had occurred. Again a thin moss-and-lichen cover had developed. Drier, bare spots were being invaded by vascular plants, through vegetative means. This revegetation extended ½ m into the track, an advance of 10 cm/yr. On other portions of the trail *Dupontia fischeri* had invaded at an estimated rate of between 14 and 20 cm/year average. One specimen, *Senecio congestus*, found in the track, invaded by seed.

In conclusion, track disturbance resulted in very definite alterations of the vegetation, soil and soil solution such that biological activity and primary production was stimulated. This does not mean that the disturbance was good, however, for if much of a slope gradient existed there likely would have been severe and detrimental soil erosion. The results do give an indication that controlled physical disturbance of the surface vegetation and peat layer might be used to stimulate more vigorous vegetative growth with beneficial results. However, these conclusions must be tempered until complete analysis of samples and data have been accomplished.

Barrow Aquatic Perturbations

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Bob Lewellen	University of Denver
Don Vietor	USA CRREL
Jerry Brown*	USA CRREL

Two types of aquatic perturbations were sampled in order to obtain base-line data on these man-induced features. The first was the channel above and below the eroding headwall of Footprint Creek. The second was a thermokarst pit formed as a result of sustained tracked vehicle activity.

Footprint Creek and its drainage offered an excellent opportunity to investigate a stream gradient perturbation. The most prominent feature of this gradient is the nearly vertical headwall that erodes actively upstream during periods of spring and summer runoff. Above the headwall the creek occupies a shallow swale and runs through emergent vegetation and occasional small ponds. A bulldozer trench intercepts the upper drainage area and introduces runoff from the artificially drained Footprint Lake basin. Above the headwall, free of suspended particles, the water is clear although noticeably colored by brown organic acids. Below the headwall, the stream bed is unstable and nearly devoid of vegetation, as large amounts of fine-grained sedimentary material are transported downstream from the headwall area. The water is highly turbid. The headwall with essentially no flow over it is illustrated in Figure 26.

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Figure 26. Headwall erosion on Footprint Creek after summer had ceased.

Table XXIX. Footprint Creek water chemistry, productivity and related factors.

Property	Concentration units	Station a	b	c	d	e	f
		Major dissolved cations					
Ca	mg/liter	25	23	20	18	18	20
Na	mg/liter	24	15	13	12	12	13
K	mg/liter	2.7	2.5	1.8	0.67	0.75	1.4
Mg	mg/liter	14	12	11	11	11	11
		Minor cations (total)					
Co	mg/liter	<0.001	<0.001	0.018	<0.001	<0.001	<0.001
Cu	mg/liter	0.018	0.026	0.038	0.006	0.006	0.006
Fe	mg/liter	12	25	50	4	3	5
Mn	mg/liter	0.4	1.0	2.0	0.03	0.07	0.02
Zn	mg/liter	0.035	0.055	0.124	0.006	0.016	0.005
		Phosphorus fractions*					
DRP	μg /liter	23	34	17	7	14	35
DUP	μg /liter	39	34	1	16	21	46
PRP	μg /liter	34	102	225	1	8	6
PUP	μg /liter	164	498	439	12	29	22
TP	μg /liter	255	558	582	36	72	109
		Dissolved nitrogen compounds					
NH_4^+	μgN/liter	14	110	200	14	14	28
NO_2^-	μgN/liter	3.4	1.7	0.6	0.7	0.0	1.3
NO_3^-	μgN/liter	0	0	1	0	0	1
Particulate solids	mg/liter	160	280	820	27	< 10	< 10
Turbidity	JTU	250	470	610	9	11	6
pH		8.6	8.4	8.3	7.0	6.8	7.5
Alkalinity	meq/liter	1.71	1.68	1.45	1.41	1.37	1.50
Primary productivity							
Light	μg C/liter-hr	10.74	4.89	0.20	0.59	0.00	0.2
Dark	μg C/liter-hr	0.48	0.46	0.59	0.35	0.29	0.28
Net	μg C/liter-hr	10.26	4.43	0.00	0.27	0.25	0.99
Chlorophyll a	μg/liter	0.7	< 0.8	< 0.2	< 0.2	< 0.4	1.7

* DRP, DUP, PRP, PUP, TP, respectively, represent dissolved reactive and unreactive, particulate reactive and unreactive and total forms of phosphorus.

The rate of erosion in this channel has been observed on the ground and photogrammetrically since the late 1940's. At that time the stream's base level was lowered as a result of dredging the lagoon into which the stream flows. This, plus several other man-made alterations in the drainage basin, has resulted in accelerated erosion of the channel as the stream seeks a new base level. Headward erosion of the headwall in the period 1964 to 1970 amounted to 125 m (Fig. 3).

As a result of practically no summer runoff, the rapid erosion of the Footprint Creek headwall was restricted to the period of spring runoff. During 1970, erosion was approximately 10 m of headwall movement. Of this amount, 3 to 4 m occurred after spring runoff as slumping of the undercut headwall. The entire period of spring breakup, runoff, and erosion at this headwall was obtained on color, time-lapse movie and is available from USA CRREL. This movie shows interesting seasonal and diurnal features of the early summer runoff and erosion.

On 12 July 1970, at the end of the spring runoff period six stations were sampled along Footprint Creek, three above and three below the headwall (Fig. 3). Particulate solids, turbidity (in Jackson Turbidity Units), pH, alkalinity, other chemical data along with ^{14}C primary productivity and chlorophyll contents were determined and are presented in Table XXIX.

Substantial quantities of dissolved and particulate substances are introduced into the water at the headwall. In large part, these substances leave the water a relatively short distance downstream from the principal site of disturbance. Planktonic and benthic primary productivities are severely depressed at the headwall but rise to unusually high values further downstream.

The thermokarst pond G lies in an area of upland tundra with well-developed high-center polygonized ground lying about 500 m west of the IBP pond site 7. A tracked vehicle trail which was used extensively in the early 1960's follows the troughs of the polygons up onto the higher ground. At the transition from low to high ground, ice-wedge melting was induced by the track disturbance and pond G was formed. The margins of this pond are unstable, and continuing erosion results in a distinct turbidity in the water.

While it was not possible to initiate a comprehensive study of pond G, it was sampled twice during the 1970 field season on 11 July and 28 August. On the first sampling date, the water was thermally stratified, probably due to clear sky conditions and low wind velocity in combination with high water color and turbidity, factors which tend to restrict heating to the uppermost layers. From the available data, it appears that the phosphorus nutrients are quite abundant and that plankton primary productivity is depressed in comparison with undisturbed tundra ponds.

Barrow Spills

Terrestrial

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Aquatic

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Richard Prentki	University of Alaska
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Simpson Seeps

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Jerry Brown	USA CRREL
Paul Murrmann*	USA CRREL
Richard Haugen	USA CRREL
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Pat Coyne	USA CRREL
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Bob Benoit*	Virginia Polytechnic Institute
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The influence of crude oil on the arctic ecosystems was investigated both at Barrow in the IBP study area and at Cape Simpson on the naturally occurring oil seeps. The Barrow studies consisted of two experiments on terrestrial spills and one on aquatic spills. All spills utilized Prudhoe Bay crude oil (Sag. River Well Number 1) which was flown in from Prudhoe Bay by ARCO in early June in sealed 55-gallon drums. Both the terrestrial oil spill and seep investigations were originally initiated by USA CRREL scientists. But it was obvious very early in the field season that greater involvement by a variety of biological disciplines would be highly desirable. The oil ecology investigations quickly became a focal point for almost all IBP subprojects. The results presented in the following sections represent the collective efforts of a number of senior investigators. It should be emphasized early in the report that the 1970 observations were at pilot project or reconnaissance levels. Much more research of a sustained and comprehensive nature is required before definitive recommendations or interpretations can be offered.

Barrow oil spills

Terrestrial. A series of oil spills were created at Barrow, Alaska, to fulfill several objectives:

1. To investigate the effects of oil spills on tundra plant/soil systems, and to become familiar with the quantitative aspects of oil pollution on tundra terrain.

2. To determine if fertilization of an oil spill on the tundra will increase the rate of recovery of the plant/soil system.

Treatment sites were chosen in two areas of different moisture levels. Site 1 was relatively dry, having a sandy gravel subsoil and a shallow surface organic layer less than 4 cm thick. The thaw at the time of treatment (22 June 1970) ranged between 3 and 6 cm. Site 3 had standing water at the surface and was on a silty soil. The thaw at site 3 at the time of treatment was 12 cm and the organic layer was more than 4 cm thick. Similar plots in each site were selected

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and surrounded by 20-cm-high corrugated aluminum lawn edging which was sunk to the frost. The joints were sealed with rubber cement to prevent oil penetration into the adjacent tundra.

Fresh crude oil contained in sealed 55-gallon drums was shaken before dispensing. The oil was applied with a 10-liter, hand-pressurized garden sprayer with the nozzle removed. The tip of the sprayer was placed below the foliage and directed at about a 45° angle to the soil surface with applications being made on an approximately 5 × 5 cm grid throughout the plot. Very little oil was spilled on the foliage, thus simulating an oil spill flowing along the soil surface. This application technique seemed to give good distribution of oil throughout the plot.

The following amounts of oil were applied to each site:

	Plot*	Rate (liters/m²)
Site 1	113a	5.0
	113b	5.0
	114a	5.0
	114b	5.0
Site 3	311	12.0
	312	1.4
	313	5.0
	314	0.7

The rates of oil application were essentially determined in the field since no prior information existed as to the quantities of oil that could be handled and spread uniformly on tundra. The rate of 0.7 liter/m² was the least amount of oil that could be spread and still give adequate surface coverage. The amount of oil that could be contained safely set the maximum rate at 12 liters/m². Since the oil was spread on a water-saturated soil, most of the oil floated and the highest rate left a depth of standing oil of 2 to 3 cm. The 5 liters/m² rate was selected because it corresponded to the upper limit that can be tolerated by plants on inorganic soils as reported for the temperate regions. Figure 27 is a close-up of one of the site 3 oil plots.

The presence of hydrocarbons in the soil was analyzed by a fluorometric comparator technique developed by USA CRREL. Although the technique was still unrefined, the results obtained seemed to give reliable indications of the presence of hydrocarbons derived from petroleum. The technique involved extracting a 1-g sample of the soil with hexane, mixing, and then saturating a filter paper disk of 5.5 mm diameter with the extract. The filter paper was placed under an ultraviolet light in a black box and the intensity of the fluorescence compared with a series of disks prepared to provide a standard curve from 0.01 to 80 mg crude oil/ml (18 to 19,000 ppm). The same oil applied to the plots was used in preparing the standard curve.

The microbial activity of the soils containing the oil spills was also investigated. Reports from temperate climates indicate that the consumption of oxygen increases markedly as the oil is metabolized by microorganisms. Therefore, this may be an indication of both the effect of oil spills on soil systems and the rate of oxidation of the oil. The activity of the soil microorganisms was analyzed by manometric methods. Cores (1.9 cm) were removed from the plots, sampled at the appropriate intervals, broken into small clods, weighed, and placed in respirometer flasks containing KOH in the center well. After equilibrium on the respirometer, hourly readings of

* Plots 113a and 113b were fertilized with 20-10-10 at a rate of 400 lb acre. Plots 113b and 114b were reserved for next year's sampling.

Figure 27. Close-up of one of the site 3 oil plots.

microliters of oxygen absorbed were taken for a period of 3 hours. The values were corrected for standard conditions and expressed on a per gram dry soil per hour basis.

By the end of the growing season, after the oil had been on the plot for 60 days, several areas of damage could be discerned. Plants or leaves that had been physically covered by the oil were dead. This was especially noticeable with the low-growing mosses and liverworts in the 5 liter/m^2 and greater applications. In addition, the plants in the most heavily treated plot, 12 liters/m^2 showed more yellowing than adjacent plots, although the intensive sampling in this plot made comparisons difficult.

Plant production data are available from the most intensive rate of oil application. Samples were taken on 9 Aug 1970:

Treatment (12 liters/m^2)	Dry wt (g/m^2)	Chlorophyll (mg/m^2)	Chlorophyll (mg/g dry wt)
Plot 211	100, 97.9	353, 323	353, 329
Control	112, 129	409, 494	366, 383

These data indicate that the presence of crude oil produced a reduction in biomass and chlorophyll production. However, much more sampling will be required before these observations are finalized.

The soil temperatures from plot 113 and the adjacent untreated area were measured but not reported here. No appreciable differences were observed between treated and non-treated. The method of application of the crude oil achieved one of its objectives – enough of the oil was kept off the vegetation and the soil surfaces so that no increase in temperature was recorded because of greater absorption of solar energy. Therefore, any damage observed should be caused by the oil itself and not as the indirect result of increased temperatures.

In order to determine the depth of penetration of the oil, soil cores were taken, sampled, and analyzed for the presence of hydrocarbons. Several conclusions can be drawn from these preliminary data:

1. The oil penetrated in some cases to the permafrost on the drier soils of site 1, but did not penetrate much below the organic layer on the wetter site 3, even with the heavy application. Possibly the standing water at the time of application prevented the downward movement of the oil. Even though the surface water had drained by July, the oil no longer penetrated the soil.

2. The organic matter, although quite wet at the time of application, was capable of absorbing large quantities of oil. This was particularly noticeable on the wet site with its thicker organic layer. When a buried soil organic layer was encountered, it absorbed much more oil than the adjacent soil.

3. There appear to be no natural constituents of the soil or of the living or dead biota that interfere with the soil-hydrocarbon test. This makes the extremely simple test widely applicable.

The failure to detect downward movement of the oil in the wet site after the standing water had drained indicates that most of the volatile fraction of the oil had evaporated before recession of the water, thus increasing the viscosity of the oil and making it relatively immobile in the surface organic matter at the prevailing temperatures. This seems reasonable, since it is known that from 30 to 50% of an oil spill will evaporate in 50 hours under temperate region conditions. Although the temperatures were lower at Barrow than they would be in temperate regions, the oil had a longer period to evaporate (the surface waters took at least a week to drain). More important is the fact that many important phytotoxic components of the crude oil are lost with the volatile fraction.

Data from temperate regions indicate that damage to plants can be expected at soil hydrocarbon levels above 20 mg/g dry soil. Lethal levels of oil occur around 40 mg oil/g dry soil. Observed levels of hydrocarbons in the present study were at least double these values. Such levels would probably result in severe injury and death in temperate climates, but the full effects in the arctic climate and soil conditions are not known at this time.

Comparison of soil respiration between control and oil-treated areas generally showed that the most active soil layers were at the surface and at the bottom of the core. The layer just below the top 3 cm of soil was usually the least active. The soils from site 3 had a respiration rate more than five times that at site 1. The difference was maintained throughout the soil profile.

Based on limited data, the heaviest oil treatment (12 liters/m^2) produced, on the average, a two-fold increase in respiration over the untreated control. In no instance was oil observed to inhibit soil respiration. Although penetration of oil into the profile on the wet site was not detectable by the fluorescent comparator technique, respiration was stimulated throughout the profile. This suggests some component of crude oil was in fact percolating below the surface even though petroleum components are extremely insoluble in water.

Data from the fertilizer treatments were very limited. At this time, no conclusions can be made. Based on the literature and pilot studies, an increase in respiration rate would be expected when fertilizer is applied to an oil spill. Added mineral nutrients probably allow a more rapid microbial population response and hence an increase in measurable oxygen consumption.

Several observations on the effects of adding oil to soil samples within the respirometer flasks were made. An equilibrium respiration rate was established followed by addition of oil. Control samples showed no significant change in oxygen consumption while respiration in oil-treated soils was stimulated by oil. The proposed explanation for differences in behavior between control and oil-treated areas is that the latter had developed a relatively high microbial population which could decompose oil.

Preliminary evidence from site 1 suggested that the quantity and quality of microbial biomass was affected by oil treatment. A two- to three-fold increase in bacteria numbers was indicated. On the other hand, organisms such as fungi and algae appeared to be inhibited by oil.

Aquatic. Study Pond E occupies the eastern half of a subrectangular depressed-center polygon about 45 m square. In mid-July the pond was 36 m long (north-south) and 19 m wide (east-west), with a maximum depth of 0.3 m and a mean depth of 0.2 m. The pond's western boundary, which lies at the center of the polygon, is poorly defined and grades through the emergent vegetation into wet tundra meadow. The dominant emergent and surrounding terrestrial vegetation is *Carex aquatilis.*

On 16 July 1970, 200 gallons (760 liters) of Prudhoe Bay crude was applied to this small tundra pond at a density of 1.3 liters/m^2 or a thickness of 1.3 mm. Several hours after application, the oil was distributed uniformly across the pond. By the following day, driven by the wind, it had accumulated in a 3- to 5-m-wide band against the emergent vegetation on the west margin of the pond. Figure 28 illustrates the accumulation of oil on the margins of the emergent vegetation. A portion of the oil remained in the emergent vegetation on the west side of the pond, but approximately half the oil continued to migrate in response to changes in wind direction through August and early September. The viscosity of the oil increased with time, and it began to adhere to the stems of emergent vegetation in mid-August. Oil penetration into the organic sediments and wet

Figure 28. Oil treated pond showing accumulation of oil amongst emergent vegetation as a result of wind action.

Figure 29. Edge of oil treated pond showing damage to terrestrial vegetation where oil spill was introduced.

litter was negligible, although small spills on terrestrial peat near the pond were absorbed readily. However, the above-ground vegetation was killed as illustrated by the dark area in the lower right hand corner of Figure 29.

For the month previous to the oil spill routine observations were made of the pond's physical regime including air, water, and sediment temperatures and depth of thaw and water level; for water chemistry including nitrogen and phosphorus nutrients, pH, and alkalinity; and for biological determinations including primary productivity, chlorophyll, and seston weights. Monitoring of these parameters was continued into September.

High temperatures and dissolved oxygen depletion occurred in shallow water beneath the oil; however, determination of the degree to which oil is responsible for this awaits the analysis of data which have been collected in shallow water in control ponds. Fauna in Pond E were affected to some degree by the oil application. A massive and complete mortality of tadpole shrimp (*Lepidurus* sp.) occurred with the addition of the oil, and fairy shrimp (*Branchinecta* sp.) no longer could be found ten days after the spill, although they remained abundant in the adjacent control ponds. Conclusions concerning the impact of the oil on plankton productivity and nutrient cycling await completion of the analytical work.

Cape Simpson oil seeps

Terrestrial. After a reconnaissance flight over several of the natural oil seeps in the vicinity of Simpson, it was decided that several seeps near Cape Simpson were the most promising for biological studies. A short reconnaissance visit was made to seep A (Fig. 30) in early June by Brown, Benoit and McCown. During the period 18-20 July, a more detailed series of observations and samples were conducted with McCown, Murrmann, Hunt and Barsdate. Shortly thereafter McGaw and Haugen installed a temperature recording system.

Figure 30. Location map for the Cape Simpson seeps.

The objectives of the studies are:

1. To become familiar with the long-term reaction of tundra plant and soil systems to the presence of crude oil and crude oil breakdown products.

2. To gain information on which arctic plant and microorganism species may be able to adapt to the presence of a hydrocarbon-saturated rhizosphere.

Seep A was chosen for the terrestrial seep studies for several reasons:

1. There was a minimum of disturbance by man which occurred elsewhere in the area during the period of the PET 4 activities.

2. There appeared to be a difference between the vegetation immediately adjacent to the seep and that several meters away.

3. There were two distinct plant communities intersected by the seep.

This seep consisted primarily of asphaltic material flowing down a slope which ended at the shore of a small lake. New seepages of fresh oil were most obvious in the center of the asphaltic area, but fresh oil could also occasionally be seen in the peripheral ground. Large areas to the sides of this flow showed sparse vegetation covering a well-oxidized asphaltic soil. This indicated that major active seeps and flows were once in a position different from the present flow. The fresh oil and tar flowed along frost cracks in the ground at the periphery of the seep and thus formed finger-like projections into the tundra. This was especially noticeable at the lower part of the slope where fresh flows could be seen advancing over the vegetation. Figure 31 is an overall view of the Simpson seep. Figure 32 is a close-up of an active flow.

The area seemed to be a good example of the successive stages in the natural oxidation and degradation of oil. The freshly exuded oil was quite fluid but eventually formed a tar, probably because of the evaporation of volatiles. After weathering, an asphalt was formed which was quite resistant to further changes. However, when oil, tar, or asphalt came into contact with free water, either at the edge of the lake or in pools of water collected on the seep, degradation into a gummy light-brown material and finally into a loose brownish humus-type material occurred. The degradation in water was probably due to microbiological attack. Literature from temperate climate studies also indicates that the microbial oxidation of hydrocarbons occurs faster under high water content conditions.

Plants were found growing in close association with the asphalt and oil, both at the periphery and when entrapped by the flows. The plants surrounded by the seeps had their root systems embedded in the tar. In places, plant shoots could be seen advancing into the asphalt. In those areas where the flows contacted water, the plant growth was lush and more advanced phenologically than in the surrounding tundra. Only when the foliage became covered with an oil deposit was injury visually noticeable.

Two communities of vegetation were evident in the area of the seep. On the lower, wetter portion of the slope, a community with *Carex aquatilis* as the dominant species was present. A sharp change occurred farther up the slope with the beginning of a community dominant in *Arctagrostis latifolia*. Along the east side of the seep, the *Carex* community lined the periphery; in no other place was this community seen at this elevation on the slope.

Three transects were established running 4 meters in length from the east side of the seep, into the surrounding tundra. The transects were placed so that they intersected changes in vegetation, which generally meant that 2 meters of the transect were in the *Carex* community and 2 meters were in the *Arctagrostis* community.

1. Transect 1 was located near the top of the slope. Much of the top of the slope showed asphalt outcroppings. This was the driest of the transects. The transect did not intersect the major seep, but began about four meters away from its edge.

2. Transect 2 was located further down the slope and extended from the edge of the seep.

Figure 31. Ground view of a Simpson oil seep.

Figure 32. Close up of active oil flow inundating the vegetation.

Figure 33. Close-up of the transect with the oil seep in the background.

3. Transect 3 was at the lower part of the slope where only the *Carex* community was present. The transect began at the edge of the seep. This was the wettest of the transects. Figure 33 shows the areas adjacent to the transects and the seep.

Each transect was sampled to determine plant composition and to gain information as to what might be causing the change in vegetation types. The species present in the transect were identified and their numbers counted. To facilitate comparison, the transect was divided into four sections 1 meter in length and 30 cm in width. The soil was probed for thaw penetration every 25 cm along each transect. Five-centimeter-diameter cores of soil were taken at each meter along the transect. These cores were then analyzed for the presence of hydrocarbons by the fluorometric comparator method. In order to eliminate contamination from coring, samples were taken from the center of each core after it had been split with a razor blade.

A ten-point thermistor temperature recorder was placed on transect 1. The probes were installed at meter 0 and meter 4 along the transect, with three probes in frozen ground, two in thawed ground, two in the vegetation, and two on stakes 1 meter above the soil surface. Another probe was also located in the seep.

The following species were found along the three transects: *Carex aquatilis, Arctagrostis latifolia* var. *latifolia, Salix rotundifolia, Poa arctica, Senecio atropurpureus* subsp. *frigidus, Ranunculus sulphureus, Hierochloe pauciflora, Petasites frigidus, Salix pulchra, Stellaria longpipes,* and *Alepecurus alpinus* subsp. *alpinus*. *Carex* community which was predominant all along the lower portion of the slope as well as the seep (transect 3) was also dominant along the edge of the seep in transects 1 and 2.

The abruptness in the shift of communities was noted by the marked differences in the numbers of plants of *Carex aquatilis* and *Arctagrostis latifolia*, especially between the second and third section of transects 1 and 2. Large differences were also observed with several of the less-numerous members, specifically *Senecio atropurpureus*.

A plant very prominent in the seep, but not encountered in the transects, was *Eriophorum scheuchzeri*. This plant was found in patches completely surrounded by soil, tar, or asphalt, and was especially prominent where the seep tended to entrap water. Large bloom and seed heads were plentiful and the plants were actively spreading by below surface shoots.

Thaw depths measured on the three transects were greatest near the oil seep and changed abruptly to shallow values between the second and third meters on all transects. The deep thaw values varied between 55 and more than 85 cm, whereas the shallow values were on the order of 20-25 cm. The change in thaw was coincident with the change in vegetation types.

Samples of *Carex aquatilis* from the edge of the seep were compared with plants from the undisturbed tundra in the vicinity. The plants from the seep were taller, had thicker stems, and were more advanced in flowering and fruiting. Whether this was just the effect of higher ground temperatures around the seep or whether other factors were involved such as the availability of nutrients or the presence of stimulatory chemicals remains to be determined.

Comparison of soil and seep temperatures at the 10 cm depth revealed that the seeps are warmer by some 3 to 5°C during the day and 1 to 2°C at night.

The hydrocarbon content in the upper 8 cm of soil was generally insignificant (<0.5 mg oil/g soil) except for one instance in transect 2 (25-40 mg/g). Even when considering the moisture content of the soil and converting the readings to a dry weight basis, the levels are probably too low to cause an inhibition of growth. In fact, levels such as these have been shown to have a stimulatory effect in temperate soils. At these low levels of hydrocarbon content, the presence of oil in the soil probably did not act as an important factor in plant species distribution.

The interrelationships between the vegetation, temperature effects, and the presence of the various stages of oil seep development are obviously complex. It is probable that a succession in plant type occurs on the seepage areas as the physical characteristics of the asphalt soil change due to oxidation and breakdown of the oil. The stages of succession may progress from the pioneer lichens and mosses to plants such as the *Carex* community and *Eriophorum*, and finally to the *Arctagrostis* community when the soil becomes colder and the thaw shallower as a result of plant cover and seepage inactivity.

Comparison of water associated with the asphalt deposits at Cape Simpson with that from a typical tundra pond showed some interesting differences in microorganism composition. The former was approximately three orders of magnitude richer in bacteria, fungi, and algae. This would appear to be good circumstantial evidence that microorganisms in situations like Cape Simpson for fairly long periods of time are tolerant of oil and are capable of decomposing it.

Twelve species of bacteria and yeast from Cape Simpson were cultured on a crude oil-mineral salts medium. These organisms were capable of using hydrocarbons from crude oil as their sole energy and carbon source. The exact components of crude oil used by the bacteria and yeast were not determined.

Aquatic. Four natural oil seeps in the Cape Simpson area were visited with site investigations concentrating on small ponds associated with two seeps (seeps B and D). Samples were taken for pH, alkalinity, and nutrient chemistry, and temperature and conductivity measurements were made. The biological work consisted of ^{14}C primary productivity and plankton pigment determinations and qualitative estimates of faunal abundance and diversity. In addition, preserved samples of planktonic and benthic organisms were obtained.

At seep B, three ponds were studied. Pond B-1 is a rather long pond extending along the east margin of the major asphalt flow. Much of the water is in contact with unaltered fresh asphalt or water-asphalt emulsions, and very little floating oil is present in this pond. Pond B-2 is located about 100 m east of B-1 in an area free of any recent oil seeps, although old, completely revegetated flows are adjacent. B-3 is a small pond on the west margin of the major asphalt flow, and there is an active although small spill of fresh asphalt into this pond.

Table XXX. Limnology of the Cape Simpson oil seep ponds.

	B-1	*B-2*	*B-3*	*D-1*	*D-2*
Temperature, air (°C)	3.0	3.0	3.0	10.0	10.0
Temperature, water (°C)	9.0	8.5	8.5	12.2	13.6
pH	5.79	6.36	5.55	5.85	6.55
Alkalinity (meq/1)	0.05	0.14	0.04	0.17	0.60
^{14}C primary productivity (μg C/1-hr)					
Light	2.84	0.139	2.99	2.59	0.395
Dark	0.03	0.014	0.126	0.22	0.071
Net	2.81	0.125	2.86	2.37	0.324
Chlorophyll a (μg/1)	<0.8	<0.4	<1.0	<0.8	<1.0
Dissolved reactive phosphorus (μg/1)	1.7			1.4	30
Dissolved unreactive phosphorus (μg/1)	8.3			8.9	50
Total particulate phosphorus (μg/1)	19	12	22	10	43
Maximum depth (m)	0.4	0.3	0.5	0.15	0.12
Length (m)	130	15	15	8	5
Width (m)	10	6	10	3	4
Oil stress	Light	None	Medium	Light	Heavy

At seep D two ponds were observed. D-1 apparently is a thermokarst pit lying in old, partially revegetated water-asphalt emulsion. A few chunks of emulsion containing gas bubbles were floating on the surface of the pond. D-2 is a shallow, perhaps ephemeral, pond actively receiving a small asphalt flow. This pond has a continuous oil slick and blobs of floating oil around the margins. D-2 was surrounded by a ring of dead or oil-damaged *Carex aquatilis*, presumably related to a higher pond water level earlier in the season. The somewhat incomplete analytical data for these ponds are listed in Table XXX, together with the pond dimensions and a subjective estimate of the degree of potential oil stress, which is based primarily on the abundance of light fraction hydrocarbons in contact with the pond water.

In addition to these ponds a large number of other ponds and pools on the asphalt flows were measured for conductivity. The results indicate that in all cases the total ionic concentration is moderate to low, no brines being present in association with the oil seeps. The pH and alkalinity also range to quite low values. With the exception of B-2 all of these ponds appear to some degree impacted by the oil seeps. Faunal diversity decreased noticeably with increasing potential oil stress, although zooplankton and aquatic insect abundances were reasonably high in all except the most highly impacted pond (D-2). The ^{14}C plankton primary productivities ranged well above those of undisturbed tundra ponds, although this would not be predicted from the chlorophyll a concentrations, which were quite low.

Future studies

Although the studies this year were only exploratory in scope, some general comments about the impact of oil pollution on the arctic terrestrial systems can be made. The presence of toxic levels of oil in the Barrow soils did not produce immediate severe damage to the vegetation. However, the shortness of the growing season and the cool temperatures may delay the effects of oil pollution, and thus necessitate studies extending over several growing seasons.

From the work on both the oil seeps and the oil spills, the phytoxicity of oil appears to be high when it contacts foliage. Experiments are being planned for the summer of 1971 to further study this process.

The differences observed in the distribution of hydrocarbons between the wet and dry sites indicates that the soil moisture level at the time of oil application may be an important factor. High moisture levels apparently not only inhibit penetration of this oil into the soil but also allow for considerable evaporation of the volatiles before they can come in contact with the root system. A laboratory study is planned for the next growing season to further evaluate this factor.

Prudhoe Bay Ecosystem

Climate

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Primary Production

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Ken Olson	Augustana College
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Consumers

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Liaison and Coordination

Jerry Brown	USA CRREL
George West	University of Alaska

For purposes of this report the Prudhoe Bay region is defined as the land area between the Sagavanirktok and Kuparuk Rivers (Fig. 34). As such, it constitutes a representative portion of the eastern arctic coastal plain. The region is more diversified geomorphically and biologically than the Barrow region. Major landforms include stabilized and active sand dunes, numerous shallow and occasional deep lakes, polygonized and nonpolygonized drained lake basins and interfluves, small entrenched and meandering streams, broad floodplains and terraces of the larger rivers, and numerous small pingos. The variety of landscapes offers many more biological habitats than occur at Barrow. In addition, the summer climate is somewhat warmer than that at Barrow.

The region under examination contains the Prudhoe Bay oil field which is currently under development. This development involves the construction of permanent camps, an industry-operated airfield, road networks and pipeline systems to connect the wells and gathering plants located on large gravel pads, storage and docking facilities, and a variety of related processing and support facilities. Figure 35 is a view of a gravel pad and road in characteristic terrain. The Environmental Subcommittee of the Prudhoe Bay Unit is responsible for developing and implementing programs concerning the ecology of the region. During the summer of 1970, the Tundra Biome Program worked directly through the Environmental Subcommittee and two of its member companies: British Petroleum and Atlantic Richfield - Humble. These cooperative activities prompted the subcommittee to sponsor a general ecosystem modeling effort for the arctic coastal tundra under the supervision of the Tundra Biome Program. Various state and federal agencies are also conducting regulatory and research activities within the Prudhoe Bay region.

The Tundra Biome Program's objectives in the Prudhoe Bay ecosystem were twofold:

1. To obtain initial biological and environmental information so that early comparisons could be made with other arctic coastal plain sites. (The following report emphasizes this aspect.)

2. To identify short- and long-term bioenvironmental research problems through on-the-ground acquaintance with the natural and man-modified ecosystems.

These involved numerous visits by Barrow- and University of Alaska-based scientists for varying amounts of time. The excellent road network and the availability of industry ground vehicles made it possible to cover the entire area repeatedly in a matter of hours. The following section

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*Principal authors.

Figure 34. Location map for Prudhoe Bay region, showing road network and sample sites A through E.

contains observations by the scientists who visited the region. In addition, the Tundra Biome Program Review Committee visited the region. Its comments on the Prudhoe Bay operations and potential for future research are contained in the report which was distributed in September 1970.

Climate

Recent climatic data from Prudhoe Bay are now available in conjunction with Federal Aviation Agency observations. The nearest permanent long-term climatological station is at Barter Island. For this report, a simple comparison of Prudhoe Bay and Barrow air temperatures for the 1970 growing season will suffice (Table XXXI).

Temperatures at Barrow and Prudhoe rose above freezing on 27 May. The May temperatures at both locations were quite similar. By June the trend for warmer than Barrow temperatures at Prudhoe was obvious: the maximum air temperature at Prudhoe for that month was 18.3°C and that at Barrow was 12.8°C. July was the warmest month at both locations, with Prudhoe temperatures 2°C or more warmer than those at Barrow. Maximum summer temperatures were 21.1°C at Prudhoe and 17.8°C at Barrow. August was decidedly warmer at Prudhoe than at Barrow. This, plus the fact that Barrow

Figure 35. Aerial oblique view of characteristic Prudhoe Bay terrain showing a gravel pad and road. Drier polygonal terrain is seen in foreground and wetter areas in background.

Table XXXI. Comparison of Barrow and Prudhoe Bay air temperatures (°C).

Barrow data: U.S. Weather Bureau; mean values based on daily minimum-maximum readings.

1970		*Mean*	*Mean minimum*	*Mean maximum*	*Freezing threshold**	*Days min. ≤ freezing*
May	Barrow	–7.2	–9.4	–5.0	1	31
	Prudhoe	–6.7	–9.4	–3.8	4	31
June	Barrow	+0.4	–2.1	+3.0	5	23
	Prudhoe	+2.3	–0.4	+5.1	6	19
July	Barrow	+3.2	+0.2	+6.2	1	20
	Prudhoe	+5.3	+2.1	+8.4	0	9
Aug	Barrow	+1.7	–0.2	+3.5	1	19
	Prudhoe	+5.0	+2.3	+7.7	0	1
Sept	Barrow	NA†	NA	NA	NA	NA
	Prudhoe	–2.4	–4.8	+0.1	6	24

*Number of days temperature goes above 0°C and below –2.2°C.

†NA - Data not available.

had 39 days with minimum temperatures at or below freezing during July and August versus 10 days at Prudhoe, indicates the potential difference in growing seasons between the two locations.

Primary production and vegetation

On 29 July a ground tour of the Prudhoe Bay area was conducted and plant species were collected and identified at numerous stops. These species are listed in Appendix B. This should not be considered a complete list of the plants of the Prudhoe Bay area, since many species were undoubtedly not found, and in some groups, notably the genera *Carex*, *Salix*, and *Draba*, field identifications could not be made. The flora of Prudhoe Bay appears to be more diverse than that of the Barrow area. This is probably the result of greater habitat variability at Prudhoe since individual community diversity does not appear dramatically larger. The sand dunes adjacent to the Sagavanirktok River are one example of the greater habitat variability. They support many species not found on the adjacent tundra at Prudhoe Bay or at Barrow. In addition, the Prudhoe tundra supports many species not found at Barrow, while most of the common Barrow species were also found at Prudhoe.

Four representative sites were selected for careful analysis of the vegetation. The first three sites were located at three points along a continuous moisture gradient and represent a large proportion of the tundra at Prudhoe (Fig. 34, Location B). The fourth site represents a large expanse of a relatively homogeneous community consisting, however, of a diverse species composition (Fig. 34, Location A). These are listed below:

Location B: Site 1 – Near the top of a well-drained slope, in an area dominated by tussock (*Eriophorum vaginatum* var. *spissum* and *Eriophorum angustifolium*) tundra.

Location B: Site 2 – Near the bottom of the same slope, ground broken by small hummocks.

Location B: Site 3 – A low-centered polygon basis adjacent to a large lake and immediately below site 2. Dominated by *Carex aquatilis*.

Location A: Site 4 – A flat, drained lake basin.

At each of these sites an inclined point frame, identical to frames described for the Barrow sites, was used to determine the composition and canopy structure of the vegetation. The results are given in Table XXXII. As discussed earlier in the Barrow section of the report, the leaf area index may be considered as the ratio of area of leaf surface to the area of ground surface. Thus, a leaf area index of 0.8 means that 80% of the land area is covered by leaves. The leaf area index for live leaves for the comparable period at the intensive site at Barrow is greater than that for Prudhoe.

The vegetation at Prudhoe is taller than that at Barrow, but is less dense, especially in the lowest 5 cm of the canopy. Thus, the vegetation at Prudhoe consists of fewer, more robust shoots, while that of Barrow consists of more numerous, smaller shoots. This is not due to a difference in species composition at both sites *Eriophorum angustifolium*, *Carex aquatilis*, and *Dupontia fischeri* are the three most abundant species (Table XXXIII). These make up 83% of the point-frame contacts at Barrow. The major difference in composition is the greater abundance of *Dupontia fischeri* at Barrow. At both locations, grasses and other species with a grass-like growth form (sedges, rushes) predominate in the vegetation.

The rooted vegetation was clipped at the base of the moss layer from an area 0.1 m^2, immediately under the location selected for point-frame analysis. The clipped vegetation was returned to the laboratory where the green material (produced in the present growing season) was separated from the standing dead material (produced in prior growing seasons). The material in each of these categories was dried and weighed. In addition, subsamples of the green material were analyzed spectrophotometrically for chlorophyll content.

Table XXXII. Comparative leaf area indices at Barrow and Prudhoe Bay.

Live Leaves

HEIGHT IN CANOPY, CM	PRUDHOE BAY (JULY 30) 1	2	3	4	MEAN	BARROW (JULY 25) MEAN
-X TO -0.1*	0.000	0.226	0.000	0.000	0.056	0.019
0 TO 4.9	0.508	0.167	0.000	0.226	0.226	0.725
5 TO 9.9	0.141	0.141	0.254	0.395	0.223	0.410
10 TO 14.9	0.113	0.167	0.338	0.282	0.226	0.042
15 TO 19.9	0.000	0.028	0.167	0.000	0.049	0.005
20 TO 24.9	0.000	0.000	0.056	0.000	0.014	0.000
SUM	0.762	0.733	0.818	0.903	0.804	1.201

Standing Dead

HEIGHT IN CANOPY, CM	PRUDHOE BAY (JULY 30) 1	2	3	4	MEAN	BARROW (JULY 25) MEAN
-X TO -0.1*	0.000	0.056	0.028	0.056	0.035	0.035
0 TO 4.9	0.931	0.508	0.338	0.367	0.536	0.961
5 TO 9.9	0.395	0.085	0.113	0.508	0.275	0.219
10 TO 14.9	0.028	0.113	0.056	0.254	0.113	0.014
15 TO 19.9	0.000	0.000	0.028	0.028	0.014	0.000
20 TO 24.9	0.000	0.000	0.000	0.000	0.028	0.000
SUM	1.354	0.762	0.564	1.213	0.973	1.230

* MICROTOPOGRAPHIC CHANGES BENEATH THE FRAME RESULTED IN SOME CONTACTS BELOW MEAN GROUND LEVEL. THESE VALUES ARE UNCORRECTED FOR THIS ERROR.

Despite the differences in structure of the vegetation at Prudhoe Bay and Barrow, the seasonal primary production is quite similar (Table XXXIV). In Prudhoe Bay, the wettest site (site 3) was the most productive and the driest site (site 1) was the least productive. Associated with the increasing moisture gradient, however, was a consistent decrease in standing dead material. This agrees with results obtained near Barrow and suggests a more rapid turnover of vegetation and nutrients with an increase in moisture. The Barrow communities possess considerably more chlorophyll than those at Prudhoe, especially when calculated on a dry weight basis, suggesting a greater proportion of photosynthetic tissue in the Barrow plants. This was associated with a higher chlorophyll a:b ratio in the plants from Prudhoe Bay (3.47) than in those from Barrow (2.96).

In summary, the vegetation at Prudhoe and Barrow is similar in production and in dominant species. The two areas differ, however, in that there is greater habitat diversity, a taller more open canopy, and, apparently, a lower amount of chlorophyll in the plants at Prudhoe. These tentative conclusions need to be verified by additional observations in the Prudhoe Bay area before the significance and interpretations can be stated.

Table XXXIII. Community composition number of contacts and percent of total by vascular species.

SPECIES	PRUDHOE BAY (JULY 30) 1 NO.	PCT	2 NO.	PCT	3 NO.	PCT	4 NO.	PCT	MEAN NO.	PCT	BARROW (JULY 25) MEAN NO.	PCT
ERIOPHORUM ANGUSTIFOLIUM	23	76	35	61	14	25	10	12	115	43	363	32
CAREX AQUATILIS	4	5	3	5	42	75	57	70	106	40	240	21
DUPONTIA FISCHERI	0	0	17	30	0	0	2	2	19	7	335	30
DRYAS INTEGRIFOLIA	13	18	1	2	0	0	0	0	14	5	0	0
POA ARCTICA	0	0	0	0	0	0	0	0	0	0	47	4
CALAMAGROSTIS HOLMII	0	0	0	0	0	0	0	0	0	0	41	4
OTHER	1	1	1	2	0	0	12	15	14	5	103	9
TOTAL	74		57		56		81		268		1129	
NO. OF SPECIES	4		5		2		6		9		NOT COMPARABLE	

Table XXXIV. Primary production, chlorophyll content, and standing dead at Prudhoe Bay and Barrow.

	PRUDHOE BAY (JULY 30) 1	2	3	4	MEAN	BARROW (JULY 25) MEAN
PRIMARY PRODUCTION (G DRY WT/SQ.M)	65.8	87.0	132.0	94.5	94.9	88.8
CHLOROPHYLL (MG/SQ.M)	199.8	307.7	463.2	343.9	328.7	458.0
CHLOROPHYLL (MG/G DRY WT)	3.03	3.54	3.50	3.64	3.43	5.15
STANDING DEAD (G DRY WT/SQ.M)	195.0	159.9	214.6	197.9	191.8	142.4

Consumers

Arthropods: The site visits to Prudhoe Bay were made after the end of the main period of emergence of adult insects. This occurred in mid-July 1970 at Barrow, with a rapid decline after 20 July. Samples of tundra sod from each of the study areas at Prudhoe were returned to Barrow for extraction of insect larvae and other soil arthropods. As at Barrow, the major Prudhoe arthropods were cranefly larvae (Diptera, Tipulidae). Two large larvae of *Prionocera gracilistyla* were found in the samples from site 3, the polygon basin. Two larvae of *Pedicia hannai* were extracted from the samples from site 4, the drained lake basin. Larvae of the former species are saprivorous, while the smaller larvae of *Pedicia hannai* are carnivorous.

The insect fauna at Prudhoe included many species, and even several families not found at Barrow. Several species of large wolf spiders (Araneida, Lycosidae) were particularly abundant and conspicuous. Although the number of samples taken was too small to support firm conclusions, the number of insect larvae in the soil appeared to be equal to or less than the number found in similar areas at Barrow.

Microtine rodents: The tundra of northern Alaska is noted for the cyclic population fluctuations of small rodents, particularly the brown lemming, *Lemmus trimucronatus*. At Barrow this species undergoes population cycles of large amplitude. The collared lemming, *Dicrostonyx groenlandicus*, is present at Barrow in smaller numbers and is not conspicuously cyclic. During July, August and September, several separate sets of observations were made principally by MacLean and Whitney. MacLean noted the following:

In late July, a moderate amount of burrowing and cutting of vegetation, apparently dating from the preceding spring, was evident; however, the microtine population was not large and no animals were seen. Raised mounds and polygons were examined for cast pellets and nest scrapes of predatory birds. The scarcity of these makes it doubtful that the microtine rodents ever reach high populations of the magnitude seen near Barrow. Eleven raptor pellets [snowy owl (*Nyctea scandiaca*) and pomarine jaeger (*Stercorarius pomarinus*)] were collected and their contents were analyzed. These contained remains of 19 *Lemmus*, 15 *Dicrostonyx*, 1 *Microtus oeconomus* (tundra vole), 1 *Spermophilus undulatus* (arctic ground squirrel), and 3 birds. Thus, at Prudhoe, the collared lemming is far more abundant relative to the brown lemming than it is at Barrow, and two mammal species occur there which are not found at Barrow. Careful trapping in the Prudhoe area may prove to be particularly interesting.

In early September, Whitney established two live trapping grids (Fig. 34, Location C) in the area close to the plant observations and the revegetation plots. One grid contained 100 traps at 5-m intervals (10×10) and the other 65 traps at 5-m intervals. No microtines were captured during the two days of trapping. The traps were left in place in locked-open positions, for future reruns of the trap grid. Sixty man-hours were spent on the tundra looking for fresh signs of animal activity. Signs were nil, with no evidence of green cuttings, green fecal matter, or recently used runways. The September observations indicate a decrease in the microtine population over that postulated from the observed July and August signs.

Large herbivores: At each of the study sites, and in the Prudhoe Bay area in general, many well traveled trails and piles of fresh feces evidenced the frequent passage of caribou *Rangifer tarandus* through the area. This was particularly conspicuous at site 2, where the ground was terraced by a series of parallel game trails, and at site 3, where the polygon was surrounded, but not traversed, by recently used trails. The passage of large numbers of caribou, as was seen at Prudhoe in mid-July, resulted in a heavy grazing pressure on the vegetation as well as severe physical disturbance from tramping. Thus, unlike the immediate Barrow area, caribou are an important element in the tundra ecosystem near Prudhoe Bay.

The Prudhoe Bay area, like other areas on the coastal plain of northern Alaska, includes numerous ponds and lakes. The perimeters of many of these showed the effects of fertilization by waterfowl. Eiders (*Somateria*) and old squaw (*Clangula hyemalis*) were seen resting on the banks, and feces of larger waterfowl were present in abundance. The vegetation of such areas showed a lush, green moss layer and included a greater diversity and density of flowering plants than adjacent nonfertilized tundra. Thus, the waterfowl must act as significant mediators of nutrient exchange between the aquatic and terrestrial segments of the ecosystems.

Soil nutrients

The Prudhoe sites were selected to determine the seasonal variation in available soil nutrients after disturbance. The sites were located adjacent to the BP Pit no. 1 discovery well (Fig. 34, Location D). Three disturbed sample sites were randomly located on an abandoned winter airstrip which was used for landing C-130 Hercules cargo aircraft. This had produced markedly minor physical disturbance, although disruption of the surface organic matter layer was evident. Three undisturbed (control) sampling sites were randomly located in an area contiguous with the airstrip. Both groups of sites are located adjacent to the revegetation site (Fig. 34, Location E).

Early, mid-summer and end-of-summer samples were obtained for the upper 15 cm of mineral soil. Table XXXV gives results of the sampling. With the exception of the phosphate concentrations at the 10 September sampling time, the soils from the disturbed site showed significantly higher nitrate and phosphate concentrations than soils from the undisturbed sites. Although the disturbance at the site sampled on 10 September was relatively minor, the surface thermal regime was undoubtedly altered to the degree where increased soil temperature might be associated with an increase in microbial activity. This would result in a more rapid turnover of nitrogen and release of phosphorus in the disturbed sites as compared with the undisturbed, adjacent areas. Similar trends were suggested on the controlled manipulations at Barrow.

Table XXXV. Concentrations of selected nutrients in disturbed and undisturbed tundra soils.

			mg nutrient/g dry wt of sample		
Area	*Date*	*Treatment*	*Nitrate*	*Phosphate*	*Glucose*
Prudhoe Bay	6/30/70	Control	0.0005	0.00010	0.013
	6/30/70	Disturbed	.0028*	.00052*	.002
	7/31/70	Control	.0002	.00023	.001
	7/31/70	Disturbed	.0016*	.00075*	.001
	9/10/70	Control	.0003	.00004	.004
	9/10/70	Disturbed	.0020*	.00016	.002

*Difference between control and disturbed means significant at 1% level as determined by *t* test.

Microbiology

Microbiologically, the Prudhoe Bay area at first glance has a tundra area considerably different from that at Barrow. Three control areas and two revegetation areas were sampled adjacent to locations D and E (Fig. 34). Results are given in Table XXXVI. Except for minor differences in numbers, the three control areas were identical mycologically. The oiled revegetation area and the revegetation area free of oil show striking differences from each other and from the control areas. The

Table XXXVI. Microbiology of Barrow and Prudhoe Bay.

	Barrow samples			Prudhoe bay samples		
	Controls sample no. Plot no.			Samples designation		
	206	207	208	Control	Reveg	Oiled Reveg
Total no. of species	81		[21 Shared species]		51	
No. Fungal propagules/g soil						
Litter	11,000	19,000	10,000			
Soil	2,300	1,000	3,000	11,000	600-800	190,000
No. Species						
Litter	24	42	30			
Soil	11	7	12	29	22	20
No. Shared species between litter and soil levels	8	6	4	5	Shared species	
No. Yeasts/g soil	All around 140-150,000/g			10,000	6,000	200,000
Fungal biomass % dry soil	1.6	.7	1.0	0.8	0.25	2.7
Fungi as % organic matter	5.3	2.0	3.0	4.0	1.25	11.0
Bacterial biomass lb/in. acre	9.0	18.0	72.0	19.6	88.0	41.4
No. Bacteria/g soil* in millions	.45 m	1 m	3.6 m	1 m	4.4 m	2.07 m
Soil pH	5.5	5.7	5.3	7.2	7.9	8.1
% Moisture content	57	51	63	43	26	26
Nitrate nitrogen	Mostly not measurable			< 2 lb/acre everywhere		
Ammonium nitrogen lb/acre	100	100	100	15	15	15
Phosphorus lb/acre	25	25	25	25	25	25
Potassium lb/ace	160	160	160	160	160	240

*Probably the most reliable figures since tundra is so varied and these samples were from just one area.

Prudhoe Bay control areas were quite different from the Barrow control areas. Eighty-one species of microfungi were isolated from Barrow soils. Only 51 were recovered from Prudhoe Bay soils. The two areas shared only 21 species out of a total of 132 species. Yeast biomass at Barrow was 15 times greater than that found at Prudhoe Bay except that the oiled area at Prudhoe Bay had a higher yeast biomass than any other site investigated: 200,000 yeast cells/g soil.

In comparison, the revegetation area not oiled had a mere 6000 cells/g soil. The same phenomenon was seem for the filamentous fungi. On the oiled area there was a much greater fungal biomass and number of propogules (spores and hyphae) than in the control or non-oiled revegetation zones. This suggests that oiling the disturbed soil greatly increased fungal and yeast populations at least at the biomass level. The variety of fungal species in the oiled area had decreased. In fact, one specimen of fungus accounted for 66% of the fungi isolated. In the control area this fungus only occurred with 16% frequency and in the revegetated area not oiled it occurred hardly at all.

Apparently this organism is able to utilize some of the components of crude oil or break down products from yeast metabolism of crude oil. Studies were initiated to determine why this one fungus is so successful in the oiled area. The identity of the yeasts present in the oiled soil remains to be worked on but a decrease in total species composition with an increase in the number of particular species also seems to have occurred amongst the yeasts.

III. BIOENVIRONMENTAL GRADIENTS

Abiotic

Gunter Weller*	University of Alaska
Gary Hess	University of Alaska

Primary Producers

James Anderson*	University of Alaska
Bruce Bright	University of Alaska
Kent Goumley	University of Alaska
Frank Bogardus	University of Alaska

Consumers

Paul Whitney*	University of Alaska
Ray Kendel	University of Alaska
Laurence Frank	University of Alaska
George West	University of Alaska

Microbiology

Patrick Flanagan*	University of Alaska
Arla Scarborough	University of Alaska
John Ho	McGill University

Nutrient Cycling

Soil Nutrients

Keith Van Cleve	University of Alaska
Benjamin Sands	University of Alaska
Nancy Anthony	University of Alaska
Rudolph Chandler	University of Alaska
Lorraine Noonan	University of Alaska
Bonita Snarski	University of Alaska
Carol Brass	University of Alaska
JoAnn Holland	University of Alaska

Nitrogen Fixation – Alpine Site

Vera Alexander*	University of Alaska
G.B. Threlkeld	University of Alaska
David & Barbara Murray	University of Alaska
Donald M. Schell	University of Alaska

Coordination and Services

George West	University of Alaska
Keith Van Cleve	University of Alaska
James Baldridge	University of Alaska

A natural extension of the ecosystem program which is focused at Barrow and extended eastward to Prudhoe Bay was the continuation of studies southward along the route of the proposed trans-Alaska pipeline from Prudhoe Bay through Fairbanks to Valdez. Such a program, although having obvious immediate practical advantages in aiding those involved in all aspects of the pipeline problem, will also provide comparative information of natural ecosystems from coastal arctic tundra, through high latitude alpine tundra, into the northern rim of the taiga, and through the zone of permafrost which underlies taiga forests to the Gulf of Alaska coast. In many areas, studies underway since 1969 on revegetation of disturbed areas sponsored by Alyeska Pipeline Service Company (formerly TAPS) are comparable to those initiated in 1970 by Tundra Biome scientists.

Revegetation sites exist at Prudhoe Bay, Sagwon, Galbraith Lake, Anaktuvuk Pass, Wiseman, Fish Creek Summit, Hess Creek, Eagle Summit, and Fairbanks (Fig. 1). Comparative studies of the natural ecosystem have been initiated at Prudhoe Bay, Sagwon, Galbraith Lake, Wiseman, Fish Creek Summit, Hess Creek, Eagle Summit, Fairbanks and Poker-Caribou Creeks. Other investigations have been made at additional sites Rosie Creek, Caribou Mountain, Healy Lake, and an alpine site in the Alaska Range.

In addition, several related projects are active in interior Alaska which provide the Tundra Biome Program with bioenvironmental information. Alpine sites along the Elliott Highway and in the vicinity of Eagle Summit are being investigated by University of Alberta and USA CRREL personnel to determine rates of production and decomposition and timberline climate. The Caribou-Poker Creeks watershed program, an interagency and University of Alaska effort, yields baseline hydrologic and climatic data.

*Principal authors

At Fairbanks, intensive investigations are being made on disturbed areas in which a 200-m section of heated pipe has been buried to serve as a model for heat flow calculation by Alyeska. Revegetation studies are being conducted over the pipe. The pipe passes through two ecological zones, a drier white birch (*Betula papyrifera*) forest and a wetter white (*Picea glauca*) and black (*Picea mariana*) spruce forest. Extensive base-line studies have been carried out in the adjacent undisturbed wooded areas through the Tundra Biome Program (Fig. 36).

In the first summer of base-line studies of the sites from Fairbanks to Prudhoe, it was not possible to achieve any degree of completeness in investigations at any one site. Therefore, rather than treating the bioenvironmental gradient site by site, this section of the report will follow the outline of the previous sections by detailing status of research progress by ecosystem components: abiotic, producer, consumer, and decomposer-nutrients.

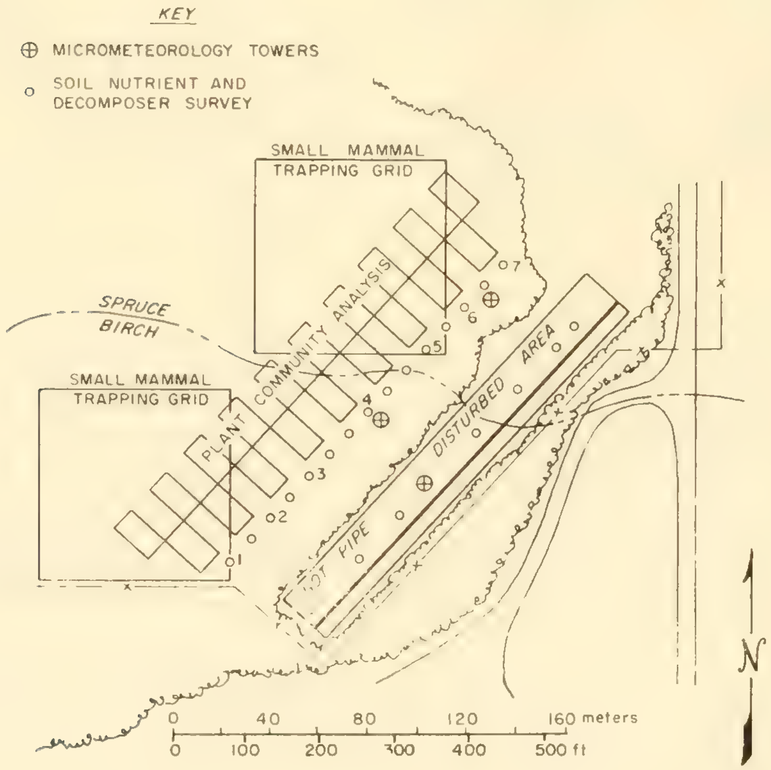

Figure 36. Location map of study sites adjacent to the hot-pipe disturbed area.

Figure 37. Aerial oblique photograph of the hot-pipe test section and the adjacent undisturbed birch and spruce stands (photograph by Don Borchert and helicopter flight by Alyeska).

Abiotic

It was not possible to undertake any continuous measurements of microclimates (temperature, wind, humidity, etc.) at sites along the gradient since the sites were visited briefly and, in most cases, were not revisited, so that microclimate monitoring equipment or recorded data could not be retrieved.

However, the climatic data from Fairbanks permit several generalizations to be made about the 1970 summer climate in the interior. Both temperature and precipitation appeared to be well within the normal range. June was slightly wetter than normal; July and August were slightly warmer than normal. All averages were within a standard deviation of the 30-year normal mean for Fairbanks. Temperatures at several alpine sites have been monitored by USA CRREL for a number of years. These temperatures also appeared to be near normal. Table XXXVII presents a summary of these data and those of a new lowland station at West Fork, near the junction of the TAPS road and Elliott Highway.

In early June 1970, thermocouples were installed at two sites in the birch and spruce stands adjacent to the hot pipe on the University of Alaska campus. Figure 37 is an aerial ablique photograph of the site.

Table XXXVII. Summer 1970 climatic data from several stations in interior Alaska.*

Month	Avg temp (°C)	Departure	Precip (mm)	Departure
		Fairbanks (130 m)		
June	14.4	–0.2	65.3	+30.0
July	16.9	+1.5	46.0	– 0.8
Aug	13.8	+1.5	50.3	– 5.4
		West Fork (128 m)		
June	12.4		59.9	
July	14.9		70.9	
Aug	11.9		67.8	
		Eagle Summit (1200 m)		
June				
July	8.2			
Aug	5.2			
		Elliott (800 m)		
June	4.9			
July	10.2			
Aug	5.8			

* Table and narrative by R. Haugen, USA CRREL.

Thermocouples were installed at both sites at 10, 5, and 1m, and 20, 10 and 5 cm above the soil surface, and at 5, 10, 20, 50 cm and 1 m below the soil surface. The thermocouples above the ground were attached to trees, extending approximately 5 cm away from the tree trunk on the north side. They were painted white to reduce radiation errors. In September two 2.5-cm-diam 12-m-high aluminum towers were placed in small natural clearings in both tree stands. Ventilated thermocouples were attached to the towers at the above six heights. A small 24-v dc ventilation motor at each level ensured proper ventilation of each thermocouple.

Thermocouples were wired into a crossbar scanner and automatic data logger that recorded readings on punched paper tape. This data logger was also used to record readings from areas in the hot-pipe disturbed area and was operated by the Institute of Arctic Biology. Unfortunately, the data logger operated for a short period only at the beginning of the summer. Electronic difficulties still are not solved. Very little data were therefore collected since a manual reading of the data would have involved a substantial amount of time to make the data meaningful.

The data collected in June indicated that air temperatures in the spruce forest were higher than those in the birch forest, but ground and underground temperatures in the spruce stand were lower than those in the birch stand (Fig. 38).

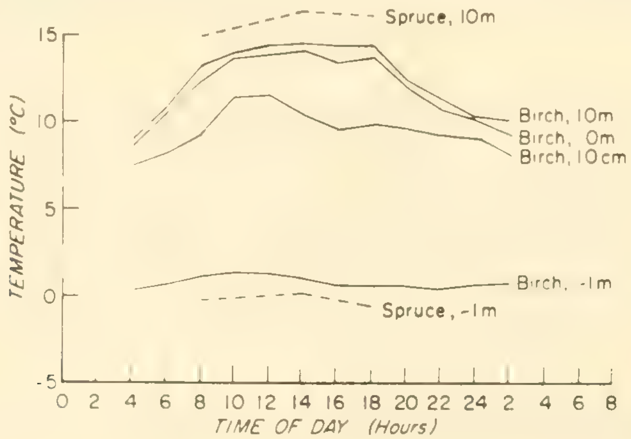

Figure 38. Diurnal temperatures in spruce and birch forests.

Producers

The primary objective of the 1970 field season was the initiation of analysis of vegetation types of significant areal distribution, including their physiognomy (community structure), species composition, biomass, and net primary productivity along the bioenvironmental gradient. In addition, profile descriptions of soil were obtained for most vegetation types examined. It was not possible to obtain significant biomass and productivity data during the first season. As a result of the first season's activities, knowledge of some fundamental characteristics of important vegetation types along the transportation corridor transect between Fairbanks and Wiseman is now available. Initial correlations of these types to environmental factor gradients are being made. Additional field activities, including studies of more stands of vegetation at established and new sites, especially further south along the corridor, and the incorporation of the measurements mentioned above, will provide some basis for explaining the seemingly complex pattern of vegetation types of the Alaska landscape in addition to the more important objective of providing a more nearly complete understanding of the vegetative productivity of this diverse region.

Six study areas were investigated: Fairbanks; hot-pipe control area, University of Alaska; Healy Lake; Hess Creek construction camp; Fish Creek Summit; Fish Creek State Highway Department maintenance camp; and Wiseman.

In the Fairbanks area activities were confined to the forest adjacent to the experimental hot-pipe installation (hot-pipe control area). Data from Healy Lake were minimal as they were obtained as an adjunct to other work in that area, but they are useful in projecting the transect southward. At each site a reconnaissance was made to develop a general impression of the nature and extent of each vegetation type. Stands representative of the significant vegetation types in the area were located for study. A stand consisted of vegetation which appeared homogeneous throughout; therefore, stands varied greatly in size from several square meters to several square kilometers. For each stand a list of species was compiled.

One or more quadrats usually 10 × 10 m were marked out, and all species and species groups on the stand list which were found within the quadrat were given by visual estimate a value on the following scale of cover and abundance (C-A) values:

X - Isolated, a single small individual, insignificant cover.

1 - Very scattered, rare, insignificant cover

2 - Scattered, uncommon, low cover.

3 - Scattered, common, low cover.

4 - Scattered, common, cover about 5%.

5 - Common, cover up to 20%.

6 - Common, cover 20-33%.

7 - Abundant, cover 33-50%.

8 - Abundant, dominant, cover 50-75%.

9 - Dominant, cover 75-100%.

10 - Dominant, cover over 100% (in the case of overlapping foliage).

In larger stands, when time allowed, two or more quadrats were studied in order to assess the intrastand variability. Information from 10 quadrats in each of one or more stands is considered desirable as a measure of a vegetation type in an area. At some sites, 1-m^2 quadrats were marked out in which stem counts and percentage cover of each species could be estimated.

In most stands, usually within or near a study quadrat, a pit was dug to obtain soil profile description, to determine depth of the active layer, and to remove soil samples for later laboratory analysis. Basal areas of all stems over 1 cm DBH were also measured. These data in addition to C-A values, help to show the relative importance of the tree species, in most cases the community dominants, within and among stands and areas, and they may also enable rough estimates of standing crop biomass to be made.

The list of species and C-A values, along with the quadrat location, elevation, and other abiotic information, constitutes a relevé. A relevé is a meaningful set of data on environmental conditions giving species composition and vegetation structure as well as abiotic conditions necessary for gradient analysis. A series of relevés from a large number of stands covering the range of vegetational variability in an area may serve as the basis of a vegetation classification scheme. Sets of classified vegetation types may be positioned on one- to n-dimensional diagrams of coordinate axes which show value ranges of selected abiotic variables. By determining stand indicator values from the data contained in the relevés, an ordination of the vegetation may be calculated. During the 1970 season, 71 relevés were obtained. The data are currently being transferred from field notebooks to computer format for further analysis.

The following discussion is limited to preliminary vegetative analysis of the control area located adjacent to the experimental hot-pipe section.

The results of the hot-pipe vegetation transect survey provide an example of the analysis possible with the vegetation data gathered at each transect site. At the hot-pipe control area, the analysis provides an indication of the physiognomy, or structure, and species composition of the undisturbed vegetation adjacent to the hot-pipe disturbed area.

The vegetation is dominated by arboreal species throughout. These include birch (*Betula papyrifera*), white spruce (*Picea glauca*), black spruce (*Picea mariana*), and alder (*Alnus crispa* ssp. *crispa*). Figure 39 shows the relative importance of these in the 23 0.02-ha quadrats along the transect. Three vegetation types, or plant communities, can be recognized. The first, designated a birch community, is represented by quadrats 1-8, and is dominated by birch. The second, represented by quadrats 9-14, is dominated by birch and alder and is considered a transition community because it includes a mixture of species dominant in each of the adjacent communities. The third community, including quadrats 15-23, is dominated by white spruce, black spruce, and alder and is designated a mixed spruce, or simply spruce community. This community may be considered an ecotone. The status of other woody species is shown in Figures 40 and 41.

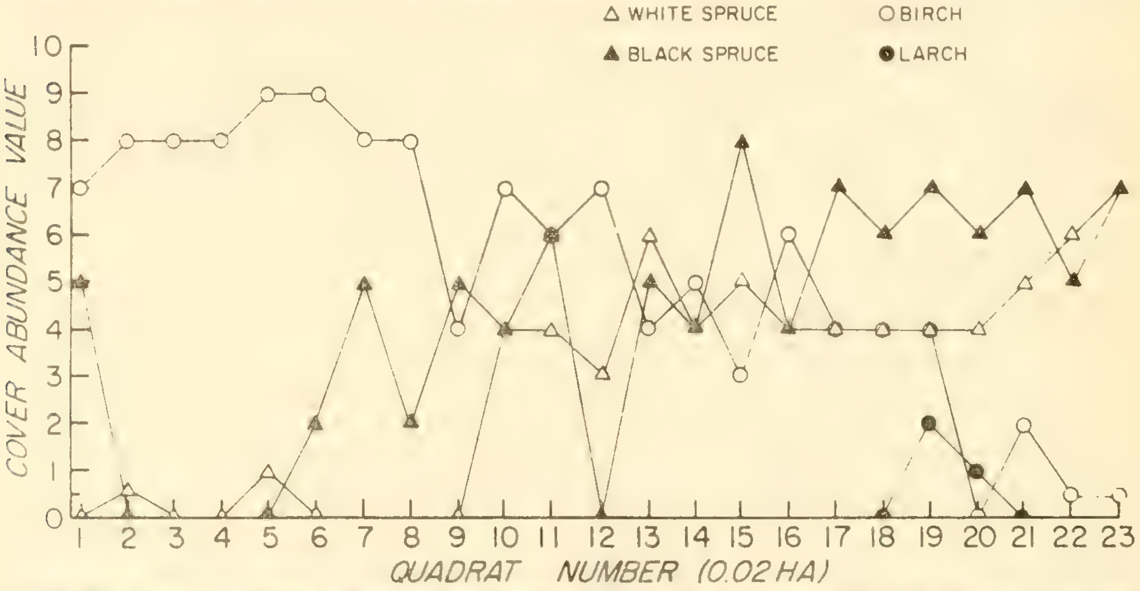

Figure 39. Cover-abundance values for four tree species in 23 0.02 ha (10 × 20-m) quadrats along the hot-pipe vegetation survey transect. (See text for explanation of the cover-abundance scale.)

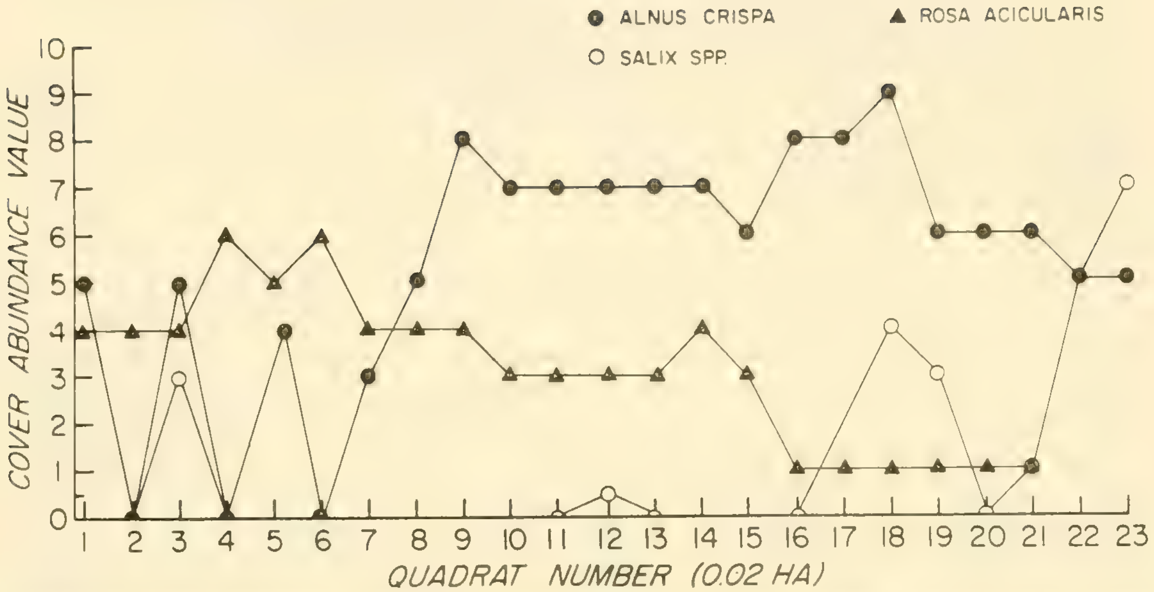

Figure 40. *Cover-abundance values for three shrub species in 23 0.02-ha (10 × 20-m) quadrats along the hot-pipe vegetation survey transect.*

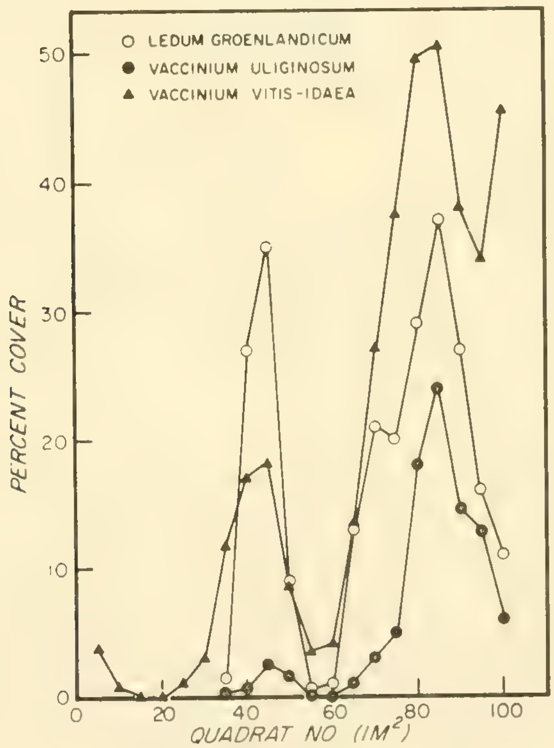

Figure 41. *Percentage cover of three shrubs in 105 1-m² quadrats along the hot-pipe vegetation survey transect. Values shown are moving averages of 10 quadrats each, calculated at 5-quadrat intervals.*

These are, in most cases, diagnostic of the three communities as recognized above because major changes in status along the transect correspond with changes in importance of trees. For example, alder has, on the average, low cover-abundance (C-A) values in the birch community and high values in the transition and spruce communities. *Rosa acicularis* C-A values are relatively high in the birch community, somewhat lower in the transition community, and low in the spruce community. Willow (*Salix* spp.) has its highest importance only in the latter community.

The ericaceous shrubs, *Ledum groenlandicum* and *Vaccinium vitis-idaea* ssp. *minus* are important primarily in the spruce community. The prominent peak in the *Ledum* curve and accompanying lesser peaks in the *Vaccinium* curve in quadrats 8 - 10 (Fig. 41), correspond to moderately high values of black spruce (Fig. 39). This combination of species probably reflects a local topographic swale where drainage is somewhat inhibited and soil pH is higher than in the adjacent birch community.

Figure 42 shows the relative importance along the transect of the six most abundant herbaceous species. *Equisetum arvense* and *Equisetum pratense* show high to very high stem counts in quadrats 1 - 40. These quadrats are located along that segment of the transect which lies within the birch community. An abundance of these two species of *Equisetum* appears, therefore, to be diagnostic of this community. *Moehringia lateriflora* is also diagnostic, as stem counts were much higher in the birch community than in the others. The occurrence of *Calamagrostis canadensis* in moderately high numbers in both the birch and transition communities helps to distinguish these from the spruce community, although this species is still of significant occurrence in the latter. The *Geocaulon lividum* curve in Figure 42 is high in the spruce community segment of the transect. In contrast, this species appears to be rare in the transition community, and it was not encountered at all in the birch community. Interestingly, *Cornus canadensis* is fairly important in both the birch and spruce communities but is nearly absent in the transition community. This is an exception to the rule, in that most species tend to show trends of increasing or decreasing importance along the transect. Tables XXXIX and XL contain four other species and groupings (*Calamagrostis canadensis*, *Rubus arcticus*, other mosses, and other ground lichens) which do not show such trends. Here, however, the differences in importance between communities are not significant as compared with those for *Cornus canadensis*.

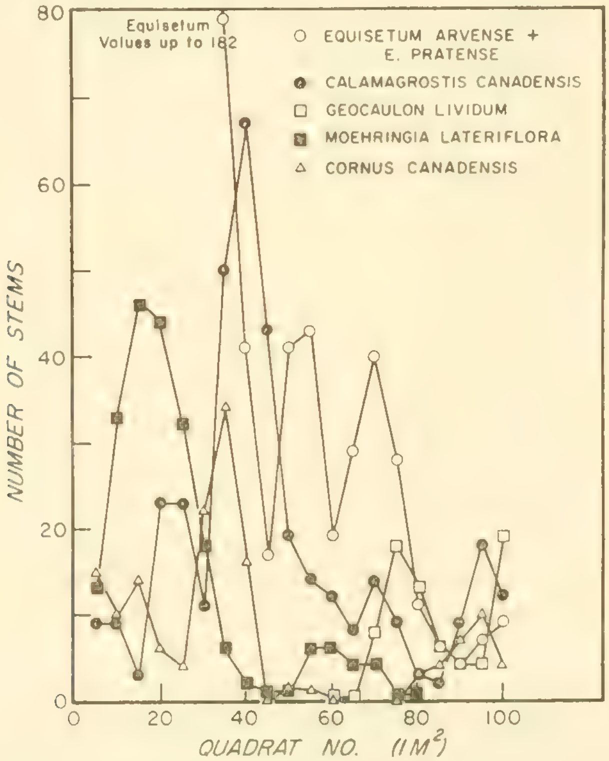

Figure 42. Stem counts of six major herbaceous species in 105 1-m² quadrats along the hot-pipe vegetation survey transect. Values shown are moving averages of 10 quadrats each, calculated at 5-quadrat intervals.

Table XXXVIII. Mean cover-abundance values of trees and shrubs in 0.02-ha quadrats in three plant communities along the hot-pipe vegetation survey transect.

Species	Birch community (N=8) Quad 1-8	Transition community (N=6) Quad 9-14	Spruce community (N=9) Quad 15-23
Tree species (based on occurrences in all strata)			
Larix laricina var. *alaskensis*	0	0	X
Picea glauca	X	4	5
P. Mariana	2	4	6
Betula papyrifera	8	6	3
Low tree high shrub strata			
Salix spp. (primarily *S. depressa* ssp. *rostrata*)	X	1	2
Alnus crispa ssp. *crispa*	3	7	7
Shrub stratum			
Ribes spp.	X	0	*
Rosa acicularis	5	5	1
Ledum groenlandicum	1	5	*
Vaccinium vitis-idaea ssp. *minus*	1	4	*
Viburnum edule	X	0	*
Rubus idaeus ssp. *melanolasius*	X	X	*
Vaccinium uliginosum ssp. *alpinum*	X	X	*

* Data unavailable.

In general, herbs appear to be relatively numerous in the birch and transition communities and significantly less so in the spruce community. The latter, however, contains the greatest diversity of herbaceous, as well as other species.

Figure 43 indicates the relative importance of a moss and of two major groupings of cryptogams along the transect. Values for *Hylocomium splendens* are, on the average, low in quadrats 1-40 (birch community), higher in 41-70 (transition community), and somewhat higher yet in the remaining quadrats (spruce community). The moderately higher values for this species in certain quadrats between 35 and 48, corresponding to numbers 8-10 of the 0.02-ha quadrats, relate to the highs for the ericaceous shrubs and black spruce discussed. As with these species, *Hylocomium splendens* also indicates more abundant soil moisture than in adjacent parts of the transect. The local environmental situation here appears to be similar to that in the spruce community. In general, as a moisture indicator, the gradual increase of *Hylocomium splendens* along the transect reflects the higher topographic position of the birch community, the northeastward sloping terrain of the transition community, and the lower position of the spruce community.

Table XXXIX. Mean number of stems (column A) and mean percentage cover (column B) of shrubs in 1-m² quadrats in three plant communities along the hot-pipe vegetation survey transect.

Species	Birch community (N=38) Quad 1-40		Transition community (N=30) Quad 41-70		Spruce community (N=35) Quad 71-105	
	A	B	A	B	A	B
Ribes glandulosum	0	-	0	-	0.1	-
R. triste	0.3	-	0	-	0	-
Rubus idaeus ssp. *melanolasius*	0.6	-	0.1	-	0	-
Potentilla fructicosa	0	-	0	-	0.2	-
Rosa acicularis	6.9	-	4.3	-	1.4	-
Ledum groenlandicum	-	0.4	-	15.8	-	21.4
Vaccinium vitis-idaea ssp. *minus*	-	3.9	-	10.5	-	45.4
V. uliginosum ssp. *alpinum*	-	0.03	-	1.0	-	11.9

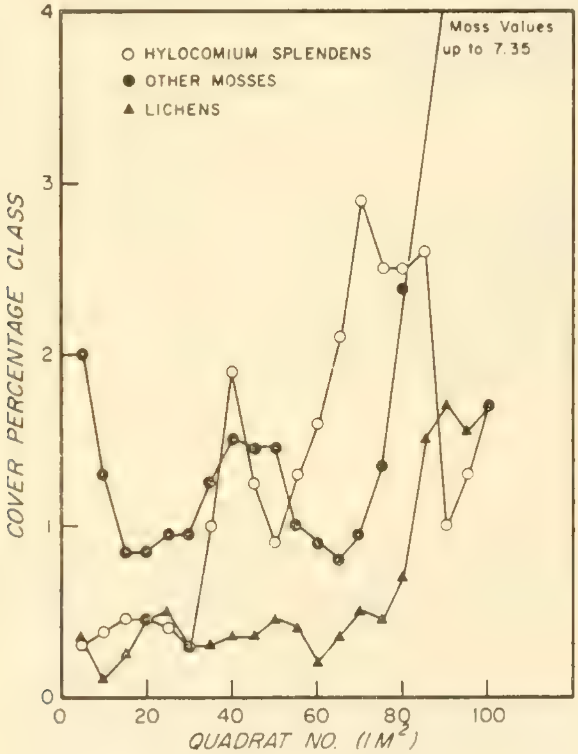

Figure 43. Cover percentage classes of Hylocomium splendens and two major groupings of cryptogams in 105 1-m² quadrats along the hot-pipe vegetation survey transect. Values shown are moving averages of 10 quadrats each, calculated at 5-quadrat intervals.

Table XL. Mean number of stems of herbaceous species in 1-m² quadrats in three plant communities along the hot-pipe vegetation survey transect.

Species	Birch community (N=38) Quad 1-40	Transition community (N=30) Quad 41-70	Spruce community (N=35) Quad 71-105
Fern allies			
Lycopodium complantum	0	0	0.03
Equisetum scirpoides	0	0	22.6
E. sylvaticum	0	0.1	0.5
E. arvense and E. pratense	123.1	29.9	12.7
Graminoids			
Arctagrostis latifolia var. arundinacea	0	0	0.6
Calamagrostis canadensis ssp. canadensis	22.1	21.9	9.5
Carex oederi ssp. viridula	0	0	0.9
Forbs			
Geocaulon lividum	0	0.1	12.4
Stellaria longipes	0	0	0.8
Moehringia lateriflora	24.8	4.4	0.1
Rubus arcticus	0.03	0	0.4
Epilobium angustifolium	2.6	1.2	0
Cornus canadensis	16.8	0.3	3.8
Pyrola secunda	0	0	0.1
Mertensia paniculata	1.1	0.7	0.6
Linnaea borealis	2.8	1.4	1.3
Adoxa moschatellina	0.1	0	0
Valeriana capitata	0	0	0.7
Petasites sp.	0	0	0.7

Values for other mosses, as shown in Figure 43, are similar in the birch (quadrats 1-40) and transition (quadrats 41-70) communities. In the spruce community (quadrats 71-105) moss values are considerably higher. Mosses appear to be a much more important component of the vegetation here. The lichen curve, though averaging lower values throughout the transect, is similar in shape to that of other mosses.

In Tables XXXVIII – XLI the mean (arithmetic average) values for the measure or estimates of importance of all species or groups of species encountered along the transect are given according to plant community.

Table XLII shows the species composition of the three plant communities in terms of dominant species, secondary dominants, intermediate, lesser, and rare species. Plants were assigned to these five categories after studying their relative importances as depicted in the preceding tables

Table XLI. Mean values of cover percentage classes for cryptogams in 1-m² quadrats in three plant communities along the hot-pipe vegetation survey transect.

Species	Birch community (N=38) Quad 1-40	Transition community (N=30) Quad 41-70	Spruce community (N=35) Quad 71-105
Hylocomium splendens	0.6	1.8	1.9
Polytrichum spp.	0	0.1	0.3
Sphagnum spp.	0	0	0.03
Other mosses	1.2	1.0	4.2
Peltigera spp.	0.03	0.1	0.4
"Reindeer" lichens	0.1	0.2	0.5
Other ground lichens	0.3	0.2	0.3
Macrofungi, undifferentiated	0.2	0.1	0.1

* Scale 1-10, where 1 = 1-10% cover, 2 = 11-20% cover, etc.

and on the basis of firsthand knowledge of their character in the natural vegetation. Dominant species are defined as those members of the tree and low tree/high shrub strata having C-A values of five or more. Secondary dominants include members of all strata below the tree stratum with similarly high values. In the case of shrubs a mean C-A value of five in 0.02-ha quadrats, a mean stem number of 6, or a mean cover percent of 20 in 1-m² quadrats, depending on the measure used, was necessary to qualify. Herbaceous members of the secondary dominants category are those with a mean of 20 or more stems/1-m² quadrat. A cryptogam species or grouping was placed in this category if it occupied an average of 40% or more of the 1-m² quadrats.

Trees and shrubs with C-A values of three or four were placed in the intermediate species category. Herbs with stem count averages between approximately 5 and 20 were also assigned to this category. The same method, but with progressively lower values, was used to place the remaining species in their respective categories.

Table XLII shows, in the dominant species and secondary dominants rows, the distinctiveness of each of the communities. The birch community, with five species, and the spruce community, with five species plus the grouping various mosses, have no species in common. The intermediate species community, on the other hand, comprises three species characteristic of the birch community and two characteristic of the spruce community.

There is a general increase in diversity of species from the birch to the spruce communities. This is accompanied by a considerable increase in the total amount of plant material.

Table XLII. Composition of the three plant communities along the hot-pipe vegetation survey transect.

Birch Community	Transition Community	Spruce Community
	Dominant Species	
Betula papyrifera	*Betula papyrifera* *Alnus crispa* ssp. *crispa*	*Picea glauca* *P. mariana* *Alnus crispa* ssp. *crispa*
	Secondary Dominants	
Rosa acicularis *Equisetum arvense* and *E. pratense* *Calamagrostic canadensis* ssp. *canadensis* *Moehringia lateriflora*	*Rosa acicularis* *Ledum groenlandicum* *Calamagrostic canadensis* ssp. *canadensis*	*Ledum groenlandicum* *Vaccinium vitis-idaea* ssp. *minus* various mosses
	Intermediate Species	
Alnus crispa ssp. *crispa* *Cornus canadensis*	*Picea glauca* *P. mariana* *Vaccinium vitis-idaea* ssp. *minus* *Equisetum arvense* and *E. pratense* *Moehringia lateriflora* *Hylocomium splendens*	*Betula papyrifera* *Vaccinium uliginosum* ssp. *alpinum* *Equisetum scirpoides* *E. arvense* and *E. pratense* *Calamagrostis canadensis* ssp. *canadensis* *Geocaulon lividum* *Cornus canadensis* *Hylocomium splendens*
	Lesser Species	
Picea mariana *Ledum groenlandicum* *Vaccinium vitis-idaea* ssp. *minus* *Ribes triste* *Rubus idaeus* ssp. *melanolasius* *Epilobium angustifolium* *Mertensia paniculata* *Linnaea borealis* *Hylocomium splendens* other mosses "Reindeer" lichens other ground lichens macrofungi, undifferentiated	*Salix* spp. *Vaccinium uliginosum* ssp. *alpinum* *Epilobium angustifolium* *Mertensia paniculata* *Linnaea borealis* *Polytrichum* spp. other mosses *Peltigera* spp. "Reindeer' lichens other ground lichens macrofungi, undifferentiated	*Larix laricina* *Salix* spp. *Rosa acicularis* *Equisetum sylvaticum* *Arctagrostis latifolia* var. *Carex Oederi* ssp. *viridula* *Stellaria longpipes* *Rubus arcticus* *Cornus candensis* *Mertensia paniculata* *Linnaea borealis* *Valeriana capitata* *Petasites* sp. *Polytrichum* spp. *Peltigera* spp. "Reindeer" lichens other ground lichens macrofungi, undifferentiated
	Rare Species	
Picea glauca *Salix* spp. *Ribes triste* *Viburnum edule* *Vaccinium uliginosum* ssp. *alpinum* *Rubus arcticus* *Adoxa moschatellina* *Peltigera* spp.	*Rubus idaeus* ssp. *melanolasius* *Equisetum sylvaticum* *Geocaulon lividum* *Cornus canadensis*	*Ribes glandulosum* *Potentilla fruticosa* *Lycopodium complanatum* *Moehringia lateriflora* *Pyrola secunda* *Sphagnum* spp.

Consumers

Other than the observations made at Prudhoe Bay, reported in Section II of this report, the only detailed studies of the consumer populations on the bioenvironmental gradient were made at two sites in the taiga woods at Fairbanks. One site, an open white birch association on a hillside with an understory primarily composed of grasses, has been under intensive study since 1968. Study of the second site was initiated in summer 1970 in the hot-pipe control area, where small mammal populations were censused in both the birch and the spruce stands.

The immediate goal is to follow the energy flow from the producers through the small herbivore populations in the three areas. There are three primary objectives: 1) net primary production, 2) net and gross production of small herbivore populations, and 3) herbivore utilization of net primary production.

The small herbivores present are the meadow voles (*Microtus oeconomus* and *Microtus pennsylvanicus*), the red-backed vole (*Clethrionomys rutilus*) and the jumping mouse (*Zapus hudsonicus*). Unfortunately, the two species of *Microtus* cannot be distinguished in the field. Autopsy of snaptrapped specimens shows that *Microtus oeconomus* constitutes 90% of the *Microtus* population.

Small-mammal numbers are determined with live-trapping (capture-recaptured) and snap-trapping techniques, according to the following schedule:

Area	Size	Time trapped
Open birch - grassland (3-mile Steese Highway)		
Grid A (Live)	100 stations at 5-m intervals	Every 2 wks in summer (snow-free) 4 wks in winter (snow present) 1968-1970
Grid B (Live Control	100 stations at 5-m intervals	2 wks in summer 1969-1970
Grid E (Live) Control	100 stations at 5-m intervals	2 wks in summer 1970
Grid F (Snap)	256 stations at 10-m intervals	Aug 1969 - May 1970 Sept 1970
Hot-pipe control		
Grid C (Live) Birch	64 stations at 10-m intervals	2 wks in summer
Grid D (Live) Spruce	64 stations at 10-m intervals	2 wks in summer 4 wks in winter 1970

Live trapping operations yield demographic data on a large scale; this very quickly overwhelms simple computational methods. A series of computer programs are being utilized to analyze demographic information gathered during the course of this study. The following programs will be utilized.

1) Instantaneous growth rates
2) Survivorship curves
3) Minimum survival rates
4) Minimum numbers present
5) Jolly stochastic estimation of numbers present
6) Juvenile survival
7) Reproductive status of all animals
8) Leslie's Z (t) to determine whether sampling is random
9) Movement patterns

Energetics of the herbivore populations are being estimated by three measurements: 1) at regular intervals throughout the year, 24-hour oxygen consumption measurements are being made with a closed circuit manometric respirometer; 2) snap-trapped animals are autopsied and analyzed for reproductive status, organ weights, total body fat and total animal caloric content; 3) stomach analysis will be made to describe seasonal food habits as well as the amount of ingested vegetation present.

Preliminary demographic data (minimum numbers of animals alive on the plot) is shown in Figure 44 for grids A, B, C, D and E. These graphs reveal several interesting phenomena. First, *Zapus hunsonicus* played a major role as a herbivore for a short period in the middle of the summer. Fairbanks is considered to be a northern limit for *Zapus hudsonicus*. Past estimates of taiga small mammal populations did not consider *Zapus* as a component of the subarctic ecosystem. Second *Clethrionomys rutilus* populations were relatively the same during both summers while *Microtus oeconomus* and *Microtus pennsylvanicus* densities showed marked fluctuations. Third, *Clethrionomys* populations in the dense birch and spruce woods were less than half the size of those in open birch woods with a grass understory.

Clethrionomys rutilus can be the dominant herbivore in a primarily grassland community and at the same time, in a nearby area, be the prevalent small mammal in birch and spruce taiga stands. *Zapus hudsonicus* has shown high survival rates between the two summers, 1969 and 1970. Nearly 50% of the animals tagged in 1969 were recaptured in 1970 as compared to no recaptures of other species over the same time span in the same area. Preliminary analysis of demographic data show high turnover rates in the *Microtus* and *Clethrionomys* populations. At certain times of the year, as many as 70 to 80% of the animals present one week will be absent two weeks later.

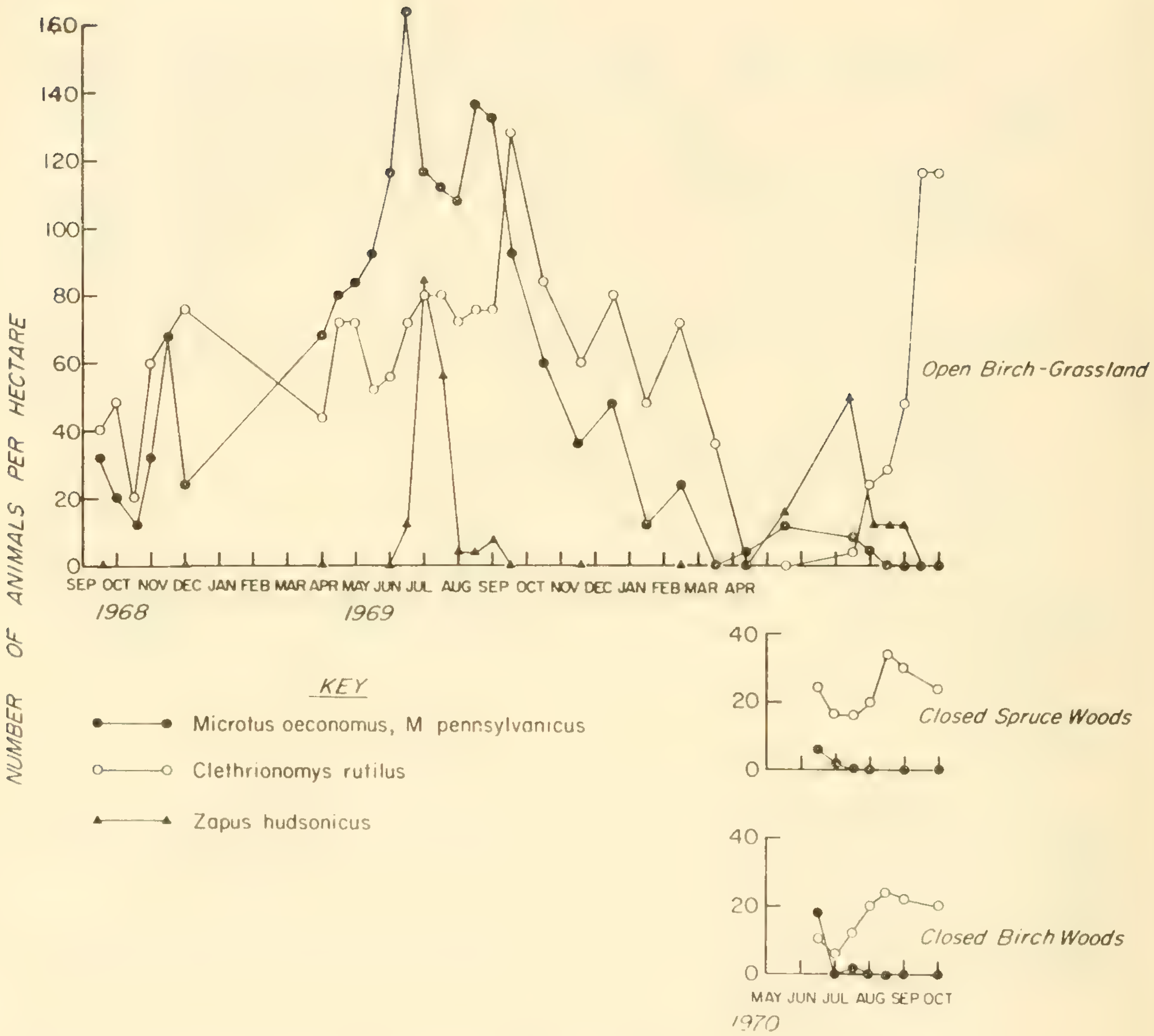

Figure 44. Demographic data for three samples sites near Fairbanks, Alaska.

Decomposers: Microbiology and nutrient cycling

Soil microbiology

A base line study of soil microfungi was initiated during the summer of 1970 along the bioenvironmental gradient in ten study areas. The hot-pipe control area was studied intensively while eight other sites along the bioenvironmental gradient up to and including a site at Prudhoe Bay were surveyed less intensively (Fig. 1). Three control plots on site 2 at Barrow were also sampled for filamentous soil microfungi and yeasts. Results from the Prudhoe and Barrow sites have been reported in previous sections. All areas were studied from soil samples taken within a three-week period. Estimates were made of fungal, bacterial, and yeast biomass at all site. Comparative studies were made of natural and disturbed areas in Prudhoe Bay, Sagwon, Hess Creek, and College. At Barrow, Eagle Summit, and College soil and litter samples were treated separately so as to observe changes in species composition with change in soil depth and substrate. Soil samples were taken at a depth of 5 to 15 cm.

The numbers of filamentous fungi and yeasts were determined from dilution counts using acidified potato dextrose rose bengal-streptomycin agar medium. The numbers of soil bacteria were estimated using the dilution plate technique and a soil extract-cyclohexamide agar medium. In the case of yeasts and bacteria only number of organisms/gram of soil was estimated.

In the ten study sites taxonomic and ecological studies were performed on the filamentous soil microfungi. A total of 5000 fungi were isolated, and from these 300 different species were identified. Major species components have been identified for sites and the density and frequency of each species has been determined within and between sites. In this way we were able to study the distribution of taiga isolates northward and tundra isolates southward. Fungal biomass was estimated by direct observation and measurement of fungal hyphae as percent of total soil organic matter. Whenever possible, microenvironmental parameters were measured at the sites during sample collection. These parameters included pH, depth of permafrost, soil temperature, N, P, K. It was not always possible to make all these measurements in the field. Variation in frequency and density of species in the different study areas was measured and assessed against the biological and abiotic (including site latitude) aspects of the site.

The sites were grouped according to the gross physiognomy of phanerogam characteristics. Accordingly, sites 4, 5, 6 and 7 in College, Hess Creek, Caribou Mt., and Wiseman were considered as mixed spruce dominated upland taiga. All these sites contained *Vaccinium vitis-ideae* and *Ledum groenlandicum* as undershrub. The most common moss in these sites was *Hylocomium splendens*. The sites at Rosie Creek, Galbraith Lake and Sagwon were all wet tundra, dominated by tussocks of *Eriophorum vaginatum* and mixed tundra sedges and grasses. *Geum rossii, Potentilla fruiticosa* and *Dryas octopetala* occurred in the drier parts of these study sites. The Eagle Summit site was considered as an example of alpine tundra containing *Betula glandulosa*, *Dryas octopetala* and dwarf *Salix* sp. On cursory observation striking differences are seen in the distribution and densities of major species components between selected sites.

Table XLIII relates some microbiological measurements made at the hot-pipe study area in College. There, seven sampling areas were stretched out along a 200-m transect.

One hundred and twenty-two species of microfungi were isolated from these study areas. Forty-two species occurring in the birch community were absent from the spruce community in which a total of 80 species occurred at varying densities. Parallel to this natural area a disturbed area also 200 m long was sampled. This area had all the trees and underbrush removed by bulldozing. Reportedly, the litter present was turned into the mineral soil.

Table XLIII. Microfungi and bacteria counts from soils on the hot pipe and control sites.

	Control sites						Adjacent hot pipe sites			
Sample no.	No. fungal propagules/g	pH	Moisture (%)	Organic matter (%)	Fungal bio-mass as % organic matter	Bacteria/g	Bacteria/g	pH	Moisture (%)	Organic matter (%)
1	$.476 \times 10^6$	4.9	15	15	2.4	10.1×10^6	23×10^6	7.9		9.0
2	$.567 \times 10^6$	4.7	19	16	2.4	5.7×10^6	56×10^6	7.4	17	7.0
3	$.455 \times 10^6$	4.5	20	18	2.0	3.5×10^6		6.7	19	9.5
4	1.4×10^6	4.2	22	20	4.8	2.8×10^6	46×10^6	7.2	12	6.0
5	$.425 \times 10^6$	3.7	20	13	3.0	2.25×10^6			15	5.5
6	$.031 \times 10^6$	3.5	23	23	1.8	2.28×10^6	42×10^6	5.8	12	4.0
7	$.625 \times 10^6$	5.1	24	24	2.6	2.3×10^6		8.6	14	

The soils in the disturbed site were taken in areas opposite and parallel to those sample areas in the natural forest and over the heated pipe. From these comparative samples the effects of the perturbation on the microfungi were assessed. Much of the data collected are still being processed and correlated. Preliminary observations are as follows.

A total of 150 species of microfungi were isolated from the two sites: 122 from the natural and 83 from the disturbed area. There were 54 shared species of which, in the natural and the disturbed areas respectively, 35 species occurred in a ratio of 2:1 and 19 occurred in ratios ranging from 1:1 to 98:1. Seven species occurring in high density in the natural area were completely missing from the disturbed area and conversely two high-density species occurred in the disturbed area which were absent in the natural sites. Between the two areas considerable differences were noticed in relative densities of major species components (Table XLIV).

Abiotically and microbiologically the area disturbed has been changed drastically. The changes are both qualitative and quantitative for fungi and bacteria. The extent to which there is species change in bacteria populations has not yet been determined. There are obvious gross changes in pH, organic matter and moisture content of these perturbed soils. More than likely an observed change from acid to alkaline pH is the major cause for rise in bacterial biomass and concomitant decrease in fungal biomass. In many taiga soils the pH changes from acid to alkaline with increased depth. Turning soil in the disturbed College site could account for the marked change in pH. Heating the soil below can cause upward migration of water and solute salts. This effect could well account for the increased alkalinity.

These changes in pH will select for entirely different plant and microbial communities. The absence of a litter layer is most probably causing some very profound ecological changes. During metabolism, fungi excrete many organic acids. Litter contains many organic acids. These acids in combination maintain a suitable pH for fungi and rapid turnover of organic material. The removal of litter upsets this balance, resulting in loss of acidifying agents. These factors also could account in part for the increase in pH and bacterial biomass. The absence of a litter layer together with influx of fungi on non-sterilized seeds could account at least partially for changes in species components. Changes in relative densities of major species components could be accounted for by lack of certain substrates and removal of competition. The changes in pH would select for certain fungal species. Two variants of the extremely competitive celluloytic *Trichoderma viride* are completely absent from the perturbed sites but occur very commonly in the adjacent natural area. The ecological lacuna is probably being filled by one of the high density species in the perturbed area e.g. f10 or f27.

Table XLIV. Density (%) figures for major species components in hot-pipe experimental area.

Isolate	% Density Control	% Density Disturbed
f 5	5.7	12.3
f 10	0.3	12.4
f 27	1.2	19.9
f 3	6.8	0.1
f 9	3.6	0.6
f 33	3.1	0.6
f 34	4.2	4.6
f 35	8.2	5.5
f 78	3.5	0
f 92	5.0	2.9
f 107	5.8	0.1
f 132	3.5	0
L 8	3.6	0
Total no. isolates:	1441	686.0
No. of species:	122	83.0

The Hess Creek study area was another spruce-dominated taiga stand. Here again natural and disturbed sites were compared. A total of 38 species were isolated from the natural area and 16 from the perturbed site. There were only 11 shared species. Again, bacterial biomass had increased tenfold in the perturbed areas and the soil pH had shifted towards alkalinity though not as sharply as it did at College. Comparable natural and perturbed areas were studied in tundra at Sagwon and Prudhoe Bay. The effects of disturbance followed the same pattern: a decrease in soil acidity, increase in bacterial biomass with concomitant changes in fungal species, density, and biomass.

At College, Hess Creek, Caribou Mt., and Wiseman, respectively, 80, 38, 30 and 60 species were isolated (Table XLV). Each site had its unique species. These are being compared in species composition and density and correlated with phanerogam and abiotic parameters. In the tundra the number of fungal species does not seem to bear any relationship with the numbers of fungal propagules per gram of soil. The species composition in each tundra site is different and density figures for species fluctuate greatly. Mycological differences between litter and soils were exhibited by every study area examined (Table XLVI). Matching species with density figures in the different layers indicates which organisms are most active in the particular zone and provides information on the decomposition gradient within the different soils.

The Alaskan tundra and taiga soils contain comparable numbers of fungal species. Some of these species are restricted to taiga or tundra but there is appreciable overlap. Significant yeast populations occur only in soils north of the Brooks Range. The number of fungal propagules in taiga soils is highest in the College area, decreasing northward to Wiseman. Numbers of fungal propagules in the tundra soils also show a decrease northward. All figures for biomass (i.e. actual active mycelium in soils) have not yet been calculated; however, during July 1970 fungal biomass was essentially the same in College, Barrow and Prudhoe Bay. These figures for taiga areas do not take litter into account. If this were done then the taiga sites would have much greater fungal

Table XLV. Site comparisons.

Site	Total species	Species unique to site	No. of fungal propagules/g: Composite sample (no. samples)	Litter	Mineral soil	No. share species: Litter/mineral soil
College	122	37	21.-16 x 10^6(3)	5-15 x 10^6	.03-1.4 x 10^6	44
Eagle Summit	30	8	2.0-2.2 x 10^6(2)	2.2 x 10^6	.025 x 10^6	5
Hess Creek	38	17				
Caribou Mt.	30	6				
Rosie Creek	36	10				
Wiseman	60	8	0.35 x 10^6 (4)			
Galbraith Lake	30	13				
Sagwon	66	19	.016 x 10^6 (2)			
Prudhoe Bay	51	9	.011 x 10^6 (3)			
Barrow	81	19	.01-.02 x 10^6(3)	.01-.02 x 10^6	.001-.003 x 10^6	18

Table XLVI. Percent density in litter and soil of major species components (species making up more than 50% of total species).

Location/ Total no. species	Species code	Litter	Soil
College/122	FL	3.0	0.1
	5	3.6	7.7
	9	6.3	0.8
	11	4.8	0.7
	34	5.9	2.6
	35	10.8	5.5
	78	2.4	4.4
	33	6.9	1.5
	92	2.0	7.9
	107	9.8	1.8
	132	4.4	2.5
	158	3.0	1.1
	3	3.8	9.7
	42	0.3	4.8
Eagle Summit/30	ES1	32.5	26.2
	2	6.7	22.5
	18	32.5	7.5
Barrow/81	B3	8.6	1.4
	4	1.2	5.9
	10	1.6	5.9
	17	0.4	5.4
	21	3.2	7.4

biomass. While the tundra is not species poor in fungi relative to taiga, it contains fewer active decomposers. Again, all the figures are not available but it seems that the number of active fungal decomposers decreases northward, so that at Prudhoe Bay five fungi account for 55% of isolates. At Barrow five organisms account for 45% of isolates. The alpine tundra site at Eagle Summit, in the midst of a taiga area, has a high number of species but three organisms account for 72% of isolates. Based on percent density figures, 53% of the active decomposers at College is accounted for by eleven species.

The tundra and taiga species lists of fungi are continually growing as new soils are examined. Sixteen species of cryophyllic fungi have been recovered from tundra soils. These organisms will grow well at temperatures of 2 to 5°C. This summer's work will more than double the list of micr-fungi species recorded for Alaska. Many of the genera are also new records for these latitudes. Information on the occurrence, association and distribution of fungi in Alaska will soon be available when figures are finally correlated with study sites and the higher vegetation.

Soil nutrients

The availability of soil nutrients and its temporal variation due to surface disturbances is of considerable importance from the standpoint of natural or man-induced revegetation. In order to assess the short-term responses of soils to disturbances, their nutrient statuses were investigated at several sites in the Fairbanks area and Prudhoe Bay. Results of the Prudhoe studies were briefly discussed in a previous section. The two sites in the Fairbanks area represent characteristics and terrain for the interior. Four plots were established in the lowlands of the Poker-Caribou Creek watershed on a southeast slope consisting of a black spruce bog. Four 6-m-square plots, separated by 6-m buffer strips were established on the same elevation contour. Selected treatments applied to each plot were: control; stripped and tilled; stripped, tilled and fertilized with 400 lb/acre of 20-10-10 and 8-32-16 fertilizer each. The stripping treatment removed all green vegetation including overstory trees, underbrush and surface cryptogams. The tilling treatment involved cultivating the surface organic matter with a rake. Fertilizer was broadcast by hand on the plots. Because of limited time and personnel, the treatments were not replicated. Personnel under the supervision of C.S. Slaughter (USA CRREL) assisted in establishing the plots.

The Fairbanks bog plots were located near the University at College, in a site where pipeline trenching studies had been conducted during the winter of 1968-1969. During trenching operations the surface vegetation was removed exposing the subsoil organic matter layers. Two sampling sites were located in this area: one in an undisturbed paper-birch forest on the edge of the bog and the second in an immediately adjacent stripped area.

Field soil sampling procedures, processing of samples and analytical nutrient determinations were the same for material collected from the various study areas. Soil saturation extracts were analyzed for nitrate (phenoldisulfonic acid method), phosphate (stannous chloride method) and glucose (glucostat procedure). Results are expressed as milligrams nutrient per gram dry weight of sample at the field moisture content. Sampling and analytical procedures were similar to those utilized at Barrow.

In general, the concentrations of nutrients at all sampling sites were low and no consistent seasonal trends are evident between disturbed and control samples (Table XLVII). More intensive sample collections over time might disclose trends in nutrient concentrations not evident at this time. Nutrient concentrations were not consistently different between Fairbanks bog-stripped and control plots. The Poker Creek samples also showed no consistent trends in nutrient concentrations during the sampling period. Concentrations of glucose at all sites were generally low. The high glucose concentration in the September 2 Poker Creek control sample may indicate contamination by animal droppings. There is need for more frequent replicated sampling and concurrent acquisition of environmental data such as soil temperature. Although initial responses to the several manipulations are not dramatic, cumulative effects over several seasons may prove significant. These observations are being compared with other soil nutrient studies throughout the interior.

Table XLVII. Concentrations of selected nutrients in disturbed and undisturbed taiga soil.

Site	Date	Treatment*	mg nutrient/g dry wt of sample		
			Nitrate	Phosphate	Glucose
Fairbanks Bog	7/2/70	Forested	.0010**	.0028**	.404
	7/2/70	Stripped	.0007	.0008	.065
	7/24/70	Forested	.0017	.0029	.000
	7/24/70	Stripped	.0024	.0047**	.000
Poker Creek	7/2/70	1	.0034	.0041	.045
	7/2/70	2	.0063	.0088	.050
	7/2/70	3	.0055	.0035	.019
	7/2/70	4	.0028	.0035	.012
	7/23/70	1	.0051**	.0085**	.000
	7/23/70	2	.0015	.0028	.000
	7/23/70	3	.0030	.0031	.000
	7/23/70	4	.0038	.0035	.000
	9/2/70	1	.0030	.0080	3.297
	9/2/70	2	.0031	.0059	.016
	9/2/70	3	.0013	.0016	.000
	9/2/70	4	.0018	.0019	.002

* Treatment designation: 1 - control; 2 - stripped and filled; 3 - stripped and filled and 400 lb/acre of 8-32-16 fertilizer; 4 - stripped and filled and 400 lb/acre of 20-10-10 fertilizer.

** Difference between control and disturbed means significant at 1% level as determined by t test. At Poker Creek only means for treatments 1 and 2 were compared.

Nitrogen fixation – Alpine site

The alpine study area is at 63°40'N and 146°5'W (USGS 1:250,000 Quad., Mt. Hayes), in the foothills of the Alaska Range, within sight of Donnelly Dome and the Delta River. The objectives of this study were similar to those discussed in a previous section on nitrogen fixation. Six study sites were selected within the area, five at about 1000 m elevation just above the tree limit and one on a NNE-facing slope of a high ridge at about 1500 m. The area is a broad, sloping plateau of tundra vegetation with extensive willows in the drainage channels and scattered white spruce in sheltered pockets at its lower limit. An end moraine gives relief to the landscape, sharply contrasting soils, and accounts for the occurrence and distribution of the small ponds (kettles). The sites studied were:

Site A. This is a ridge crest site that receives the full force of downslope winds. There is a coarse mineral soil, and the vegetation is limited to prostrate woody forms and decumbent herbs. The common macrolichen species are also present. Less than 50% of the surface is vegetated.

Site B. This is a relatively well-drained portion of the dwarf birch tundra, the most extensive vegetation type in the area and common throughout interior Alaska at this elevation. It is dominated by birch and low ericaceous shrubs in a rich mat of lichens and mosses, thus the vegetative cover is continuous.

Site C. This is a small shallow tundra pool that is floored with a layer of fine-grained, water-sorted particles with an abundance of vegetative detritus. Both emergent and floating aquatic plant species were present.

Site D. This is another small tundra pool very close to site C, but supporting an entirely different set of aquatic plant species. This pond has a very prominent blue-green algal mat on the bottom.

Site C. This is a characteristic alpine site well above the shrub tundra. The soil is rich with humus and moisture, but here and there it is interrupted by natural disturbances producing very different habitats and therefore supporting a variety of tundra plant species. There is very little overlap of species distribution between this site and those below.

Site F. This is a kettle pond which is now shallow and probably dependent upon surface runoff to maintain even its present level. The upper portion of its steep sides is covered with the same species as compose the surrounding tundra. The lower area supports an entirely different assemblage. The floor of the kettle has emergent and submerged aquatic plant species.

Plants in each study site were tagged, herbarium specimens taken, *in situ* photographs taken, and sketches prepared. The plants were then removed and set up for nitrogen fixation testing as described in the Barrow section of the report. Acetylene-reduction was the principal method used, with back-up nitrogen fixation tests using nitrogen-15. Pond water samples were tested both unconcentrated and concentrated through a 10-micron screen in a plankton concentrator. Incubation was carried out under conditions closely approximating natural. A full range of blanks and controls was included. Representative lichens from each site were collected and tested similarly for nitrogen fixation.

The results shown on table XLVIII indicate nitrogen fixing activity associated with a variety of plants. Table XLIX is a list of plants showing no acelylene reduction activity. Several lichens, all belonging to groups with blue-green algae as the algal phycobiot, appear to be major contributors to the nitrogen budget. Blue-green algae from the tundra and tundra ponds are also extremely active nitrogen fixers. *Oxytopis*, a legume, also showed high rates of acetylene reduction. *Dryas* in site A also reduced acetylene, although the rate was low. On a unit biomass basis, the lichens and blue-green algae are by far the most effective, when the relatively small plant size tested is taken into account.

The ubiquity of nitrogen fixation at pond site C and the low rates suggest that perhaps blue-green algae attached to the plants in small numbers may be responsible. The results of the nitrogen 15 work will help in interpreting these results. The high sensitivity of the acetylene reduction method results in positive results where small numbers of contaminants are included in the sample. On the other hand, the frequent appearance of *Carex* sp. in connection with positive results requires further investigation. Similarly, the positive results associated with *Sparganium miniumu* at site D are surprising.

Analysis of these results on a site by site basis suggests that nitrogen fixation is important on exposed wind-strained ridges, where soil buildup is very limited (site A). A lower, well-vegetated area (site B) had fewer nitrogen fixing components. However, even in such an area, the extent of nitrogen fixation of lichen cover under the taller vegetation could be considerable. In the aquatic environments, nitrogen fixation appears to be an important input.

At this point, it is not possible to estimate the percentage of the daily nitrogen input with tundra plants supplied by nitrogen fixation. The information obtained during this summer suggests that it is a very significant proportion in some of the environments. Since blue-green algae steadily release ammonia and organic nitrogen compounds within the environment, these at least may provide the nitrogen source for other contiguous plants.

Table XLVIII. Nitrogen fixation by terrestrial ecosystem components alpine tundra.

	Ethylene produced (μmoles/hr) x 10^{-2}	Equivalent N fixation (μg-at/hr) x 10^{-2}	At% excess* ^{15}N
Site A			
Loiseleuria procumens	.029	1.8	
Dryas octopetala	0.14	9.3	
Oxytropis (nigrescens)?	8.2	540.0	0.02
Peltigera aphthosa (L) Willd.	547.0	364.0	
Stereocoulon sp.	42.8	28.5	
Stereocoulon sp.	142.0	94.6	
Site B			
Nephroma arcticum (L.) Torss.	2.3	152.0	
Site C			
Carex cancocens	0.014	1.0	
Hippuris vulgaris	0.14	9.4	
Potentilla palustris	0.058	3.8	
Eriophorum scheuchzeri	0.106	7.0	
Carex aquatilis	0.082	5.4	
Site D			
Sparganium minimum	0.35	22.0	
Nostoc sp.	6.3	420.0	4.41
Pond Water	0.058	3.8	
Site E			
Oxytropis scammaniana	0.031	2.0	
Saxifraga oppositifolia	0.062	4.2	
Site F			
Carex saxatilis	0.029	1.8	
Viola epipsila	0.026	1.8	
Star Moss	0.041	2.8	
Miscellaneous			
Anabaena sp.	0.38	24.0	53.91

Nitrogen-15 results only:

Site C pond water concentrate 0.581 at% excess

* Only a limited number of these have been processed to date. Many more will appear in the final report.

Table XLIX. List of plants tested for N fixation which showed no evidence for acetylene reduction activity.

Site A

Arctostaphylos alpina
Vaccinium uliginosum
Salix arctica
Rhododendron lapponicum
Alectoria (4017)
Cladonia (4012)
Cladonia (4011)
Cetraria islandica (L.) Ach. (4007)
Cetraria cucullata (Bell.) Ach. (4009)
Sphaerophorus globosus (Huds.) Vain. (4021)
Cetraria nivalis (L.) Ach. (4023)
Cetraria tilesii Ach. (4018)
Asahinea chrysantha (Tuck.) W. Culb. and C. Culb. (4015)
Thamnolia subuliformis (Ehrh.) W. Culb. UV and (4016b)
Alectoria (4019)
Cladonia in tundra pool, saturated but no standing water (4004)
Umbilicaria (4030)
Solorina crocea (L.) Ach. (4002)
Baeomyces roseus Pers. in kettle, sloping side (4005)
Rhizocarpon geographicum (L.) DC. (4026)
Alectoria (4024)

Site B

Vaccinium uliginosum
Ledum decumbens
Betula glandulosa
Pedicularis labradorica
Equisetum sylvaticum
Polygonum bistorta
Carex bigelowii
Cetraria richardsonii (Hook.) (4031) Site B dwarf birch tundra
Dactylina arctica (Hook.) Nyl. (4028) Site B open dwarf birch tundra, well-drained area

Site C

Acetylene reduction activity was measured in connection with all plants from site C. However, some of the production rates were low, and pending N-15 confirmation, acceptance of nitrogen fixation activity by the plants must be tentative. Contaminant blue-green algae included with the plant in the experimental containers seems possible in these aquatic samples.

Site D

Juncus castaneus
Ranunculus aquatilis
Petasites frigidus

Table XLIX. (Cont'd)

Site E

Dryas octopetala
Diaspensia laponnica
Silene acaulis
Syntheris borealis
Astragalus umbellatus

Site F

Ranunculus reptans
Potamogeton sp.
Cladonia (4036)
Peltigera malacea (Ach.) Funck (4035)

APPENDIX A: SAMPLING SCHEDULE

Table AI. Site 1 plots and sample schedules

		Plot number							
	Month	106 (core 7)	107	111 (core 9)	112 (core 11)	113	114 (core 12)	115 (core 4)	116
Production	(June)	20 30		20 30					
	(July)	10 20 30		10 20 30					
	(Aug)	9 19 29		9 19 29			9		9
Plant nutrients	(June)	20 30		20 30					
	(July)	10 20 30		10 20 30					
	(Aug)	9 19 29		9 19 29			9		9
Leaf area index	(June)								
	(July)								
	(Aug)	3		3					3
Chlorophyll	(June)	20 30		20 30					
	(July)	10 20 30		10 20 30					
	(Aug)	9 19 29		9 19 29			9		9
Caloric	(June)	20 30		20 30					
	(July)	10 20 30		10 20 30					
	(Aug)	9 19 29		9 19 29			9		9
Extinction	(June)								
	(July)								
	(Aug)								
Carbohydrates	(June)								
	(July)	20							
	(Aug)								
Lipids	(June)								
	(July)	20							
	(Aug)								
Reflection	(June)					30			20 30
	(July)			9 19		9 19			9 19
	(Aug)			5 10 26		5 10 26			5 10 26
Arthropods	(June)	19 29	19 29						
	(July)	9 19 29	9 19 29						
	(Aug)	8 18 28	8 18 28						
Tipulidae emergence	(June)								
	(July)								
	(Aug)								
Microorganisms	(June)								
	(July)								
	(Aug)	3				3	3		
Soil-veg tesseras	(June)	20		20	20	20	20	20	20
	(July)								
	(Aug)								
	(Sept)	1	1	1	1	1	1		1
Moisture-temp block	(June)	23 24 26		23 24 26			23 24 26		23 24 26
	(July)	1-30*		1-30*			1-30*		1-30*
	(Aug)	4-29†		4-29†			4-29†		4-29†
Thaw	(June)	19 23 25		19 23 25		19	19	19 25	19 25
	(July)	4 14 24	4 14 24	4 14 24	4 14 24			4 14 24	4 14 24
	(Aug)	3 13 23	3 13 23	3 13 23	3 13 23	13 23	13 23	3 13 23	3 13 23
Lysimeter	(June)								
	(July)	16 23 30	16 23 30	16 23 30	16 23 30		16 23 30	16 23 30	16 23 30
	(Aug)	11 22	11 22	11 22	11 22		11 22	11 22	11 22
Soil temp **	(June)	4-30		16-30	20-30		26-30	4-30	
	(July)	1-31		1-31	1-31		1-31	1-31	
	(Aug)	1-31		1-31	1-31		1-31	1-31	
Canopy temp **	(June)	26-30		26-30					
	(July)	1-31		1-31					
	(Aug)	1-31		1-31					
Soil nutrients	(June)	21		21					
	(July)	1 11 21 31		1 11 21 31					
	(Aug)	11 20 30		11 20 30			11		11

* Measured on 1, 5, 10, 15, 20, 25, 30 of the month.
† Measured on 4, 10, 15, 19, 24, 29 of the month.
** Measured half hourly (inclusive dates).

Table AII. Site 2 plots and sample schedule.

	Month	201 (core 10)	202	203	204	205	206	207	208	209	210	226	227	228	229	230	231	232	233
		Plot no.																	
Production	(June)						15 25	15 25	15 25	15 25	15 25								
	(July)						5 15 25	5 15 25	5 15 25	5 15 25	5 15 25								
	(Aug)						4 14 24 30	4 14 24 30	4 14 24 30	4 14 24 30	4 14 24 30			4			4	4	4
Plant nutrients	(June)						15 25	15 25	15 25	15 25	15 25								
	(July)						5 15 25	5 15 25	5 15 25	5 15 25	5 15 25								
	(Aug)						4 14 24 30	4 14 24 30	4 14 24 30	4 14 24 30	4 14 24 30			4			4	4	4
Leaf area index	(June)						20	20	20										
	(July)	1 11 21					1 11 21	1 11 21	1 11 21										
	(Aug)	3 22					3 22	3 22	3 22										
Chlorophyll	(June)						15 25	15 25	15 25	15 25	15 25								
	(July)						5 15 25	5 15 25	5 15 25	5 15 25	5 15 25								
	(Aug)						4 14 24 30		4 14 24 30		4 14 24 30			4			4	4	4
Caloric	(June)						15 25	15 25	15 25	15 25	15 25								
	(July)						5 15 25	5 15 25	5 15 25	5 15 25	5 15 25								
	(Aug)						4 14 24 30		4 14 24 30		4 14 24 30			4			4	4	4
Extinction*	(June)																		
	(July)	1–31										18 26					18 26		
	(Aug)	1–31																	
Carbohydrates	(June)						25												
	(July)						5 15												
	(Aug)						4 14												
Lipids	(June)						25												
	(July)						5 15												
	(Aug)						4 14												
Reflection	(June)	30						30	30 20			30	20				20 30		
	(July)	9 19										9 19					9 19		
	(Aug)	5 10 26										5 10 26					5 10 26		
Arthropods	(June)						16 26	16 26	16 26	16 26	16 26	19 29		19 29		19 29			
	(July)						6 16 26	6 16 26	6 16 26	6 16 26	6 16 26	9 19 29		9 19 29		9 19 29			
	(Aug)						5 15 25	5 15 25	5 15 25	5 15 25	5 15 25	8 18 28		8 18 28		8 18 28			

*Intermittent hourly data.

Table AII. (Cont'd).

	Month	201 (core 10)	202	203	204	205	206	207	208	209	210	226	227	228	229	230	231	232	233
		Plot no.																	
Tipulidae emergence	(June)																		
	(July)						1-31*	1-31*	1-31*	1-31*	1-31*	1-31*		1-31*		1-31*			
	(Aug)						1-5*	1-5*	1-5*	1-5*	1-5*	1-5*		1-5*		1-5*			
Microorganisms	(June)						16 26	16 26	16 26										
	(July)						6 16 26	6 16 26	6 16 26										
	(Aug)						3 15	3 15	3 15			3					3	3	3
Soil-veg tesseras	(June)	20	20	20			20	20	20	20	20	20	20	20	20	20	20	20	20
	(July)																		
	(Aug)																		
	(Sept)	1	1	1	1	1	1	1	1	1	1	1	1		1	1	1	1	1
Moisture-temp block	(June)	23 24 26	23 24 26	23 24 26									23 24 26				23 24 26	23 24 26	23 24 26
	(July)	1-30†	1-30†	1-30†									1-30†				1-30†	1-30†	1-30†
	(Aug)	4-29**	4-29**	4-29**			4-29**						4-29**				4-29**	4-29**	4-29**
Thaw	(June)	23 25	23 25	25	25	25	25	23 25	25	25	25	23 25	23 25	25	25	25	23 25	25	25
	(July)	4 14 24	4 14 24	4 14 24	4 14 24	4 14 24	4 14 24	4 14 24	4 14 24	4 14 24	4 14 24	4 14 24	4 14 24	4 14 24	4 14 24	4 14 24	4 14 24	4 14 24	4 14 24
	(Aug)	3 13 23	3 13 23	3 13 23	3 13 23	3 13 23	3 13 23	3 13 23	3 13 23	3 13 23	3 13 23	3 13 23	3 13 23	3 13 23	3 13 23	3 13 23	3 13 23	3 13 23	3 13 23
	(Sept)	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Lysimeter	(June)																		
	(July)																		
	(Aug)																		
Soil temp ††	(June)	18 30																	
	(July)	1-31										1-31					1-31		
	(Aug)	1-30										1-30					1-30		
Canopy temp ††	(June)	1-31										1-31					1-31		
	(July)	1-30										1-30					1-30		
	(Aug)																		
Soil nutrients	(June)						16 26	16 26	16 26	16 26	16 26								
	(July)						6 16 26	6 16 26	6 16 26	6 16 26	6 26	1					1	1	1
	(Aug)						6 15 25 31	6 15 25 31	6 15 25 31	6 15 25 31	6 15 25	6		5			6	11	11

*Inclusive dates.
†1, 5, 10, 15, 20, 25, 30.
**Sampled 4, 10, 15, 19, 24, 29.
††Intermittent hourly data.

Table AIII. Site 7 ponds and sample schedule.

		Pond													
	Month	*B*	*B-1*	*B-2*	*B-3*	*C*	*C-1*	*C-2*	*C-3*	*D*	*E*	*F*	*G*	*H*	*I*
Temp-water	June	11 15 18 21 23 26 28 30				11 12 14 18 21 23 26 28 30					11 12 15 18 19 21 23 26 28 30	9 10 24			
	July	2 5 10 15 17–22 24 28	28	28	28	2 5 10 15 17–22 24 28	28	28	28	24 28 31	2 5 7 10 15 17–22 24	2 7 17–22 24	11	11	11
	Aug	1 5 10 28 30	5 10	5 10	5 10	1 6 8 11 28 30 31	1 6 11	1 6 11	1 6 11	1 3 5 7 9 13	1 4 8 10 9 12 14 28 31	9 28 30	28	28	28
	Sept	9 12	9 12	9 12	9 12	1 6 7 8 9 11 14	9 11			3 9	1 3 4 7 8	3 9			
Temp-sediment	June	11 15 18 21 23 26 28 30				11 12 15 18 21 23 24 28 30					11 12 15 18 19 21 23 26 28 30	9 10 24			
	July	2 5 10 15 17–22 24 28	28	28	28	2 5 10 15 17–22 24 28	28	28	28	24 28 31	2 5 7 10 15 17–22 24	2 7 17–22 24	11	11	11
	Aug	1 5 10 28 30	5 10	5 10	5 10	1 6 8 11 28 30 31	1 6 11	1 6 11	1 4 11	1 3 6 7 9 13	1 4 8 9 10 12 14 28 31	9 28 30			
	Sept	9 12	9 12	9 12	9 12	1 6–9 11 14	9 11	9 11	9 11	3 9	1 3 4 7 8	3 9			
pH	June	7 11 15 18 21 23 26 28 30				7 11 15 18 21 23 26 28 30					11 15 18 21 23 26 28 30	10 20 24			
	July	5 10 15 20 28	28	28	28	5 10 15 20 28	28	28	28	24 26–31	5 10 15 20 30	2 7 17 30	11	11	
	Aug	1 5 10	1 5 10	1 5 10	1 5 10	1 6 11 30	1 6 11	1 6 11	1 6 11	1 3 5 6 7 9 13	4 9 14	9	28	28	28
	Sept	12	12	12	12	6 11	11	11	11	3	3	3			
Alkalinity	June	7 11 15 18 21 23 26 28 30				7 11 15 18 21 23 26 28 30					11 15 18 21 23 26 28 30	10 20 24			
	July	5 10 15 20 28	28	28	28	5 10 15 20 28	28	28	28	24 26–31	5 10 15 20 30	2 7 17 30	11	11	
	Aug	1 5 10	1 5 10	1 5 10	1 5 10	1 6 11 30	1 6 11	1 6 11	1 6 11	1 3 5 6 7 9 13	4 9 14	9	28	28	28
	Sept	12	12	12	12	6 11	11	11	11	3	3	3			
Nitrogen chemistry	June	11 15 18 21 23 26 28 30				11 15 18 21 23 26 28 30					11 15 18 21 23 26 28 30	10 20 24			
	July	5 10 15 20 28	28	28	28	5 10 15 20 28	28	28	28	24 26–31	5 10 15 20 30	2 7 17 30	11	11	
	Aug	1 5 10	1 5 10	1 5 10	1 5 10	1 6 11	1 6 11	1 6 11	1 6 11	1 3 5 7 9 13 15–22	4 9 14	9	28	28	28
	Sept	12	12	12	12	11 14	11	11	11	3	3	3			
Nitrogen kinetics	June	4 18				4 18									
	July	23 29	29	29	29	22 28	28	28	28	25–30					
	Aug	1 17	1 17	1 17	1 17	1 18	1 18	1 18	1 18	1 3 17–23					
	Sept														
Phosphorus chemistry	June	11 15 18 21 23 26 28 30				11 15 18 21 23 26 28 30					11 15 18 21 23 26 28 30	10 20 24			
	July	5 10 15 20 28	28	28	28	5 10 15 20 28	28	28	28	24 26–31	5 10 15 20 24 30	2 7 17 30	11	11	
	Aug	1 5 10	1 5 10	1 5 10	1 5 10	1 6 11	1 6 11	1 6 11	1 6 11	1 3 5 7 9 13	4 9 14	9	28	28	28
	Sept	12	12	12	12	6 11 14	11	11	11	3	3	3			
Phosphorus kinetics	June	26 28				26 28					26 28				
	July	5 10 15 20 28	28	28	28	5 10 15 20 28	28	28	28	24 26–31	5 10 15 20 30	2 7 17 30	11	11	
	Aug	5 10	5 10	5 10	5 10	6 11 30	6 11	6 11	6 11	3 5 7 9 13	4 9 14	9	28	28	28
	Sept	12	12	12	12	11	11	11	11	3	3	3			
Plankton composition	June	11 15 18 21 23 26 28 30				11 15 18 21 23 26 28 30					11 15 18 21 23 26 28 30	10 20 24			
	July	5 10 15 20 28	28	28	28	5 10 15 20 28	28	28	28	24 26–31	5 10 15 20 24 30	2 7 17 30	11	11	
	Aug	1 5 10	1 5 10	1 5 10	1 5 10	1 6 11	1 6 11	1 6 11	1 6 11	1 3 5 7 9 13	4 9 14	9	28	28	28
	Sept	12	12	12	12	6 11 14	11	11	11	3	3	3			
Productivity	June	11 15 18 21 23 26 28 30				11 15 18 21 23 26 28 30					11 15 18 21 23 26 28 30				
	July	5 10 15 20 28	28	28	28	5 10 15 20 28	28	28	28	24 26 31	1 5 10 15 20 30	2 7 17 30	11	11	
	Aug	1 5 10	5 10	5 10	5 10	1 6 11	6 11	6 11	6 11	1 3 5 6 9	4		28	28	28
	Sept	12	12	12	12	11	11	11	11	3	3	3			
Chlorophyll	June	11 15 18 21 23 26 28 30				11 15 18 21 26 28 30					11 15 18 21 23 26 28 30	10 20 24			
	July	5 10 15 20 28	28	28	28	5 10 15 20 28	28	28	28		5 10 15 20 30	2 7 17 30	11	11	
	Aug	1 5 10	1 5 10	1 5 10	1 5 10	1 6 11	1 6 11	1 6 11	1 6 11	1 3 5 7 9 13	4 9 14		28	28	28
	Sept	12	12	12	12	11	11	11	11	3	3	3			
Thaw	June					17 18 23 24 25					17 18 23 24 25				
	July					9 17					9 16				
	Aug					28					12 28				

APPENDIX B: THE BARROW WORD MODEL

The International Tundra Steering Committee of IBP has recommended that a narrative description or word model be prepared for each national site. This word model revised in September 1970, summarizes the current understanding of how the wet arctic tundra ecosystem is structured and how it functions. Such word models permit initial circumpolar comparisons among sites and provide the basis from which predictable models will be constructed. The following represents the contributions of numerous U.S. scientists who have carried out independent research at Barrow over the years.

The arctic tundra near Barrow, Alaska, encompasses a complex of habitats arrayed along a moisture-dominated gradient. Vegetation and soils are distributed along micro-, meso-, and macro-environments according to type and size of polygons, regional relief, and land form type. These range from upland meadow communities (arctic brown and upland tundra soils) to wet meadow and marsh types (meadow and bog soils) to emergent aquatics (hydrosols) and open water in small ponds and lakes. Ponds, an integral aspect of all principal habitats, show various stages of succession resulting from both filling and erosion. Large shallow lakes occupy 30% of the area north of 71° latitude. These vegetation, soils, microrelief and aquatic environments form a complex mosaic which influences plant productivity and animal population and diversity throughout the year. Ridges, polygon tops, and slopes commonly contain in decreasing order of occurrence *Carex aquatilis*, *Petasites frigidus*, *Salix pulchra*, *Arctagrostis latifolia*, *Poa arctica*, *Luzula confusa*, *Salix rotundifolia*, and *Eriophorum scheuchzeri*. *Dupontia fisheri*, *Carex aquatilis*, *Eriophorum angustifolium* and *E. scheuchzeri*, *Petasites frigidus*, and *Poa arctica* occur in meadows and wet polygonal troughs. *Arctophila fulva* is found in shallow ponds.

Primary production during the 45- to 90-day growing season is controlled by a combination of temperature, soil moisture, day length and nutrient supply. Production varies from a low of approximately 20 g dry weight/m^2 on dry exposed ridges and eroding high center polygons to maximum values of 200 g/m^2 in wet terrestrial habitats. Thus, the more productive habitats on micro- and meso-scales are near the wetter end of the soil moisture gradient (meadows and polygon troughs). The mean aboveground production for all community type ranges between 70 and 110 g/m^2. This is associated with a live leaf area index of about 1.2. The majority of this leaf area is positioned within 5 cm of the soil surface. Maximum production is usually attained 50 days after snowmelt, although some leaf senescence at the bottom of the canopy occurs 30 days after snowmelt. All habitats are controlled by the presence of permafrost (0°C ground temperature or colder) near the surface throughout the growing season.

Especially significant to the amount of seasonal primary production are the climatic conditions of the first two or three weeks of the growing season, the previous summer's stored reserves, and environmental factors affecting photosynthesis. Photosynthesis on a daily basis is efficient due to the long photoperiod and generally low temperatures. During the "night," however, and particularly in the lower levels of the canopy, carbon dioxide uptake is limited by the availability of light. At these lower levels senescence is initiated by July 15. Carboxylation in all species is mainly with ribulose, 1-5, diphosphate as substrate. Grasses all show a high carbon dioxide compensation concentration, a pronounced oxygen inhibition, and a low light requirement for saturation. Within species, photosynthesis varies as a function of leaf position, age, and season. Maximal rates or capacities of CO_2 uptake are low in the grasses due apparently to a high diffusion resistance or possibly a slow rate of translocation.

On all terrestrial sites, but particularly on the wetter meso-sites, production is directly influenced by the slow decay of unclipped standing dead material. It is hypothesized that the availability of nutrients to plants for growth is modulated by the lemming population through accumulation and storage of certain elements (N, K, P) in, and their ultimate release from, feces and other dead organic matter. The lemmings, by clipping the slowly decomposing standing dead hasten nutrient release as the newly fallen litter decomposes faster than the standing dead.

The long-term rate of total decomposition in the Barrow area is approximately equal to production, although initial rates of organic matter accumulation on recently drained lake beds are rapid. Based on radiocarbon evidence, depth of thaw measurements, and the absence of widespread organic terrain, organic accumulation and decomposition under uniform climatic conditions are assumed to reach a steady state within a relatively short period (presumably less than 100 years). Although the rate of organic decomposition is slow, wetter habitats show higher rates of nutrient loss through decomposition compared to better-drained, drier habitats.

Tundra decomposers are limited by cold temperatures, shortness of season, low inorganic nutrient concentrations, and in the wetter soils by anaerobic conditions. Three microbial zones are easily recognized within the active layer: surface organic, mineral and buried organic layers. The bulk of the microbial biomass and activity is located and takes place within the surface layer of grass roots, mosses, litter, and peat. Early in the summer bacteria are active in decomposing dead plant material, plant exodate, and sloughed off root material. Less actively decomposing peat is found at the lower portion of the surface layer. During mid summer, there is an increase in the quantity of yeast and filamentous fungi and slight decrease in the bacterial flora. The microflora is largely psychrophilic, although optimum growth temperature of the majority of the microbes is around 20^{o}C. The most common bacteria observed are gram negative rods which belong to the genera; Pseudomonas, Achromobacter, and Flavobacterium. Yeast are present in unusually high numbers and blue-green and green algae are present in significant numbers in the soil.

There is little organic matter in the mineral layer; therefore, the microflora has a low biomass and activity. There are few algae, yeasts or filamentous fungi. The bacteria in this layer are taxonomically similar to the surface bacteria.

The buried organic layer is not continuous, but where present there is a greater biomass than was observed in the mineral layer. Much of this population consists of strictly anaerobic bacteria on the poorly drained areas. There is little sulfate in tundra soil so sulfate reduction is not significant in situ but methane production which results from organic matter decomposition may be a significant drain on the energy and carbon in the tundra.

Annual production rates for the tundra ponds and the lakes studied are very low compared to most temperate-zone water. Many of these small ponds receive seasonal influxes of organic matter (clippings, fecus, soluble organic), especially during the spring runoff. During the summer, thermal erosion of organic-rich permafrost also contributes to lake and pond filling. Approximately 25% of the total seasonal lake production occurs beneath the ice before and after the spring thaw and after freeze-up. Production appears limited by a short growing season, low solar intensity during the growing season and nutrient deficiencies, especially for phosphorus.

The most conspicuous feature of the consumer compartment of the ecosystem is the three- to five-year population cycles of large amplitude in the brown lemming (Lemnus trimucroratus), the dominant herbivore. Numbers of lemmings vary from about 1 to 250 per ha. Insect herbivores are uncommon and other vertebrate herbivores which may be important at other tundra sites are here uncommon (other species of microtine rodent; caribou; geese) or absent (ground squirrels). In the absence of other significant herbivores, variation in lemmings density results directly in variation in the grazing process. When lemmings are scarce, vegetation accumulates as standing dead in the plant canopy. As the lemming population builds in the winter and spring preceeding the high, much of the vegetation is cut. Only a relatively small amount is consumed; most is converted directly to litter. The litter may be redistributed during spring melt-off, being removed from raised areas and concentrated in lower areas, ponds, and polygon troughs. This also produces a pulse of organic matter entering the saprovore-based food chain.

When lemmings are abundant, snowy owls and Pomarine jaegers breed in large numbers, and least weasels increase markedly in abundance. In other years these predators are scarce or absent. Ermine and both Arctic and red foxes are present, especially in lemming-high years, but are never abundant.

Plant litter, animal carcasses and feces form the input into saprovore-based food chain. The most important saprovores are collembola, orbatid mites, and diptera larvae, especially Tipulidae and Chironomidae. Tipulidae reach densities of $400/m^2$ and biomass of greater than 0.5 g dry weight/m^2.

The soil saprovores are consumed by an array of carnivorous arthropods (mites, beetles, hymenopterans, spiders, some diptera larvae). Both the saprovores and the carnivores support the other important group of vertebrate consumers, the "insectivorous" birds. Of these, the "shorebirds" (sandpipers and plovers) are the most diverse and abundant.

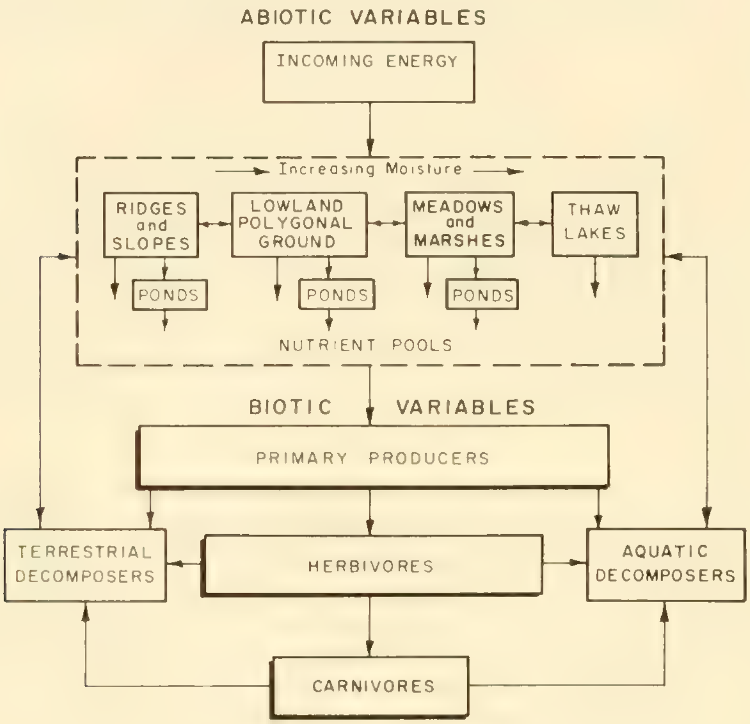

Figure B1. Interrelationship between major abiotic and biotic components of the Barrow tundra.

APPENDIX C: PROVISIONAL CHECKLIST TO PLANTS FOUND IN THE VICINITY OF BARROW AND PRUDHOE BAY, ALASKA

(These taxa are, in many cases, not yet substantiated by specimens)

Larry Tieszen — Augustana College
Virginia Wells — University of Alaska
Phyllis Kempton — University of Alaska
JoAnn Flock — University of Colorado

	Barrow		Prudhoe Bay	
	Vicinity	IBP sites	Vicinity	IBP sites
	Vascular Plants			
Equisetaceae				
Equisetum arvense	X		X	
Gramineae				
Alopecurus alpinus	X		X	
Arctagrostis latifolia	X		X	X
Arctophila fulva	X		X	
Calamagrostis holmii	X	X		
Deschampsia caespitosa				
ssp. *orientalis*	X		X	
Deschampsia pumila	X			
Dupontia fischeri	X	X	X	X
Elymus arenarius				
ssp. *mollis* var. *villosissimus*	X		X	
Festuca brachyphylla	X		X	
Hierochloe alpina	X		X	
Hierochloe pauciflora	X	X	X	
Phippsia algida	X		X	
Poa alpigena	X		X	
Poa arctica				
ssp. *arctica*	X	X		
ssp. *caespitans*	X			
Poa malacantha	X			
Puccinellia langeana	X		X	
Puccinellia phryganodes	X		X	
Trisetum spicatum	X		X	
Cyperaceae				
Carex aquatilis				
ssp. *stans*	X	X	X	X

Dave Murray, Curator, University of Alaska Herbarium compiled this list from data supplied by those listed above. The Barrow area list is based on Hulten's *Flora of Alaska and Neighboring Territories*.

	Barrow		Prudhoe Bay	
	Vicinity	IBP sites	Vicinity	IBP sites
Carex consimilis	X			
Carex glareosa	X			
Carex ramenskii	X			
Carex subspathaceae	X			
Carex ursina	X		X	
Eriophorum angustifolium				
ssp. *triste*	X	X	X	X
Eriophorum russeolum				
ssp. *rufescens*	X			
var. *albidum*	X			
Eriophorum scheuchzeri	X	X	X	
Eriophorum vaginatum				
ssp. *spissum*	X		X	
Juncaceae				
Juncus biglumis	X		X	
Luzula arctica	X	X		
Luzula confusa	X			
Luzula tundricola	X			
Salicaceae				
Salix alaxensis			X	
Salix arctica			X	X
Salix arctolitoralis	X			
Salix fuscescens	X			
Salix ovalifolia	X			
Salix phlebophylla	X		X	X
Salix polaris	X			
Salix pulchra	X	X	X	
Salix reticulata	X		X	X
Salix rotundifolia	X	X		
Polygonaceae				
Oxyria digyna	X			
Polygonum viviparum	X		X	X
Rumex arcticus	X			
Caryophyllaceae				
Arenaria peploides	X			
Arenaria rubella	X			
Cerastium beeringianum	X	X	X	
Cerastium jenisejense	X		X	
Melandrium apetalum				
ssp. *arcticum*	X		X	
Sagina intermedia	X			
Silene acaulis			X	
Stellaria ciliatosepala	X			
Stellaria crassifolia	X			
Stellaria edwardsii	X			
Stellaria humifusa	X			
Stellaria laeta	X	X	X	

	Barrow		Prudhoe Bay	
	Vicinity	IBP sites	Vicinity	IBP sites
Ranunculaceae				
Anemone parviflora			X	
Caltha palustris				
ssp. *arctica*	X		X	
Papaver hultenii	X			
Papaver lapponicum				
ssp. *occidentale*	X		X	
Papaver macounii	X			
Ranunculus gmelini	X		X	
Ranunculus hyperboreus	X			
Ranunculus nivalis	X	X	X	
Ranunculus pallasii	X			
Ranunculus pygaeus				
ssp. *sabinei*	X			
Ranunculus sulphureus	X			
Cruciferae				
Braya purpurascens			X	
Cardamine bellidifolia	X		X	
Cardamine hyperborea	X			
Cardamine pratensis	X	X	X	
Cochlearia officinalis				
ssp. *arctica*	X		X	
Draba alpina	X			
Draba bellii			X	
Draba chamissonis	X			
Draba cinerea	X			
Draba fladnizensis	X			
Draba lactea	X			
Draba macrocarpa	X			
Draba nivalis	X			
Draba oblongata	X			
Eutrema edwardsii	X			
Saxifragaceae				
Saxifraga bronchialis				
ssp. *funstonii*	X			
Saxifraga caespitosa	X			
Saxifraga cernua	X	X	X	
Saxifraga flagellaris				
ssp. *platysepala*	X			
Saxifraga foliolosa	X	X		
Saxifraga hieracifolia	X			
Saxifraga hirculus	X		X	
Saxifraga nivalis	X			
Saxifraga oppositifolia	X		X	
Saxifraga punctata				
ssp. *nelsoniana*	X	X		
Saxifraga rivularis	X			
Chrysosplenium tetrandrum	X	X	X	

	Barrow Vicinity	Barrow IBP sites	Prudhoe Bay Vicinity	Prudhoe Bay IBP sites
Rosaceae				
Dryas integrifolia	X		X	
Potentilla hyparctica	X			
Potentilla pulchella	X			
Rubus chamaemorus	X			
Leguminosae				
Astragalus alpinus				
ssp. *alpinus*	X		X	
ssp. *arcticus*	X			
Astragalus umbellatus	X			
Hedysarum mackenzii	X			
Lupinus arcticus			X	
Ericaceae				
Arctostaphylos alpina	X			
Cassiope tetragona	X		X	
Ledum palustre				
ssp. *decumbens*	X			
Vaccinium vitis-idaea	X			
Primulaceae				
Androsace chamaejasme	X		X	
Androsace septentrionalis	X			
Armeria maritima	X		X	
Primula stricta			X	
Haloragaceae				
Hippuris vulgaris	X		X	
Polemoniaceae				
Polemonium acutiflorum	X		X	
Boraginaceae				
Eritrichium aretioides			X	
Mertensia maritima	X		X	
Scrophulariaceae				
Lagotis glauca	X			
Pedicularis capitata	X		X	
Pedicularis kanei	X			
Pedicularis langsdorfii				
ssp. *arctica*	X			
Pedicularis sudetica				
ssp. *albolabiata*	X		X	
Valerianaceae				
Valeriana capitata	X		X	
Compositae				
Artemisia arctica				
ssp. *comata*	X			
Artemisia borealis			X	
Artemisia frigida	X			
Artemisia tilesii	X			

	Barrow		Prudhoe Bay	
	Vicinity	IBP sites	Vicinity	IBP sites
Chrysanthemum integrifolium			X	
Erigeron eriocephalus	X			
Petasites frigidus	X	X	X	
Saussurea viscida ssp. *yukonensis*	X			
Senecio atropurpureus ssp. *frigidus*	X			
Senecio congestus	X			
Senecio hyperborealis			X	
Taraxacum alaskanum	X		X	
Taraxacum ceratophorum	X			
Taraxacum lateritium	X			
Tripleurospermum phaeocephalum	X			
Lichens				
Alectoria bicolor		X		
Cetraria cucullata		X		
Cetraria islandica		X		
Cetraria richardsonii		X		
Cetraria simmonsii		X		
Cladonia cyanipes		X		
Cladonia pyxidata		X		
Cornicularia aculeata		X		
Dactylina arctica		X		
Peltigera aphthosa		X		
Peltigera canina		X		
Sphaerophorus globosus		X		
Thamnolia subuliformis		X		
Macro-Fungi*				
Cortinarius		X		
Galerina		X		
Hebeloma		X		
Hygrophorus		X		
Laccaria		X		
Leptoglossum		X		
Lyophyllum		X		
Naematoloma		X		
Omphalina		X		
Russula		X		

* Sufficient time was not available for the microscopic study required to determine species.

APPENDIX D: BARROW INTENSIVE SITE VISITORS-SUMMER 1970

Biome Review Group

John Buckley	Office of Science and Technology (observer)
Chuck Cooper	National Science Foundation (observer)
David Gates	Missouri Botanical Gardens
David Goodall	Utah State University
Bruce Hayden	University of Wisconsin
John Hobbie	North Carolina State
Al Johnson	San Diego State College
Phil L. Johnson	University of Georgia
George Llano	National Science Foundation (observer)
John Milton	Conservation Foundation

Visitors - Non-project participants and other than NARL resident projects

Donald Aitken	John Muir Institute
Yvonne Aitkens	University of Alaska
Dick Berg	USA CRREL
Basil Bradbury	University of Alaska
Tom Brennan	Atlantic Richfield Co.
Max Brewer	Naval Arctic Research Laboratory
Max Britton	Office of Naval Research/Arctic Institute of North America
Deltev Bronk	National Academy of Sciences
Bob Buckman	U.S. Forest Service
Al Condo	Atlantic Richfield Co.
John Cooper	British Petroleum
Fred Dean	University of Alaska
Don Dedera	Humble Oil and Refining Co.
Steve Dice	Office of Chief of Engineers
Dick Dickerman	U.S. Forest Service
Tom Gaskill	British Petroleum
James Hammond	Humble Oil and Refining Co.
Bob Harris	U.S. Forest Service
H. Hoinkes	Innsbruch, Austria
George Howard	Pan American Petroleum
Art Joens	Humble Oil and Refining Co.
Art Lachenbruch	U.S. Geological Survey
Geoffrey Larmime	British Petroleum
Peter Morrison	University of Alaska
R. Odsather	Atlantic Richfield Co.
Don Parsons	Office of Chief of Engineers
Lou Quam	National Science Foundation
Bill Quinn	USA CRREL
John Schindler	Naval Arctic Research Laboratory
Dick Schwendiger	Alyeska Pipeline Service Co.
Bill Shain	Atlantic Richfield Co.
Phil Smith	National Science Foundation
Lowell Thomas, Jr.	University of Alaska
Les Viereck	U.S. Forest Service
Gerd Wendler	University of Alaska
Wendy Wolff	Atlantic Richfield Co.
Jim Zumberge	University of Arizona

APPENDIX E: DATA PROCESSING AND STORAGE

Eve Porter* University of Alaska
Bob Porter and staff Data Processing Section, Geophysical Institute, University of Alaska

In order to process the immense amount of information collected in a program such as this, a considerable effort went into data handling. Data processing at the University of Alaska was initiated in June 1970. Staff of the Geophysical Institute's data processing section were responsible for this phase of the program. The objectives were to make processed data available to the investigator shortly after acquisition of the raw input and to provide statistical and other analytical manipulations of the data so that early inferences could be drawn from the studies and comparisons made among subprojects. Unfortunately the design of the data system began concurrently with the field program without the lead time necessary to design the optimal system. This was necessitated by lack of sufficient funds early enough in the 1970 program. As a result, the first goal of rapid turn-around was achieved by the middle of the summer for most Barrow subprojects. The second goal is still under pursuit. Limited preparation time, personnel, and funds required setting a priority on data processing. Only the Barrow projects which shared common sample periods and sites received top priority treatment in the data processing system. Other projects are now being serviced. By next summer all projects should have equal access to the data processing services.

The first step in the process was the design of format input sheets for each subproject. Field data were transferred to these format sheets at Barrow and mailed to College. The data were edited and key punched. As programs became available the data were processed. For optimal operations, a four-day turn-around was common during each 10-day sample interval.

There are approximately 65 subroutines and 15 mainline processing programs, consisting of about 16,000 source cards. All programs are written in FORTRAN IV or Assembler Language for the IBM 360 Model 40, and have been compiled on DOS Release 21. All programs can be supplied as cards, listings, card image tape, or as a restore tape for an IBM 360. The system is designed with a view to later implementation as a random access retrieval file in order to facilitate cross-correlations between the many different kinds of data collected in the Tundra Biome. The data are entered into the system on punched cards, each sample or sample group being identified by a unique identification number, and each type of data being assigned a "data type" number which is intended to meet U.S. IBP interbiome data banks criteria.

All data are heavily edited before being entered into the system for processing, to assure where possible, that the date, site identification, and the data itself are reasonably within the limitations of computer

*Principal author.

Table EI.

SPECIES NAME=C.AQUATILIS SAMPLE DATE YR=70 MON= 7 DAY=21 SITE NO.= 2

FRAME NUMBER= 1. FRAME INCLINATION= 32.500 DEG. HEIGHT= 20.100 CM. NUMBER OF PINS= 273.
NOTE---IF MORE THAN ONE FRAME AND/OR ONE SAMPLE DATE IN THIS RUN THE DATA INDICATED ABOVE IS FROM THE LAST DATA TO ENTER COMPUTER.

THERE ARE 7 PLOT/QUADRATS IN THIS SITE WHICH HAVE THIS SPECIES. THEY ARE LISTED ON THE NEXT LINE(S).
101 102 103 619 644 615 752

N U M B E R O F C O N T A C T S

HEIGHT	DEAD			LIVE		
RANGE	LEAF	STEM	FLOWER	LEAF	STEM	FLOWER
-XTO-.01 CM.	0.	0.	0.	2.	2.	0.
0 TO4.99 CM.	0.	0.	0.	25.	2.	0.
5 TO9.99 CM.	0.	0.	0.	9.	0.	0.
10-14.99 CM.	0.	0.	0.	1.	0.	0.
15-19.99 CM.	0.	0.	0.	0.	0.	0.
20-24.99 CM.	0.	0.	0.	0.	0.	0.
25-29.99 CM.	0.	0.	0.	0.	0.	0.
30 ON UP	0.	0.	0.	0.	0.	0.
TOTALS=	0.	0.	0.	37.	4.	0.

N U M B E R O F C O N T A C T S P E R P I N

HEIGHT	DEAD			LIVE		
RANGE	LEAF	STEM	FLOWER	LEAF	STEM	FLOWER
-XTO-.01 CM.	0.0	0.0	0.0	0.007	0.007	0.0
0 TO4.99 CM.	0.0	0.0	0.0	0.092	0.007	0.0
5 TO9.99 CM.	0.0	0.0	0.0	0.033	0.0	0.0
10-14.99 CM.	0.0	0.0	0.0	0.004	0.0	0.0
15-19.99 CM.	0.0	0.0	0.0	0.0	0.0	0.0
20-24.99 CM.	0.0	0.0	0.0	0.0	0.0	0.0
25-29.99 CM.	0.0	0.0	0.0	0.0	0.0	0.0
30 ON UP	0.0	0.0	0.0	0.0	0.0	0.0
TOTALS=	0.0	0.0	0.0	0.136	0.015	0.0

L E A F A R E A I N D E X

HEIGHT	DEAD			LIVE		
RANGE	LEAF	STEM	FLOWER	LEAF	STEM	FLOWER
-XTO-.01 CM.	0.0	0.0	0.0	0.008	0.008	0.0
0 TO4.99 CM.	0.0	0.0	0.0	0.101	0.008	0.0
5 TO9.99 CM.	0.0	0.0	0.0	0.036	0.0	0.0
10-14.99 CM.	0.0	0.0	0.0	0.004	0.0	0.0
15-19.99 CM.	0.0	0.0	0.0	0.0	0.0	0.0
20-24.99 CM.	0.0	0.0	0.0	0.0	0.0	0.0
25-29.99 CM.	0.0	0.0	0.0	0.0	0.0	0.0
30 ON UP	0.0	0.0	0.0	0.0	0.0	0.0
TOTALS=	0.0	0.0	0.0	0.149	0.016	0.0

verification. Complete documentation of the program and subroutines are available upon request.

A description of major programs and sample outputs follow:

1. Leaf Area Index (Table EI). The data collected by use of the point frame are edited and analyzed to determine the leaf and stem area by species and total foliage by specific sites and times during the growing season. The point frame consists of a support through which a number of pins (usually 39) can be passed at any set inclination (normally 32.5^{o}). The data for each contact are pin number, distance from pin contact to top of frame, species contacted, live or dead, leaf, stem or flowering structure. The program produces listings and summarized by quad, plot, and site, subdivided by species and later summarized to give total foliage, the output information being the calculated leaf area index, for each of 9 height ranges.

2. Primary Production and Chlorophyll Analysis (Table EII). Destructive sampling of standing foliage in quadrats of specified size permitted laboratory analysis of plant material throughout the season, commencing with harvest of standing dead material before the current year's production had begun, and ending after frost at the end of the season. These samples were weighed and analyzed for chlorophyll content at Barrow. These data were then

Table EII.

PLANT PRODUCTION ANALYSIS, TUNDRA BIOME, BARROW PROJECT, IBP DATA SET A1U01

OUTPUT DATA FOR SPECIES C.AQUATILIS L U

DATA REF.	SITE	PLOT	QUAD FRESH/DRY	CHL A/B	G DRY WT/SQ M	WET/DRY	MG CHL/G DRY	MG CHL/SQ M	MG CHL/SQ DM	MG CHL/G WET
10334	2	6	84**********	13.1055	21.9029	2.7733	6.7644	148.1607	**********	2.4391
10335	2	6	98**********	14.7605	42.0334	2.9348	6.7100	282.0427	**********	2.2863
10336	2	7	0**********	13.1549	28.0517	2.8985	5.9290	166.3192	**********	2.0455
10337	2	7	28**********	9.4154	31.8540	2.0897	4.9949	159.1078	**********	2.3903
10338	2	9	36**********	9.1369	13.8176	3.0987	6.9189	95.6028	**********	2.2329
10339	2	9	84**********	2.6735	1.4435	2.6533	5.1366	7.4146	**********	1.9359
10340	2	10	1**********	16.0405	17.3390	2.4135	7.0107	121.5581	**********	2.9048
10341	2	10	98**********	13.9912	30.2222	2.8664	6.5222	197.1148	**********	2.2754
SUM			**********	92.2784	186.6641	21.7281	49.9867	1177.3201	**********	18.5103
G DRY/SQ M					23.3330					
MEAN			0.0	11.5346	23.3330	2.7160	6.2483	147.1650	0.0	2.3138
STD.DEV.			0.0	4.3193	12.5340	0.3254	0.8013	79.3203	0.0	0.2914
ERROR			0.0	1.1152	3.2363	0.0840	0.2069	20.4804	0.0	0.0752
N			0	8	8	8	8	8	0	8

SUMMARY FOR ALL SPECIES BY QUAD

QUADRAT	G DRY/SQ M	MGCHL/SQ M	MG CHL/G DRY
20684	69.29636	382.96851	5.52653
20698	65.08749	383.45117	5.89132
20700	58.96097	320.25317	5.43161
20728	49.01492	237.14738	4.83827
20936	44.81602	296.18384	6.60888
20984	54.73445	302.68506	5.53006
21001	31.48335	223.63860	7.10339
21098	63.82568	419.51099	6.57276
SUM	437.21875	2565.83838	47.50278
MEAN	54.65234	320.72974	5.93785
STDDEV.	12.48654	70.61606	0.75733
ERROR	3.22401	18.23299	0.19554
N	8	8	8

input to the primary production programs. From the raw data, the following output parameters were generated: Fresh/Dry Ratio; Milligrams Chlorophyll/Sq. Meter; Milligrams Chlorophyll/Sq. Decimeter; Grams Dry Weight/Sq. Meter; Wet/Dry Ratio; Milligrams Chlorophyll/Gram Dry Weight; Milligrams Chlorophyll/Grams Wet Weight; Chlorophyll A/B. These values were calculated for each sample and summarized by species. In addition, output data for each quadrat included a summation of grams dry weight per square meter, milligrams chlorophyll per square meter, and milligrams chlorophyll per gram dry weight. Means, standard deviation, and standard error were calculated throughout.

3. Plant Nutrient (Table EIII, Fig. E1). These programs accept raw laboratory data and output detailed analysis. Input data consists of identification of the species, location, date of the sample, dry weight; percentages of each element as used in calibration curve (percentage transmission); ppm figures relating to the transmission values; order of the polynomial which is to be fit for the calibration; dilution factor for each element; blank value for each element; and an instruction card to indicate which of several processing routes is to be followed for this particular sample. Standard default options are provided throughout, as is the ability to carry the calibration data forward from one sample calculation to another. The program does a polynomial

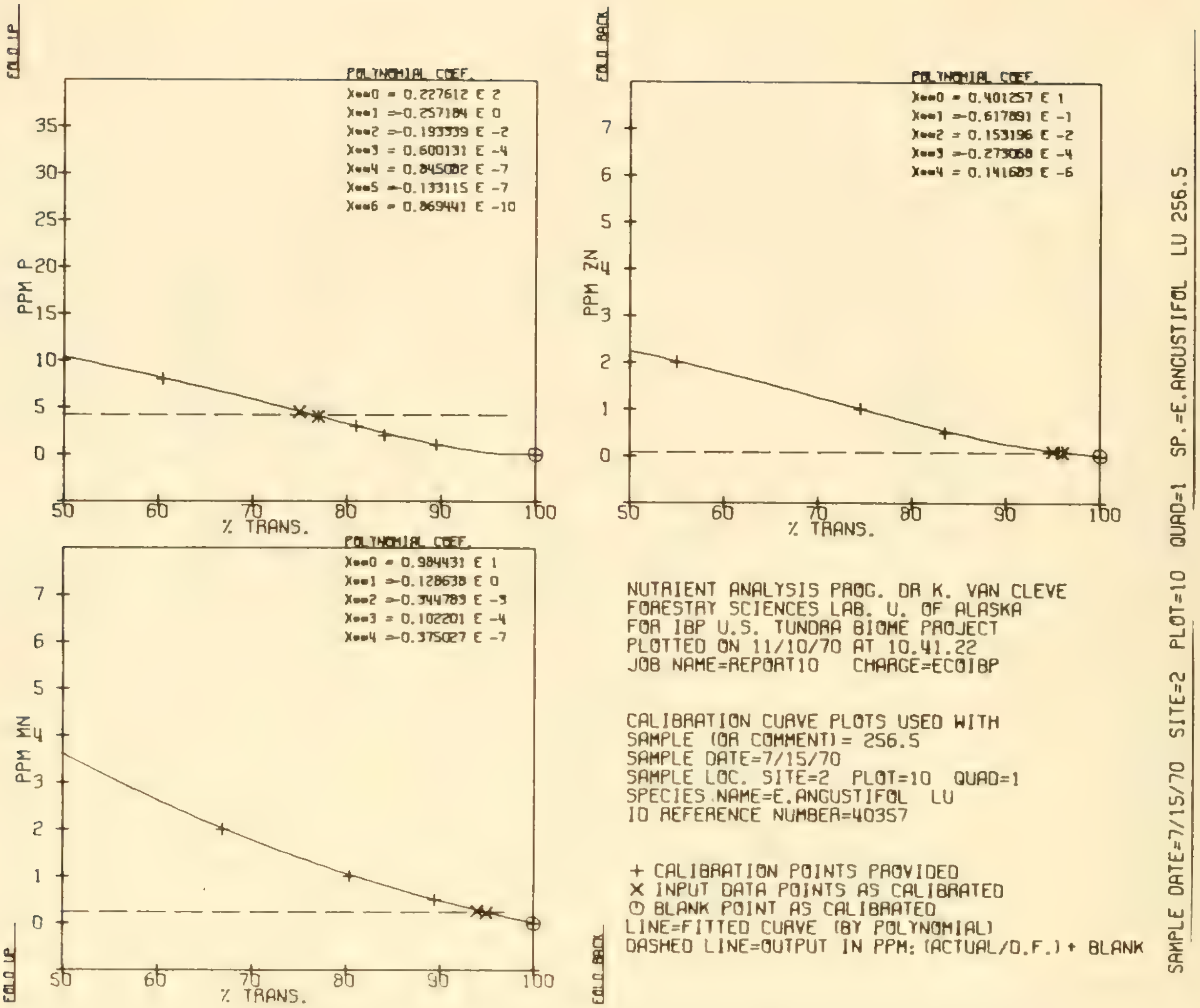

Figure E1.

regression on the calibration curve. Output consists of a graphical presentation of each calibration curve requested, nutrient analysis, and grams per square meter as requested on the input instruction card.

4. Soil Nutrient (Table EIV). Soils data were collected in cores, and preliminary laboratory analysis was performed at Barrow with further analysis at Berkeley. These data consisted of soils classification information, and detailed information on wet/dry weights and chemical composition. The programs provide calculations resulting in comprehensive data on soils structure and composition. ECOSNDST provides means, standard deviations and number of samples for each variable of samples within the set of selected plots for a given data and depth layer.

5. Soil temperature. Data consists of calibration values for each thermistor and depth at which block is buried. Given the block number, the programs return values of depth, temperature coefficient, and location, and converts meter readings (resistance) to degrees C.

Table EIII.

DATA REF. NUMBER	LOC. S/P/Q	SAM.DATE M/D/Y	SPECIES NAME	COMMENT(SAMPLE)		CA	FE	K	MG	MN	P	ZN	N
						PERCENT OF ELEMENT OR GRAMS PER SQ. METER (********=NOT AVAILABLE)							
40353	2 7 0	7/15/70	E.ANGUSTIFOL	LU SAMP 235		0.1010	0.0	0.7006	0.1259	0.0089	0.1779	0.0027	2.5452
40353	2 7 0	7/15/70	E.ANGUSTIFOL	LU SAMP 235	GSM=	0.02383	0.0	0.16524	0.02971	0.00209	0.04195	0.00065	0.60031
40355	2 936	7/15/70	E.ANGUSTIFOL	LU 239		0.0905	0.0	0.8290	0.1219	0.0095	0.1725	0.0042	3.0016
40355	2 936	7/15/70	E.ANGUSTIFOL	LU 239	GSM=	0.01971	0.0	0.18055	0.02656	0.00206	0.03757	0.00092	0.65372
40356	2 984	7/15/70	E.ANGUSTIFOL	LU 241		0.1169	0.0	1.0964	0.1259	0.0089	0.1592	0.0036	2.7244
40356	2 984	7/15/70	E.ANGUSTIFOL	LU 241	GSM=	0.03474	0.0	0.32589	0.03743	0.00263	0.04733	0.00107	0.80978
40357	210 1	7/15/70	E.ANGUSTIFOL	LU 256.5		0.1807	0.0154	0.9321	0.1239	0.0120	0.2106	0.0035	2.8742
40357	210 1	7/15/70	E.ANGUSTIFOL	LU 256.5	GSM=	0.00363	0.00031	0.01875	0.00249	0.00024	0.00424	0.00007	0.05781
40358	21098	7/15/70	E.ANGUSTIFOL	LU 256		0.1807	0.0154	0.9321	0.1239	0.0120	0.2106	0.0035	2.8742
40358	21098	7/15/70	E.ANGUSTIFOL	LU 256	GSM=	0.01406	0.00120	0.07254	0.00965	0.00094	0.01639	0.00027	0.22370
40407	2 857	7/15/70	E.ANGUSTIFOL	LU 243.2		0.1704	0.0260	0.6393	0.1140	0.0064	0.1330	0.0022	2.6768
40407	2 857	7/15/70	E.ANGUSTIFOL	LU 243.2	GSM=	0.04431	0.00676	0.16627	0.02966	0.00166	0.03460	0.00057	0.69619
45308	99999	7/15/70	E.ANGUSTIFOL	LN 243.4		0.1704	0.0260	0.6393	0.1140	0.0064	0.1330	0.0022	2.6768
NO GRAMS PER SQ. METER CALCULATION REQUESTED, OR COULD BE DONE, FOR THE 7. DATA SET.													
45309	99999	7/15/70	E.ANGUSTIFOL	LN 243.6		0.1704	0.0260	0.6393	0.1140	0.0064	0.1330	0.0022	2.6768
NO GRAMS PER SQ. METER CALCULATION REQUESTED, OR COULD BE DONE, FOR THE 8. DATA SET.													
45310	99999	7/15/70	E.ANGUSTIFOL	LU 243		0.1704	0.0260	0.6393	0.1140	0.0064	0.1330	0.0022	2.6768
NO GRAMS PER SQ. METER CALCULATION REQUESTED, OR COULD BE DONE, FOR THE 9. DATA SET.													
40399	2 857	7/15/70	C.AQUATILIS	LU 262.2		0.1966	0.0133	1.0879	0.1279	0.0150	0.1911	0.0018	3.0800
40399	2 857	7/15/70	C.AQUATILIS	LU 262.2	GSM=	0.02223	0.00150	0.12302	0.01447	0.00169	0.02161	0.00020	0.34828
40400	2 875	7/15/70	C.AQUATILIS	LB 262		0.1966	0.0133	1.0879	0.1279	0.0150	0.1911	0.0018	3.0800
40400	2 875	7/15/70	C.AQUATILIS	LB 262	GSM=	0.00435	0.00029	0.02407	0.00283	0.00033	0.00423	0.00004	0.06815
40343	2 684	7/15/70	D.FISCHERI	LU 277		0.1598	0.0111	1.3337	0.1081	0.0186	0.1554	0.0022	2.3478
40343	2 684	7/15/70	D.FISCHERI	LU 277	GSM=	0.03982	0.00278	0.33241	0.02694	0.00465	0.03873	0.00055	0.58515
40344	2 698	7/15/70	D.FISCHERI	LU 280		0.1440	0.0254	1.4897	0.1178	0.0227	0.1834	0.0016	2.3702
40344	2 698	7/15/70	D.FISCHERI	LU 280	GSM=	0.02529	0.00447	0.26171	0.02070	0.00399	0.03221	0.00028	0.41639
40345	2 7 0	7/15/70	D.FISCHERI	LU 282		0.1068	0.0254	1.7215	0.0571	0.0278	0.1766	0.0030	2.5928
40345	2 7 0	7/15/70	D.FISCHERI	LU 282	GSM=	0.00423	0.00101	0.06821	0.00226	0.00110	0.00700	0.00012	0.10273
40346	2 728	7/15/70	D.FISCHERI	LU 284		0.1068	0.0254	1.7215	0.0571	0.0278	0.1766	0.0030	2.5928
40346	2 728	7/15/70	D.FISCHERI	LU 284	GSM=	0.00656	0.00156	0.10582	0.00351	0.00171	0.01085	0.00019	0.15938

Table EIV(1).

SOIL NUTRIENT ANALYSIS -- A1U06.

SOIL DATA - PEDOLOGY AND NUTRIENT CYCLING - SOIL MOISTURE AND CHEMICAL DATA - SAMPLE DATE 7/16/70

SAMPLE REF NO	SPQ	DEPTHS UPPER CMS.	DEPTHS LOWER CMS.	SOIL COLOR HUE	SOIL COLOR HUE CODE	SOIL COLOR VALUE/ CHROMA	TEXTURE	GRAVEL PCT.	ROOTS	PH ELEC- TRODE	REDOX MICRO- AMPS	HORIZON
60101	20684	0.0	5.0	7.5YR	3	3/ 2	SILTY PEAT	0.0	MANY	5.2	225.00	01
60102	20684	5.0	10.0	10YR	2	3/ 2	MUCK	0.0	COMMON	5.6	225.00	02
60103	20684	10.0	15.0	10YR	2	3/ 3	MUCK	0.0	MANY	6.0	200.00	02
60104	20684	15.0	20.0	5YR	0	2/ 2	MUCK	0.0	FEW	5.7	275.00	02
60105	20698	0.0	5.0	7.5YR	3	3/ 2	PEAT	0.0	MANY	5.2	280.00	01
60106	20698	5.0	10.0	7.5YR	3	3/ 2	SILTY PEAT	0.0	MANY	5.4	285.00	01
60107	20698	10.0	15.0	7.5YR	3	3/ 2	SILTY MUCK	0.0	MANY	5.3	320.00	02
60108	20698	15.0	20.0	5YR	0	2/ 2	PEAT	0.0	FEW	5.1	295.00	C1
60109	20700	0.0	5.0	10YR	2	3/ 2	PEAT	0.0	MANY	4.9	265.00	01
60110	20700	5.0	10.0	10YR	2	4/ 2	CLAY LOAM	0.0	MANY	5.6	225.00	C1
60111	20700	10.0	15.0	5YR	0	2/ 2	MUCK	0.0	MANY	6.1	200.00	II02
60112	20728	0.0	5.0	5YR	0	3/ 2	PEAT	0.0	MANY	5.0	325.00	01
60113	20728	5.0	10.0	5YR	0	2/ 2	SILTY PEAT	0.0	MANY	5.3	295.00	01
60114	20728	10.0	15.0	5YR	0	2/ 2	SILTY MUCK	0.0	MANY	5.7	235.00	02
60115	20857	0.0	5.0	5YR	0	2/ 2	SILTY PEAT	0.0	MANY	5.2	300.00	01
60116	20857	5.0	10.0	10YR	2	3/ 3	SILTY MUCK	0.0	COMMON	5.6	275.00	02
60117	20857	10.0	15.0	5YR	0	2/ 2	MUCK	0.0	COMMON	5.5	270.00	02
60118	20857	15.0	20.0	5YR	0	2/ 2	SILTY PEAT	0.0	FEW	5.3	250.00	C1
60119	20875	0.0	5.0	10YR	2	3/ 3	SILTY PEAT	0.0	MANY	5.1	265.00	01
60120	20875	5.0	10.0	10YR	2	3/ 3	SILTY MUCK	0.0	MANY	5.6	245.00	02
60121	20875	10.0	15.0	10YR	2	3/ 3	MUCK	0.0	COMMON	5.4	220.00	C1
60122	20936	0.0	5.0	7.5YR	3	3/ 2	SILTY PEAT	0.0	MANY	5.3	235.00	01
60123	20936	5.0	10.0	7.5YR	3	3/ 2	SILTY MUCK	0.0	MANY	5.4	175.00	02
60124	20936	10.0	15.0	5YR	0	2/ 2	MUCK	0.0	MANY	5.3	200.00	02
60125	20936	15.0	20.0	10YR	2	3/ 3	PEAT	0.0	FEW	5.4	190.00	C1
60126	20984	0.0	5.0	10YR	2	3/ 3	SILTY PEAT	0.0	MANY	5.5	190.00	01
60127	20984	5.0	10.0	10YR	2	3/ 3	CLAY LOAM	0.0	COMMON	5.6	85.00	C1
60128	20984	10.0	15.0	10YR	2	3/ 3	SILTY MUCK	0.0	COMMON	5.5	150.00	II01
60129	20984	15.0	20.0	5YR	0	2/ 2	MUCK	0.0	FEW	5.1	125.00	II02
60130	21001	0.0	5.0	5YR	0	2/ 2	SILTY PEAT	0.0	MANY	5.0	330.00	01
60131	21001	5.0	10.0	5YR	0	2/ 2	SILTY MUCK	0.0	MANY	5.0	240.00	02
60132	21001	10.0	15.0	10YR	2	3/ 2	MUCK	0.0	MANY	5.5	230.00	02
60133	21098	0.0	5.0	7.5YR	3	3/ 2	SILTY PEAT	0.0	MANY	5.5	210.00	01
60134	21098	5.0	10.0	10YR	2	3/ 2	CLAY LOAM	0.0	MANY	5.2	285.00	C1
60135	21098	10.0	15.0	10YR	2	3/ 2	CLAY LOAM	0.0	COMMON	5.4	210.00	C1
60136	21098	15.0	20.0	7.5YR	3	3/ 2	MUCK	0.0	FEW	5.6	240.00	II01

Table EIV(2).

SOIL NUTRIENT ANALYSIS -- A1U06.
SOIL DATA - PEDOLOGY AND NUTRIENT CYCLING - SOIL MOISTURE AND CHEMICAL DATA - SAMPLE DATE 7/16/70

SAMPLE REF NO	SPQ	DEPTHS UPPER CMS.	DEPTHS LOWER CMS.	MOISTURE G/100G DWT 70 C	MOISTURE G/100G DWT 105 C	WET WEIGHT GM.	DRY WEIGHT 70 C	DRY WEIGHT 105 C	H2O ADDED	EXTRACT VOLUME ML.	E.C. MMHOS	WATER DEPTH CMS.	PH EXTRACT
60101	20684	0.0	5.0	393.8	404.0	1115.1	225.8	221.2	0.0	210.0	125.0	*****	6.3
60102	20684	5.0	10.0	119.2	121.8	1218.6	555.9	549.4	41.8	148.0	150.5	*****	5.4
60103	20684	10.0	15.0	118.2	121.0	1142.0	523.4	516.7	80.2	128.0	186.0	*****	5.7
60104	20684	15.0	20.0	149.5	152.1	1057.3	423.8	419.4	104.1	105.0	176.0	*****	6.0
60105	20698	0.0	5.0	393.8	401.5	1103.0	223.4	219.9	30.3	200.0	119.5	*****	6.0
60106	20698	5.0	10.0	165.5	169.0	1042.0	392.5	387.4	97.5	116.0	155.0	*****	5.8
60107	20698	10.0	15.0	170.1	173.9	1166.0	431.7	425.7	140.3	130.0	184.0	*****	6.0
60108	20698	15.0	20.0	381.0	389.4	930.0	193.3	190.0	59.3	216.0	157.5	*****	5.6
60109	20700	0.0	5.0	520.0	534.9	1196.0	192.9	188.4	0.0	260.0	92.0	*****	6.3
60110	20700	5.0	10.0	76.7	78.5	1226.7	694.2	687.2	100.3	102.0	******	*****	6.3
60111	20700	10.0	15.0	97.4	99.3	1201.3	608.6	602.8	113.8	125.0	131.0	*****	5.8
60112	20728	0.0	5.0	721.0	749.0	1019.5	124.2	120.1	62.5	170.0	96.5	15.0	5.7
60113	20728	5.0	10.0	188.0	194.0	1076.7	373.9	366.2	173.0	121.0	148.5	*****	6.3
60114	20728	10.0	15.0	199.6	204.0	1013.5	338.3	333.4	58.5	148.0	124.0	*****	6.4
60115	20857	0.0	5.0	318.0	327.0	936.6	224.1	219.3	59.6	190.0	125.5	*****	6.0
60116	20857	5.0	10.0	148.1	160.9	1092.9	440.5	418.9	148.3	195.0	184.5	*****	6.1
60117	20857	10.0	15.0	212.0	216.0	1077.8	345.4	341.1	116.0	130.0	171.0	*****	5.5
60118	20857	15.0	20.0	158.2	161.0	1030.7	399.2	394.9	55.6	152.0	153.5	*****	5.4
60119	20875	0.0	5.0	331.8	343.0	1228.6	284.5	277.3	46.9	180.0	154.5	*****	5.9
60120	20875	5.0	10.0	152.4	155.5	1113.1	441.0	435.7	78.3	120.0	181.0	*****	6.0
60121	20875	10.0	15.0	155.8	154.5	1118.0	437.1	439.3	152.2	167.0	150.5	*****	5.5
60122	20936	0.0	5.0	252.0	257.9	1068.0	303.4	298.4	830.0	127.0	163.5	*****	5.7
60123	20936	5.0	10.0	178.9	186.6	1017.8	364.9	355.1	43.1	153.0	164.5	*****	6.0
60124	20936	10.0	15.0	202.3	209.9	987.4	326.6	318.6	141.1	165.0	194.5	*****	5.0
60125	20936	15.0	20.0	266.0	273.0	1082.9	295.9	290.3	60.3	181.0	134.0	*****	5.3
60126	20984	0.0	5.0	82.2	169.6	1332.3	731.1	494.2	62.0	150.0	104.0	*****	5.8
60127	20984	5.0	10.0	115.5	123.9	1321.7	613.3	590.3	91.0	135.0	123.5	*****	5.4
60128	20984	10.0	15.0	127.7	102.1	1226.8	538.8	607.0	92.9	137.0	199.0	*****	5.1
60129	20984	15.0	20.0	52.3	180.0	980.7	644.0	350.3	55.4	166.0	154.5	*****	5.8
60130	21001	0.0	5.0	311.0	318.9	962.4	234.2	229.7	72.1	140.0	145.0	*****	5.4
60131	21001	5.0	10.0	166.1	169.0	1014.8	381.4	377.2	84.4	110.0	176.0	*****	5.8
60132	21001	10.0	15.0	178.0	182.5	1027.0	369.4	363.5	212.2	200.0	191.0	*****	5.4
60133	21098	0.0	5.0	317.0	321.9	877.1	210.3	207.9	0.0	240.0	103.2	*****	6.5
60134	21098	5.0	10.0	53.6	54.6	1402.1	912.8	906.9	65.8	146.0	125.0	*****	6.6
60135	21098	10.0	15.0	51.9	52.3	1501.5	988.5	985.9	108.2	158.0	150.5	*****	6.3
60136	21098	15.0	20.0	65.4	67.0	1123.3	679.1	672.6	30.4	121.0	177.8	*****	*******

Table EIV(3).

SOIL NUTRIENT ANALYSIS -- A1U06.
SOIL DATA - PEDOLOGY AND NUTRIENT CYCLING - SOIL MOISTURE AND CHEMICAL DATA - SAMPLE DATE 7/16/70

SAMPLE REF NO	SPQ	DEPTHS UPPER CMS.	DEPTHS LOWER CMS.	ALUMINUM AL PPM	ALUMINUM AL MEQ/L	TOTAL IRON FE PPM	TOTAL IRON FE MMOL/L	FERROUS IRON FE+2 PPM	FERROUS IRON FE+2 MEQ/L	FERRIC IRON FE+3 PPM	FERRIC IRON FE+3 MEQ/L	MANGANESE MN+4 PPM	MANGANESE MN+4 MEQ/L	AMMONIUM N PPM	AMMONIUM NH3 MEQ/L
60101	20684	0.0	5.0	0.95	0.106	3.75	0.067	0.20	0.007	3.55	0.191	0.0	0.0	2.50	0.178
60102	20684	5.0	10.0	3.03	0.337	11.21	0.201	1.17	0.042	10.04	0.539	0.0	0.0	5.37	0.383
60103	20684	10.0	15.0	2.03	0.226	4.51	0.081	0.39	0.014	4.12	0.221	0.0	0.0	4.51	0.322
60104	20684	15.0	20.0	0.87	0.097	3.14	0.056	0.81	0.029	2.33	0.125	0.0	0.0	5.64	0.403
60105	20698	0.0	5.0	1.19	0.132	5.74	0.103	0.41	0.015	5.33	0.286	0.0	0.0	4.55	0.325
60106	20698	5.0	10.0	2.24	0.249	6.15	0.110	0.34	0.012	5.80	0.312	0.0	0.0	6.61	0.472
60107	20698	10.0	15.0	3.09	0.344	8.09	0.145	1.31	0.047	6.78	0.364	0.0	0.0	5.83	0.416
60108	20698	15.0	20.0	2.16	0.240	5.24	0.094	0.70	0.025	4.54	0.244	0.0	0.0	9.72	0.694
60109	20700	0.0	5.0	0.45	0.050	3.15	0.056	0.35	0.013	2.80	0.150	0.0	0.0	2.55	0.182
60110	20700	5.0	10.0	1.48	0.165	5.16	0.092	0.53	0.019	4.63	0.248	0.0	0.0	4.80	0.343
60111	20700	10.0	15.0	6.25	0.695	11.25	0.201	1.37	0.049	9.88	0.531	0.0	0.0	10.29	0.735
60112	20728	0.0	5.0	0.96	0.107	9.15	0.164	0.53	0.019	8.61	0.463	0.0	0.0	3.26	0.233
60113	20728	5.0	10.0	1.43	0.159	6.11	0.109	0.37	0.013	5.73	0.308	0.0	0.0	6.23	0.445
60114	20728	10.0	15.0	1.41	0.157	4.51	0.081	0.71	0.025	3.80	0.204	0.0	0.0	4.89	0.349
60115	20857	0.0	5.0	1.79	0.199	5.80	0.104	0.65	0.023	5.15	0.276	0.0	0.0	4.71	0.336
60116	20857	5.0	10.0	6.75	0.751	10.49	0.188	1.23	0.044	9.27	0.498	0.0	0.0	11.66	0.832
60117	20857	10.0	15.0	5.96	0.663	11.57	0.207	1.45	0.052	10.13	0.544	0.0	0.0	11.46	0.818
60118	20857	15.0	20.0	6.52	0.726	11.09	0.199	1.36	0.049	9.73	0.523	0.0	0.0	10.33	0.737
60119	20875	0.0	5.0	2.89	0.321	12.75	0.228	1.47	0.053	11.28	0.606	0.0	0.0	5.51	0.393
60120	20875	5.0	10.0	2.34	0.261	5.35	0.096	0.45	0.016	4.91	0.264	0.0	0.0	7.25	0.518
60121	20875	10.0	15.0	3.80	0.422	11.69	0.209	2.02	0.072	9.67	0.520	0.0	0.0	10.90	0.778
60122	20936	0.0	5.0	6.47	0.719	23.78	0.426	1.67	0.060	22.11	1.187	0.0	0.0	11.68	0.834
60123	20936	5.0	10.0	2.51	0.279	5.76	0.103	0.64	0.023	5.12	0.275	0.0	0.0	5.54	0.396
60124	20936	10.0	15.0	4.55	0.506	11.10	0.199	1.03	0.037	10.07	0.541	0.0	0.0	9.71	0.693
60125	20936	15.0	20.0	1.61	0.180	3.77	0.067	0.32	0.012	3.45	0.185	0.0	0.0	5.76	0.411
60126	20984	0.0	5.0	0.99	0.110	3.47	0.062	0.33	0.012	3.14	0.169	0.0	0.0	3.14	0.224
60127	20984	5.0	10.0	4.74	0.527	6.09	0.109	0.73	0.026	5.36	0.288	0.0	0.0	5.08	0.362
60128	20984	10.0	15.0	2.87	0.320	6.44	0.115	0.46	0.016	5.98	0.321	0.0	0.0	63.82	4.555
60129	20984	15.0	20.0	2.50	0.278	4.43	0.079	0.52	0.019	3.90	0.210	0.0	0.0	8.50	0.607
60130	21001	0.0	5.0	1.26	0.141	3.41	0.061	0.44	0.016	2.97	0.159	0.0	0.0	7.36	0.526
60131	21001	5.0	10.0	2.77	0.308	5.10	0.091	0.68	0.024	4.42	0.237	0.0	0.0	10.19	0.727
60132	21001	10.0	15.0	8.31	0.925	13.92	0.249	0.53	0.019	13.40	0.720	0.0	0.0	24.15	1.724
60133	21098	0.0	5.0	0.80	0.089	6.20	0.111	0.20	0.007	6.00	0.322	0.0	0.0	2.20	0.157
60134	21098	5.0	10.0	1.42	0.157	5.21	0.093	0.23	0.008	4.98	0.268	0.0	0.0	3.00	0.214
60135	21098	10.0	15.0	0.36	0.040	1.27	0.023	0.18	0.006	1.09	0.058	1.21	0.088	2.30	0.164
60136	21098	15.0	20.0	0.48	0.053	3.26	0.058	0.16	0.006	3.10	0.166	0.0	0.0	2.40	0.171

Table EIV(4).

SOIL NUTRIENT ANALYSIS -- A1U06.
SOIL DATA - PEDOLOGY AND NUTRIENT CYCLING - SOIL MOISTURE AND CHEMICAL DATA - SAMPLE DATE 7/16/70

SAMPLE REF NO	SPQ	DEPTHS UPPER	DEPTHS LOWER	ALUMINUM AL		TOTAL IRON FE		FERROUS IRON FE+2		FERRIC IRON FE+3		MANGANESE MN+4		AMMONIUM N	NH3
		CMS.		PPM	MEQ/L	PPM	MMOL/L	PPM	MEQ/L	PPM	MEQ/L	PPM	MEQ/L	PPM	MEQ/L
60101	20684	0.0	5.0	0.95	0.106	3.75	0.067	0.20	0.007	3.55	0.191	0.0	0.0	2.50	0.178
60102	20684	5.0	10.0	3.03	0.337	11.21	0.201	1.17	0.042	10.04	0.539	0.0	0.0	5.37	0.383
60103	20684	10.0	15.0	2.03	0.226	4.51	0.081	0.39	0.014	4.12	0.221	0.0	0.0	4.51	0.322
60104	20684	15.0	20.0	0.87	0.097	3.14	0.056	0.81	0.029	2.33	0.125	0.0	0.0	5.64	0.403
60105	20698	0.0	5.0	1.19	0.132	5.74	0.103	0.41	0.015	5.33	0.286	0.0	0.0	4.55	0.325
60106	20698	5.0	10.0	2.24	0.249	6.15	0.110	0.34	0.012	5.80	0.312	0.0	0.0	6.61	0.472
60107	20698	10.0	15.0	3.09	0.344	8.09	0.145	1.31	0.047	6.78	0.364	0.0	0.0	5.83	0.416
60108	20698	15.0	20.0	2.16	0.240	5.24	0.094	0.70	0.025	4.54	0.244	0.0	0.0	9.72	0.694
60109	20700	0.0	5.0	0.45	0.050	3.15	0.056	0.35	0.013	2.80	0.150	0.0	0.0	2.55	0.182
60110	20700	5.0	10.0	1.48	0.165	5.16	0.092	0.53	0.019	4.63	0.248	0.0	0.0	4.80	0.343
60111	20700	10.0	15.0	6.25	0.695	11.25	0.201	1.37	0.049	9.88	0.531	0.0	0.0	10.29	0.735
60112	20728	0.0	5.0	0.96	0.107	9.15	0.164	0.53	0.019	8.61	0.463	0.0	0.0	3.26	0.233
60113	20728	5.0	10.0	1.43	0.159	6.11	0.109	0.37	0.013	5.73	0.308	0.0	0.0	6.23	0.445
60114	20728	10.0	15.0	1.41	0.157	4.51	0.081	0.71	0.025	3.80	0.204	0.0	0.0	4.89	0.349
60115	20857	0.0	5.0	1.79	0.199	5.80	0.104	0.65	0.023	5.15	0.276	0.0	0.0	4.71	0.336
60116	20857	5.0	10.0	6.75	0.751	10.49	0.188	1.23	0.044	9.27	0.498	0.0	0.0	11.66	0.832
60117	20857	10.0	15.0	5.96	0.663	11.57	0.207	1.45	0.052	10.13	0.544	0.0	0.0	11.46	0.818
60118	20857	15.0	20.0	6.52	0.726	11.09	0.199	1.36	0.049	9.73	0.523	0.0	0.0	10.33	0.737
60119	20875	0.0	5.0	2.89	0.321	12.75	0.228	1.47	0.053	11.28	0.606	0.0	0.0	5.51	0.393
60120	20875	5.0	10.0	2.34	0.261	5.35	0.096	0.45	0.016	4.91	0.264	0.0	0.0	7.25	0.518
60121	20875	10.0	15.0	3.80	0.422	11.69	0.209	2.02	0.072	9.67	0.520	0.0	0.0	10.90	0.778
60122	20936	0.0	5.0	6.47	0.719	23.78	0.426	1.67	0.060	22.11	1.187	0.0	0.0	11.68	0.834
60123	20936	5.0	10.0	2.51	0.279	5.76	0.103	0.64	0.023	5.12	0.275	0.0	0.0	5.54	0.396
60124	20936	10.0	15.0	4.55	0.506	11.10	0.199	1.03	0.037	10.07	0.541	0.0	0.0	9.71	0.693
60125	20936	15.0	20.0	1.61	0.180	3.77	0.067	0.32	0.012	3.45	0.185	0.0	0.0	5.76	0.411
60126	20984	0.0	5.0	0.99	0.110	3.47	0.062	0.33	0.012	3.14	0.169	0.0	0.0	3.14	0.224
60127	20984	5.0	10.0	4.74	0.527	6.09	0.109	0.73	0.026	5.36	0.288	0.0	0.0	5.08	0.362
60128	20984	10.0	15.0	2.87	0.320	6.44	0.115	0.46	0.016	5.98	0.321	0.0	0.0	63.82	4.555
60129	20984	15.0	20.0	2.50	0.278	4.43	0.079	0.52	0.019	3.90	0.210	0.0	0.0	8.50	0.607
60130	21001	0.0	5.0	1.26	0.141	3.41	0.061	0.44	0.016	2.97	0.159	0.0	0.0	7.36	0.526
60131	21001	5.0	10.0	2.77	0.308	5.10	0.091	0.68	0.024	4.42	0.237	0.0	0.0	10.19	0.727
60132	21001	10.0	15.0	8.31	0.925	13.92	0.249	0.53	0.019	13.40	0.720	0.0	0.0	24.15	1.724
60133	21098	0.0	5.0	0.80	0.089	6.20	0.111	0.20	0.007	6.00	0.322	0.0	0.0	2.20	0.157
60134	21098	5.0	10.0	1.42	0.157	5.21	0.093	0.23	0.008	4.98	0.268	0.0	0.0	3.00	0.214
60135	21098	10.0	15.0	0.36	0.040	1.27	0.023	0.18	0.006	1.09	0.058	1.21	0.088	2.30	0.164
60136	21098	15.0	20.0	0.48	0.053	3.26	0.058	0.16	0.006	3.10	0.166	0.0	0.0	2.40	0.171

Table EIV(5).

SOIL NUTRIENT ANALYSIS -- A1U06.
SOIL DATA - PEDOLOGY AND NUTRIENT CYCLING - SOIL MOISTURE AND CHEMICAL DATA - SAMPLE DATE 7/16/70

SAMPLE REF NO	SPQ	DEPTHS UPPER	DEPTHS LOWER	SODIUM NA		POTASSIUM K		CALCIUM CA		MAGNESIUM MG		VW 70	VW 105	WWB 70	WWB 105
		CMS.		PPM	MEQ/L	PPM	MEQ/L	PPM	MEQ/L	PPM	MEQ/L	G/CC	G/CC	G/100G	G/100G
60101	20684	0.0	5.0	8.10	0.352	0.51	0.013	6.21	0.310	2.68	0.220	0.256	0.250	*******	*******
60102	20684	5.0	10.0	10.26	0.446	0.71	0.018	7.67	0.382	4.06	0.334	0.629	0.622	*******	*******
60103	20684	10.0	15.0	14.84	0.645	1.01	0.026	7.57	0.378	4.80	0.395	0.592	0.585	*******	*******
60104	20684	15.0	20.0	16.61	0.722	1.14	0.029	10.84	0.541	4.17	0.343	0.480	0.475	*******	*******
60105	20698	0.0	5.0	8.76	0.381	0.77	0.020	9.54	0.476	4.15	0.341	0.253	0.249	*******	*******
60106	20698	5.0	10.0	9.46	0.411	0.90	0.023	9.44	0.471	4.19	0.345	0.444	0.438	*******	*******
60107	20698	10.0	15.0	14.12	0.614	1.53	0.039	6.44	0.321	5.06	0.416	0.489	0.482	*******	*******
60108	20698	15.0	20.0	10.19	0.443	1.14	0.029	11.48	0.573	5.19	0.427	0.219	0.215	*******	*******
60109	20700	0.0	5.0	5.38	0.234	0.86	0.022	4.51	0.225	1.68	0.138	0.218	0.213	*******	*******
60110	20700	5.0	10.0	6.30	0.274	1.11	0.028	*****	*****	*****	*****	0.786	0.778	*******	*******
60111	20700	10.0	15.0	9.58	0.417	2.14	0.055	11.81	0.589	4.49	0.369	0.689	0.682	*******	*******
60112	20728	0.0	5.0	6.64	0.289	0.92	0.024	5.15	0.257	2.21	0.182	0.141	0.136	*******	*******
60113	20728	5.0	10.0	7.77	0.338	1.02	0.026	6.37	0.318	2.91	0.239	0.423	0.414	*******	*******
60114	20728	10.0	15.0	10.77	0.468	0.93	0.024	7.73	0.386	3.31	0.273	0.383	0.377	*******	*******
60115	20857	0.0	5.0	9.07	0.392	0.76	0.020	13.25	0.661	3.44	0.283	0.254	0.248	*******	*******
60116	20857	5.0	10.0	16.15	0.702	3.31	0.085	16.11	0.804	7.24	0.595	0.499	0.474	*******	*******
60117	20857	10.0	15.0	11.34	0.493	0.50	0.013	12.87	0.642	5.70	0.469	0.391	0.386	*******	*******
60118	20857	15.0	20.0	15.01	0.652	2.08	0.053	10.02	0.500	4.43	0.364	0.452	0.447	*******	*******
60119	20875	0.0	5.0	9.05	0.394	3.78	0.097	9.99	0.499	3.51	0.289	0.322	0.314	*******	*******
60120	20875	5.0	10.0	10.52	0.457	1.00	0.026	9.84	0.491	3.73	0.307	0.499	0.493	*******	*******
60121	20875	10.0	15.0	12.36	0.537	1.01	0.026	12.76	0.637	4.99	0.410	0.495	0.497	*******	*******
60122	20936	0.0	5.0	16.64	0.724	1.55	0.040	16.09	0.803	7.48	0.615	0.343	0.338	*******	*******
60123	20936	5.0	10.0	11.08	0.482	1.25	0.032	11.11	0.554	5.96	0.490	0.413	0.402	*******	*******
60124	20936	10.0	15.0	15.63	0.680	1.99	0.051	18.85	0.940	8.78	0.722	0.370	0.361	*******	*******
60125	20936	15.0	20.0	9.16	0.398	0.93	0.024	9.71	0.484	4.32	0.355	0.335	0.329	*******	*******
60126	20984	0.0	5.0	9.18	0.399	1.29	0.033	5.42	0.270	2.35	0.193	0.827	0.559	*******	*******
60127	20984	5.0	10.0	11.71	0.509	0.84	0.021	5.54	0.276	2.95	0.243	0.694	0.668	*******	*******
60128	20984	10.0	15.0	10.02	0.436	1.35	0.034	10.37	0.517	6.40	0.527	0.610	0.687	*******	*******
60129	20984	15.0	20.0	12.72	0.553	2.19	0.056	8.28	0.413	6.30	0.518	0.729	0.396	*******	*******
60130	21001	0.0	5.0	11.12	0.484	1.63	0.042	10.90	0.544	4.14	0.341	0.265	0.260	*******	*******
60131	21001	5.0	10.0	13.99	0.608	2.13	0.054	15.77	0.787	5.65	0.464	0.432	0.427	*******	*******
60132	21001	10.0	15.0	13.66	0.594	1.14	0.029	2.91	0.145	9.23	0.759	0.418	0.411	*******	*******
60133	21098	0.0	5.0	5.89	0.256	0.86	0.022	5.17	0.258	1.88	0.155	0.238	0.235	*******	*******
60134	21098	5.0	10.0	11.15	0.485	0.93	0.024	7.95	0.397	3.31	0.272	1.033	1.026	*******	*******
60135	21098	10.0	15.0	14.53	0.632	1.80	0.046	8.73	0.436	3.75	0.309	1.119	1.116	*******	*******
60136	21098	15.0	20.0	3.17	0.138	0.50	0.013	2.78	0.139	0.93	0.077	0.769	0.761	*******	*******

Table EV.

SOD SAMPLES - TIPULIDAE,MUSCIDAE - S I T E - 2

DATE JULY 16, 1970
SPECIES PEDICIA

LENGTHS IN MILLIMETERS

LOCAT	SIZE MM	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	GT31	SUM
P QUAD 1	N	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
L	N/M2	0	0	0	0	0	0	0	0	0	0	27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	27
O QUAD 98	N	0	0	0	0	0	0	0	1	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4
T	N/M2	0	0	0	0	0	0	0	27	27	0	27	27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	111
10	N	0	0	0	0	0	0	0	1	1	0	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5
	N/M2	0	0	0	0	0	0	0	13	13	0	27	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	69
	BIOMASS GRAMS/M2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0091	0.0117	0.0	0.0378	0.0260	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.084

S I T E S U M M A R Y

LOCAT	SIZE MM	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	GT31	SUM
	N	0	1	1	1	3	3	1	7	6	2	6	10	16	8	8	5	5	0	0	0	0	0	0	0	0	0	0	0	83
	N/M2	0	2	2	2	8	8	2	19	16	5	16	27	44	22	22	13	13	0	0	0	0	0	0	0	0	0	0	0	230
	BIOMASS GRAMS/M2	0.0	0.0004	0.0006	0.0006	0.0024	0.0032	0.0010	0.0133	0.0144	0.0055	0.0224	0.0540	0.1100	0.0660	0.0770	0.0572	0.0702	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.498

SOD SAMPLES - OTHER BEASTS - S I T E - 2

DATE JULY 16, 1970

LOCAT	SPECIES	NEMATODES	OLIGOCHAETES	MITES	COLLEMBOLA	NEMATOCERA L.	NEMATOCERA AD.	CARABIDAE L.	CARABIDAE AD.	STAPHYLINIDAE L.	STAPHYLINIDAE AD	CHRYSOMELIDAE	CHILOXANTHUS	OTHERS
P QUAD 36	N	1	5	288	1820	11	0	0	1	0	0	0	0	0
L	N/M2	27	138	8000	50559	305	0	0	27	0	0	0	0	0
O QUAD 84	N	0	3	428	2724	8	0	0	0	0	0	0	0	0
T	N/M2	0	83	11889	75672	222	0	0	0	0	0	0	0	0
9	N	1	8	716	4544	19	0	0	1	0	0	0	0	0
	N/M2	13	111	9945	63116	263	0	0	13	0	0	0	0	0

S I T E S U M M A R Y --- 20 SAMPLES USED IN CALCULATIONS

LOCAT	SPECIES	NEMATODES	OLIGOCHAETES	MITES	COLLEMBOLA	NEMATOCERA L.	NEMATOCERA AD.	CARABIDAE L.	CARABIDAE AD.	STAPHYLINIDAE L.	STAPHYLINIDAE AD	CHRYSOMELIDAE	CHILOXANTHUS	OTHERS
	N	2	77	4236	21468	121	2	2	2	1	2	0	1	0
	N/M2	5	213	11767	59638	336	5	5	5	2	5	0	2	0

6. Soil Arthropods (Table EV). These data consist of observations of numbers of soil arthropods in three categories of collection methods: sod samples, tanglefoot boards, and emergence traps. The programs provide number per square meter for all species, and biomass in certain species for sod samples, with correlation coefficients.

7. Depth of Thaw (Table EVI). These data consist of observed thaw readings, both in cores and plots. Output is a listing of the input data, with each set of data summarized to give maximum thaw, minimum thaw, number of readings, mean, standard deviation and standard error. Summaries for each day or sample interval provide maximum and minimum thaw, number of readings, mean, standard deviation and standard error for that sample.

Table EVI.

DEPTH OF THAW STUDY

PLOT DATA, BARROW, ALASKA 7/14/70 SITE 2

	2 1	2 2	2 3	2 4	2 5	2 6	2 7	2 8	2 9	210	226	227	228	229	230	231	232	233	234	235	236
1	24.0	18.0	26.0	23.0	21.0	21.0	21.0	24.0	24.0	19.0	25.0	27.0	21.0	20.0	23.0	20.0	23.0	21.0	21.0	24.0	22.0
2	23.0	17.0	28.0	24.0	20.0	21.0	21.0	21.0	22.0	20.0	24.0	28.0	19.0	22.0	72.0	17.0	22.0	22.0	20.0	24.0	20.0
3	23.0	20.0	24.0	24.0	19.0	23.0	21.0	24.0	20.0	24.0	23.0	27.0	21.0	16.0	21.0	18.0	23.0	20.0	19.0	22.0	22.0
4	21.0	21.0	25.0	23.0	20.0	24.0	21.0	23.0	19.0	20.0	23.0	27.0	22.0	19.0	20.0	21.0	24.0	19.0	20.0	21.0	22.0
5	21.0	19.0	24.0	22.0	20.0	23.0	20.0	23.0	23.0	24.0	24.0	29.0	20.0	21.0	19.0	22.0	23.0	20.0	16.0	23.0	20.0
6	21.0	18.0	24.0	18.0	19.0	21.0	20.0	24.0	21.0	19.0	24.0	34.0	20.0	21.0	18.0	22.0	21.0	19.0	17.0	24.0	20.0
7	20.0	16.0	22.0	18.0	20.0	22.0	21.0	23.0	22.0	23.0	24.0	30.0	23.0	22.0	18.0	23.0	23.0	19.0	18.0	24.0	23.0
8	22.0	16.0	22.0	17.0	19.0	20.0	21.0	22.0	24.0	21.0	24.0	30.0	22.0	23.0	21.0	21.0	24.0	20.0	20.0	25.0	23.0
9	24.0	17.0	23.0	20.0	16.0	21.0	20.0	26.0	22.0	23.0	24.0	31.0	21.0	23.0	20.0	19.0	21.0	21.0	19.0	26.0	24.0
10	23.0	20.0	23.0	19.0	17.0	23.0	20.0	20.0	25.0	22.0	24.0	31.0	20.0	26.0	16.0	16.0	25.0	21.0	21.0	24.0	23.0
11	25.0	23.0	22.0	17.0	15.0	24.0	21.0	22.0	24.0	26.0	25.0	29.0	21.0	25.0	22.0	16.0	24.0	21.0	24.0	23.0	20.0
12	22.0	24.0	22.0	17.0	17.0	24.0	20.0	20.0	23.0	26.0	26.0	25.0	21.0	28.0	22.0	15.0	25.0	18.0	25.0	25.0	18.0
13	27.0	23.0	24.0	16.0	18.0	23.0	20.0	19.0	24.0	26.0	25.0	30.0	21.0	28.0	19.0	20.0	26.0	18.0	25.0	25.0	17.0
14	23.0	19.0	26.0	19.0	20.0	21.0	19.0	21.0	24.0	19.0	27.0	25.0	23.0	20.0	23.0	24.0	25.0	24.0	20.0	23.0	21.0
15	21.0	18.0	24.0	18.0	21.0	20.0	17.0	23.0	21.0	22.0	26.0	27.0	22.0	21.0	22.0	23.0	24.0	23.0	19.0	22.0	22.0
16	18.0	18.0	23.0	18.0	20.0	19.0	20.0	22.0	20.0	22.0	25.0	29.0	22.0	22.0	18.0	23.0	24.0	21.0	20.0	24.0	22.0
17	20.0	19.0	23.0	17.0	22.0	22.0	20.0	20.0	20.0	23.0	25.0	32.0	22.0	22.0	19.0	21.0	22.0	20.0	18.0	23.0	23.0
18	22.0	18.0	22.0	20.0	21.0	22.0	20.0	19.0	21.0	20.0	25.0	30.0	22.0	23.0	19.0	22.0	23.0	19.0	19.0	25.0	23.0
19	23.0	17.0	22.0	17.0	21.0	25.0	19.0	24.0	24.0	21.0	24.0	29.0	23.0	24.0	20.0	20.0	24.0	18.0	17.0	25.0	22.0
20	23.0	17.0	23.0	19.0	20.0	21.0	19.0	21.0	20.0	21.0	24.0	31.0	22.0	24.0	20.0	18.0	25.0	18.0	17.0	24.0	24.0
21	20.0	18.0	23.0	22.0	20.0	23.0	19.0	20.0	21.0	22.0	24.0	31.0	23.0	23.0	19.0	17.0	25.0	18.0	17.0	23.0	22.0
22	19.0	16.0	22.0	20.0	18.0	23.0	20.0	23.0	23.0	23.0	24.0	30.0	24.0	24.0	18.0	17.0	22.0	16.0	16.0	23.0	22.0
23	20.0	20.0	21.0	17.0	15.0	20.0	20.0	19.0	20.0	18.0	24.0	29.0	27.0	23.0	19.0	16.0	21.0	17.0	17.0	24.0	22.0
24	17.0	18.0	19.0	17.0	18.0	19.0	18.0	20.0	21.0	23.0	26.0	26.0	27.0	24.0	19.0	14.0	20.0	20.0	20.0	25.0	21.0
25	20.0	17.0	25.0	19.0	19.0	20.0	18.0	20.0	21.0	20.0	24.0	23.0	25.0	23.0	18.0	14.0	24.0	19.0	22.0	25.0	22.0
26	23.0	17.0	22.0	20.0	19.0	22.0	21.0	22.0	23.0	22.0	23.0	23.0	24.0	24.0	19.0	16.0	25.0	23.0	23.0	27.0	21.0

SUMMARY FOR 7/14/70 SITE 2

PLOT	MAX	MIN	MEAN	STD.DEV.	STD.ERROR	SAMPLES
2 1	27.00	17.00	21.73	2.20	0.31	26
2 2	24.00	16.00	18.62	2.17	0.30	26
2 3	28.00	19.00	23.23	1.82	0.25	26
2 4	24.00	16.00	19.27	2.39	0.34	26
2 5	22.00	15.00	19.04	1.84	0.26	26
2 6	25.00	19.00	21.81	1.63	0.23	26
2 7	21.00	17.00	19.88	1.07	0.15	26
2 8	26.00	19.00	21.73	1.89	0.26	26
2 9	25.00	19.00	22.00	1.70	0.24	26
210	26.00	18.00	21.88	2.21	0.31	26
226	27.00	23.00	24.46	0.99	0.14	26
227	34.00	23.00	28.58	2.69	0.38	26
228	27.00	19.00	22.23	1.97	0.28	26
229	28.00	16.00	22.73	2.57	0.36	26
230	23.00	16.00	19.77	1.77	0.25	26
231	24.00	14.00	19.04	3.04	0.43	26
232	26.00	20.00	23.38	1.55	0.22	26
233	24.00	16.00	19.81	1.92	0.27	26
234	25.00	16.00	19.62	2.58	0.36	26
235	27.00	21.00	23.96	1.31	0.18	26
236	24.00	17.00	21.58	1.65	0.23	26
DAY TOTALS	34.00	14.00	21.64	3.04	0.09	546

8. Graphical Display. In many instances, the clearest and most quickly understood method of data presentation is by use of an X-Y plot. Numerous programs and subroutines for plotting data have been written for the Tundra Biome. One is used to present any data plotted against time, the X-scale being fixed at 1 June to 3 September. This grid will accomodate up to eight curves, and allows use of two different scales on the Y-axis. It provides complete labelling facilities, and is set up to provide plots in as many colors as there are curves. A second basic grid provides all of the features of the one just described, except that the X-scale is established and labelled for a full 12-month period.

The ECOSYS Data System is self-contained, being resident on one disk pack. Many subroutines for handling Tundra Biome data and file maintenance are included in the program bank, including routines to copy tapes, dump tapes, merge tapes, check site-plot-quad identification, check species names, compare species names, sort data, select the data, make generalized plots, etc.

In addition to the current season's data processing, a second data-handling activity has been active over the past 14 months. This involves the past 15-20 years of environmental data from the Barrow area. All abiotic and biotic data from major studies are being retrieved and stored on punch cards and tapes at San Diego State College under the direction of Coulombe and Brown. A report covering a six-month period in 1965 was published this summer as an example of summarized weekly data. Complete documentation of this project will be available separately.