"Energy Flow in Artic Acquatic Ecosystems"
Univ. of Alaska

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INTRODUCTION

In spite of an extremely harsh environment, the lakes and ponds of the Alaskan arctic coastal plain support an abundant aquatic fauna and associated avifauna. This has been somewhat perplexing to researchers in the past because the measured in situ primary production is sufficient for only a small fraction of the energy demands of the large invertebrate populations of insect larvae and crustaceans (Butler et al., 1980). Allochthonous carbon sources were, therefore, assumed to fill the shortfall and attempts have been made to quantify the inputs of terrestrial carbon to the freshwater habitat carried by runoff or the introduction of vegetative litter derived from emergent macrophytes (Alexander et al., 1980). An additional potential carbon source is the peat which underlies the vegetative mat, but the highly degraded nature and ubiquitous presence of this substance suggested that this material was highly refractory to microbial assimilation (Hobbie, 1980). Nevertheless, problems arose in attempting to reconcile the energetics of the tundra pond ecosystem while disregarding peat as an active component (Butler et al., 1980) and the ultimate energy source allocations have remained an uncertain aspect of arctic freshwater food webs.

This proposal seeks funding for a study of aquatic ecosystem energetics of the arctic coastal plain. Since the focus is on seeking the sensitivities of the biota and habitats to oil and gas developmental impacts, a downward looking study of the food web is intended. Major vertebrate consumers -- birds and fishes -- will be sampled for carbon isotope abundances and from the resulting energetic source allocations, the appropriate prey species and carbon sources will be collected and quantified. Also, since the extreme arctic seasonal variations may shift energy dependencies completely during the winter, sampling will encompass the full annual cycle.

The principal investigator became involved in arctic food web studies through the IBP Tundra Biome Program and Toolik Lake projects supported by NSF and the NOAA Outer Continental Shelf Environmental Assessment Program (OCSEAP) on the coastal marine ecosystem in the vicinity of Prudhoe Bay, Alaska. Here, in the coastal waters, many of

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the same species of birds and fishes present in tundra lakes -- oldsquaws, phalaropes, loon, ciscoes, whitefishes and arctic char -- were also utilizing the food resources of the nearshore marine environment. Some species, such as the oldsquaws (*Clangula hyemalis*) may nest on the tundra and feed on freshwater prey organisms or may remain on the marine lagoons (males and nonbreeders) for all or part of the summer. The anadromous fishes migrate into the marine water to feed in summer and return to freshwater to spawn and overwinter. In the process of sorting out the energy supplies and trophic interdependencies of the larger apical organisms while in the lagoons, we sought to establish the magnitudes of energy (carbon) inputs arising from (1) primary production, (2) fluvial inputs of terrestrial carbon by the rivers and streams, and (3) shoreline erosion of the Holocene peat soils (Figure 1). Through various techniques it was determined that within 10 km of shore, over 50 percent of the carbon supply was derived from land (Schell, 1980) and that the major fraction of the allochthonous carbon

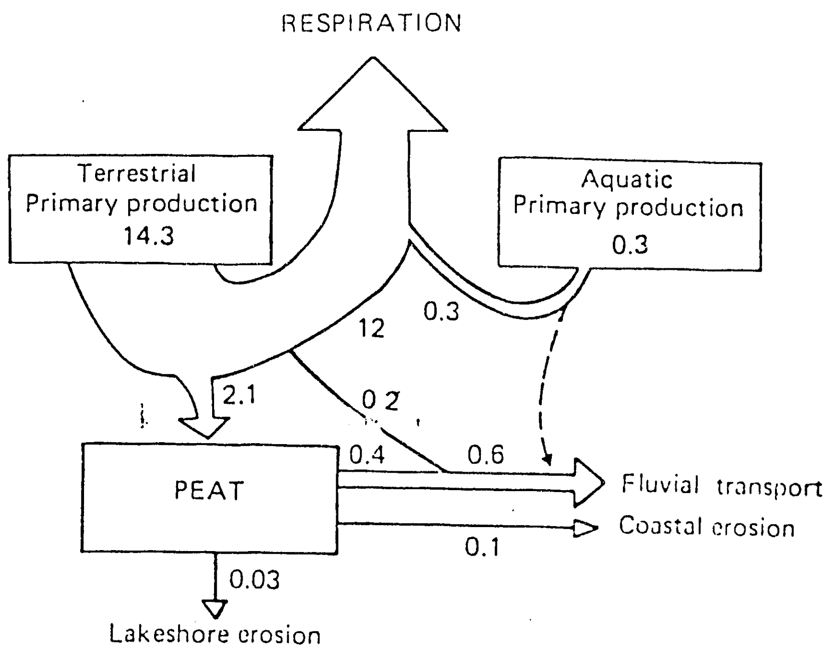

Figure 1. Box model of carbon flow for the North Slope (200 x 10^3 km^2). Fluxes are in 10^9 $kgC \cdot yr^{-1}$. (From Schell and Ziemann, 1983)

was derived from peat. Thus, any allocation of energy source dependencies required that the role of peat carbon be assessed as it constituted a potential source for the energy requirements of nearshore invertebrates.

Assessing the role of peat in the trophic energetics of the system presented a problem in that feeding studies on the major invertebrate grazers/prey species would be tedious and ran the risk of being inconclusive. By comparing the stable carbon isotope ratios of the nearshore fauna and their carbon sources it was possible to separate terrestrial from marine carbon contributions but no information could be gained regarding the respective roles of modern terrestrial vegetation versus peat in the detritus. Through the use of both ^{14}C and ^{13}C natural abundances, however, the terrestrial fraction would be separated from marine carbon and further subdivided into a peat fraction and a modern vegetative detrital fraction. Once representative carbon isotope abundances were known for source materials, the role of the sources in supporting organisms at any trophic level could be estimated regardless of the food web complexities transferring the carbon to the organism.

The results of these initial studies have been published in an overview (Schell, 1983) including the following findings:

1. Peat is consumed by microorganisms in marine waters but does not contribute significantly to the requirements of pelagic organisms in higher trophic levels.

2. In freshwater, peat is passed up the food chain and constitutes a major carbon source to top consumers such as oldsquaw ducks (*Clangula hyemalis*) and fishes.

3. Seasonal variations in food web dependence on peat are very evident in the anadromous and obligate freshwater fishes of arctic Alaska.

4. Food habits of freshwater fishes indicate that insect larvae are probably the major pathway by which peat is transferred to higher organisms. A single isotopic composition determined on a sample of chironomids supports this premise.

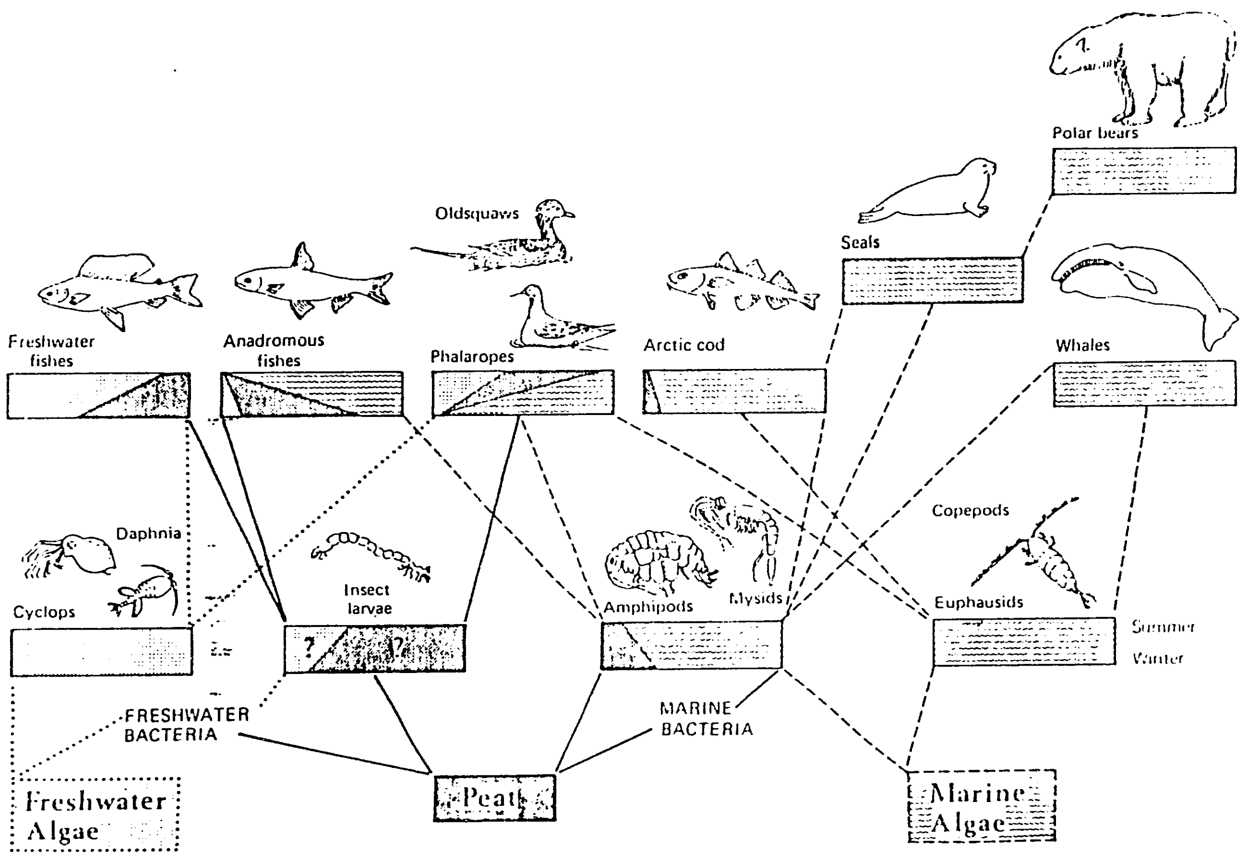

Figure 2. Generalized food web structure and major seasonal energy dependencies in Alaskan Beaufort Sea coastal ecosystems (from Schell et al., 1982).

This study seeks to estimate the role of peat carbon versus primary production by living plants in the overall energy requirements of arctic Alaskan aquatic ecosystems. This "delayed production" of consumers from peat may be critical to the overwintering success of resident fauna and to migratory avifauna which rely heavily on tundra insects for feeding their young and accumulation of fat reserves for fall migration. The overall goal of the project is to provide an estimate of the large scale energy fluxes in the North Slope ecosystem and the energy source variability over the pronounced seasonal extremes. Schell et al. (1982) presented a trophic structure for coastal energy dependencies as shown in Figure 2. The peat dependency information in freshwater organisms is very limited and would be greatly refined by this study. As the relative importance of the various energy inputs become evident, supporting studies will focus on these -- i.e., stream primary production, litterfall, tundra runoff, and eroded peat.

QUALIFICATIONS OF THE PROPOSER AND RELATED INSTITUTIONS

Principal Investigator

D. M. Schell has been involved for over 15 years in research on nutrient cycling in terrestrial and aquatic environments. The past several years studies have focused on nutrient dynamics in coastal Beaufort Sea waters and the interactions between the terrestrial and marine ecosystems. Recent work has included studies of hydrocarbon biooxidation rates in Port Valdez waters and the use of carbon isotopes in defining trophic energetics in arctic environments.

Facilities

The Institutes of Water Resources and Marine Sciences are well equipped with laboratory space and the equipment required for processing samples obtained in this program. Radiocarbon isotopic analyses will be performed by commercial laboratories or at the University of Arizona.

The mass spectrometry (^{13}C) will be performed with a new micromass SIRA-9 acquired by our institutes.

All necessary field sampling equipment is on hand except for a new power ice auger. The principal investigator is experienced in North Slope logistics and can be self sufficient within the structure of this proposed study.

BACKGROUND

The use of natural abundances of carbon isotopes (primarily $^{13}C/^{12}C$ ratios) to trace food web dependencies has been used successfully to demonstrate the relative consumption and assimilation rates of C_3 and C_4 plants and chemosynthetic food in several environments (DeNiro and Epstein, 1978; Haines and Montague, 1979; McConnaughey and McRoy, 1979; and Rau and Hedges, 1979).

In some cases, however, where the carbon sources have varied $\delta^{13}C$ values, the interpretation of consumer $\delta^{13}C$ can be ambiguous. Estuarine primary producers in the southern U.S. marshlands range from unicellular algae and chemosynthetic bacteria up to forest tree species and their respective $^{13}C/^{12}C$ isotope ratio spans a wide range. Peterson et al. (1980) were able to account for observed consumer carbon isotope ratios in a Georgia saltmarsh by proposing chemosynthetic fixation inputs to the food chains rather than the totally photosynthetic inputs which Haines and Montague (1979) used in their interpretation of the data.

Carbon-14 abundances in living and dead biological materials have been determined for many years with the radiocarbon dating process. Accurate analyses and projections of future radiocarbon activities are available for living plant matter (Swan et al., 1983) which provides a reliable end member for comparison of radiocarbon activities. Tundra plants collected during the past five years have fallen in the accepted range of radiocarbon activities (Schell et al., 1982).

OBJECTIVES

This study seeks to determine the major pathways of energy flow in freshwater ecosystems of the Alaskan arctic coastal plain (Figure 3). I would select varied sites for study of the processes supplying energy to streams and lakes to verify the generality of past findings. Survey collection of organisms would be from the Colville River drainage and the lake region around Teshekpuk Lake. Specific objectives include:

1. Collect food web apex organisms (fish and birds) from a variety of sites in the coastal plain to verify descriptive models of ecosystem structure and food web pathways.

2. Compare the utilization rates by insect larvae of fresh litter and in situ primary production relative to more refractory peaty materials through seasonal sampling for isotopic analysis.

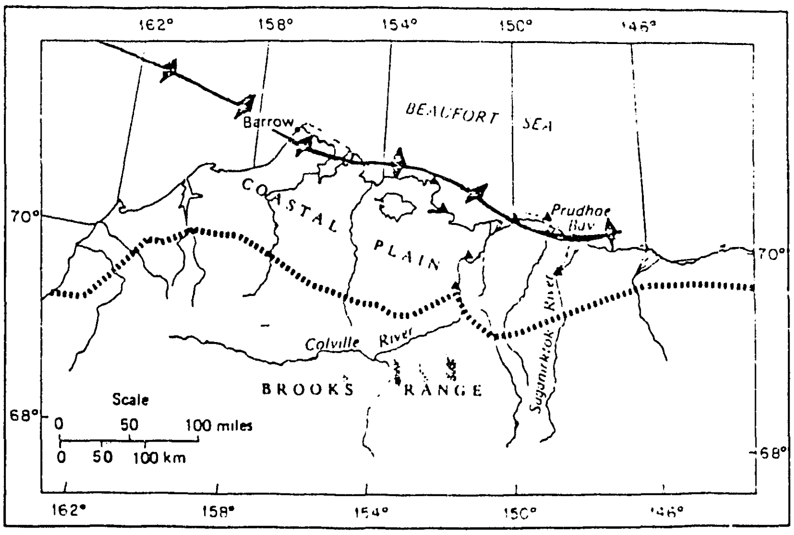

Figure 3. Arctic coastal plain. The solid line with diamonds marks the "Barrow Arch," the geologic structure with highest oil and gas potential. Small solid triangles are locations where basal Holocene peat samples have been obtained (modified from Schell and Ziemann, 1983).

3. Compare estimates of energy fluxes derived from primary productivity measurements and peat inputs with those calculated from radiocarbon and stable carbon isotope abundances in higher organisms and their prey species collected from aquatic environments.

4. Investigate the seasonal shifts in trophic dependency through measurements of ^{14}C activity in lakewater carbon dioxide relative to total water column carbon dioxide over the course of the winter season.

5. Synthesize the data obtained to identify processes and habitats that are critical to the biota and which may be impacted by oil and gas development.

METHODS

I. Radiocarbon and ^{13}C Determinations

Samples of fish, basal peats, surface sediments and other macrofauna and flora would be collected and dried for analysis. If sufficient numbers of prey organisms (chironomid larvae, amphipods, daphnia, etc.) are obtainable, a sample equivalent to 4-5 g C will be collected. Specimens are held in filtered water until gut contents are evacuated, then dried in vacuo. Samples will be sent to a commercial laboratory for radiocarbon analyses. Stable carbon isotope analyses will be performed at the University of Alaska. Small samples of invertebrates (less than 3 g C) will be analyzed for ^{14}C with the University of Arizona tandem mass accelerator. By pooling similar samples of small invertebrates or accepting less precise decay counting, routine techniques may yield useful data.

II. Peat Assimilation by Invertebrates

The capability of chironomids and other insect larvae to use cellulose (via symbiotic bacterial populations in the gut) has been demonstrated and our task here will be to seek the environmental conditions favorable for peat ingestion and assimilation. To obtain rate data, two approaches will be employed: biooxidation of radiolabeled cellulose and isotopic label acquisition upon exposure to peat. The former technique assumes that the cellulosic matter in peat is utilized at a rate similar to ^{14}C-labeled peat intimately mixed with it

Biooxidation and assimilation of peat is measured by the acquisition of ^{14}C activity in invertebrates incubated with the peat and by quantitatively stripping and counting ^{14}C-labeled carbon dioxide from the incubation water over a time course. The reverse labeling technique uses insect larvae of an isotopic composition different than peat and follows their change toward peat isotopic composition during growth while exposed to peat as a sole food source.

The use of peat carbon by specific aquatic organisms will be investigated in the laboratory using the radioisotopic tracing techniques recommended by Conover and Francis (1973). The animals of interest will be fed a radiolabeled substrate long enough to become homogeneously labeled with ^{14}C. Some will then be switched to a sterile peat diet, others will have all food removed, and animals and respired carbon dioxide from both groups will be analyzed periodically for ^{14}C specific activity. If the animals given the peat are assimilating it, the ^{14}C specific activity of their respired carbon dioxide and body carbon should both decrease since they are being diluted with "cold" carbon. If they are not assimilating the peat, there ^{14}C specific activities should change in a manner similar to the animals not given peat. This change should be very slight since their is no incoming carbon to alter their isotopic composition, and the ^{14}C specific activity of the respired carbon dioxide should be the same as the isotopically homogeneous body carbon.

The ability of the animals to assimilate specific biochemical components of the peat (i.e., cellulose, hemicellulose, lignin, etc.) will be measured by following the above procedure and feeding the radiolabeled animals a chemical extract of the component in question instead of whole peat.

III. The Importance of Peat to Organisms in Different Aquatic Habitats

The habitats in which peat is a major source of carbon for the biota will be determined from the carbon isotope composition of resident organisms collected throughout the year at each lake/pond study site. The importance of peat carbon to a particular species is proportional to its ^{14}C depression relative to modern plant material, and the fraction of an animal's body carbon derived from each of these two sources can be computed from a mixing equation (Schell, 1983). The accuracy of such a calculation depends, however, on the accuracy with which the ^{14}C specific activities of the two end members (i.e., peat and modern plant carbon) are known. The ^{14}C specific activities of modern plant material in tundra lakes/ponds fall into a narrow range of values (Schell, 1983) and therefore present no problem. The ^{14}C specific activities of peat available to the biota are more difficult to ascertain, but the approach planned for this study should produce reliable values. Since surface sediments are a mixture of the peat and modern plant material entering a basin, the mean ^{14}C specific activity of the incoming peat can be obtained from the radiocarbon age of the surface sediments and the residue of the sediment carbon derived from modern plant material. Previously (Schell, 1983), we desired an estimate of the minimum peat carbon composition of North Slope organisms, and had a limited number of radiocarbon ages for sediments. The value for peat was therefore obtained by integrating the ^{14}C specific activities of a peat column accumulating at a constant rate and having a basal peat age equal to the mean of the basal peat radiocarbon ages available. This value is only slightly lower than the ^{14}C specific activities of the surface sediments analyzed thus far, but this is not unexpected. There appeared to be no major inputs of macrophytic plants into the lakes from which these samples were taken, and algal inputs were probably similarly small since Alexander et al. (1980) found that algal biomass made up less than one percent of sediment carbon in the tundra ponds at Barrow. We plan to make radiocarbon age determinations of the basal peat of shoreline banks and surface sediments of each lake/pond from which biota are collected.

IV. The Importance of Peat in Arctic Aquatic Ecosystem Energetics

The role of peat carbon supported energetics will be assessed by determining the rates of peat oxidation and aerobic and anaerobic respiration in lakes/ponds during the ice and ice-free seasons.

When ice is present the exchange of gases between the water and atmosphere essentially ceases, such that continued aquatic respiration causes the accumulation of dissolved inorganic carbon (DIC) and the depletion of dissolved oxygen (DO) in the under-ice water. The rate of accumulation of DIC of metabolic origin (i.e., corrected for carbonate mineral dissolution) is then equal to the rate of total carbon metabolism, and the rate of exhaustion of DO is equal to the rate of aerobic metabolism. The difference between these rates is the rate of anaerobic metabolism.

Oxidative processes cause changes not only in the concentration of DIC, but also in its carbon isotope composition (^{14}C, ^{13}C, and ^{12}C). These isotope changes can be used to provide another estimate of the rates of aerobic and anaerobic respiration, and an estimate of the rate of peat oxidation. The changes in the $^{13}C/^{12}C$ ratios of the DIC are used to determine the rates of oxic and anoxic metabolic processes (Deevey and Stuiver, 1964). This is possible because the CO_2 produced anaerobically is enriched in ^{13}C relative to that produced aerobically ($\delta^{13}C \sim -5\%$ and -30%, respectively). The proportion of CO_2 derived from each process is calculated with a mixing equation and the $\delta^{13}C$ values of the aerobic and anaerobic CO_2, and the DIC of the lake water.

When peat is present in the sediments, oxidation of this material will result in changes in both the ^{13}C and ^{14}C composition of the DIC of the water column. Basal peats in the coastal plain are up to 12,000 years old, and strongly depleted in ^{14}C. The oxidation to CO_2, therefore, results in a decrease in the ^{14}C radiocarbon age of the DIC. The proportion of total oxidized carbon derived from peat is calculated from a mixing equation and the ^{14}C specific activities of the DIC, mean peat, and modern carbon.

The rates of aerobic and anaerobic metabolism, and peat oxidation will be determined for the whole system from lake/pond morphometry and ice thickness, and changes in the concentrations of DIC, DO, alkalinity, and carbon isotopes, in the ice and under-ice water during the winter. Concommitant analyses for the end products of anaerobic respiration such as H_2S and Fe^{2+}, will better define the onset of anaerobic resiration and allow a determination of peat utilization in both aerobic and anaerobic metabolic processes.

In the summer, analyses for the same constituents from in situ incubation of water, and water and sediments, will provide estimates of the rates of these processes during the short open water season. A budget will then be constructed to compare the measurements of carbon input to the ecosystem from primary productivity and terrestrial erosion with the fluxes of carbon out of the ecosystem by the catabolic processes and sediment accumulation.

Chemical analyses will be performed on water and thawed ice samples either in the field camp or upon return to the laboratory in Fairbanks.

1. Water samples will be obtained with either a van Dorn or Kemmerer sampler. During the winter they will be taken through a hole drilled in the ice with a power auger, and during the summer from a float plane or raft. Ice cores will be obtained using a SIPRE corer.

2. Oxygen will be determined at the field camp by either the azide modification of the Winkler method or with a Wheaton Sixty-Second B.O.D. System.

3. pH will be determined and potentiometric alkalinity titrations performed at the field camp. DIC will later be calculated from the carbonate alkalinity (i.e., the titration alkalinity corrected for the non-carbonate acid neutralizing capacity added by silicates, phosphates, and sulfides), pH, and tabulated thermodynamic data. This approach was compared with infra-red gas analyses by Prentki (1980) in the tundra ponds at Barrow and produced similar results. Water samples will also be preserved according to the procedure of Wong (1970) and returned to Fairbanks with unthawed ice cores for DIC analyses by gas chromatography.

4. The dissolution of carbonates from sediments will increase the DIC of the water and change its isotope composition. To avoid source this non-metabolic carbon, sediments will be tested for the presence of carbonate minerals prior to choosing study sites. This will be done by watching for the appearance of bubbles in sediments after the addition of dilute HCl.

5. Frozen water samples and unthawed ice cores will be retuned to Fairbanks for ammonia, nitrate silicate, and phosphate analyses by standard spectrophotometric methods.

6. Water samples and thawed ice cores for sulfide analyses will be injected immediately with cadmium chloride, the supernatant decanted, and the cadmium sulfide precipitate stored for later analysis by the standard spectrophotometric procedure.

7. Water samples and thawed ice cores for DIC isotopic analyses will be immediately poisoned with mercuric chloride and the DIC precipitated by the addition of ammonium hydroxide and strontium chloride. The sample bottles will then be sealed

according to the procedure of Wong (1970) and returned to Fairbanks. There the supernatant will be decanted and the precipitate sent to a commercial laboratory.

8. Surface sediment samples will be obtained with an Ekman grab and sediment cores taken with a gravity corer.

9. Sediment carbon accumulation rates will be determined from the distribution of the ^{137}Cs, ^{210}Pb, and the ^{14}C isotopes, and carbon content of cores taken from each lake/pond basin. ^{137}Cs and ^{210}Pb concentrations will be determined, respectively, by gamma and alpha spectroscopy, on instruments available at the Institute of Marine Science. ^{14}C analyses will be performed at a commercial laboratory.

10. Standard ^{14}C primary productivity measurements will be made in situ in bottles containing water, and water and sediments.

11. Measurements of lake/pond shoreline erosion rates will be made by placing stakes along the banks and measuring the change in bank edge-to-stake distance from one summer to the next. These estimates will be compared to longer-term average rates estimated from aerial photography performed in 1955 and 1978.

RELEVANCE TO OIL AND GAS DEVELOPMENT

The westward expansion of oil and gas development from the Prudhoe Bay area has resulted in an ever increasing visibility of man's presence on the coastal plain. The complex layout of roads and pads in the Kuparuk Field has altered several small drainages and required the excavation of gravel pits and reservoirs. The prognosis seems to be for continued expansion of oil development in the coastal plain -- eastward toward Camden Bay and westward toward Cape Halkett and the Teshekpuk Lake area. Although the main exploration efforts appear to be following the Barrow Arch offshore (Figure 3), the need for shore based support will require a continued expansion of roads, facilities, airports and staging areas along the coastal plain. As oil production begins, pipelines on land and shoreline crossings will also be constructed.

This study will provide insight into the critical processes supporting stream and lake fauna in the coastal plain. As the energy dependencies of these organisms become evident it will be possible to project the impacts caused by industry activities such as sand and gravel dredging thaw bulbs beneath lakes, increased erosion of peat bluffs at river crossings or altered drainages, or the effects of turbidity on primary productivity and subsequent secondary production.

Other subtle and poorly described potential problems may become evident. Increased peat erosion and organic matter inputs may be accompanied by excessive biological oxygen demand beneath winter ice cover. The effects might be disasterous on overwintering anadromous fish populations confined to very limited ice free zones in lakes and river beds. Flooding by impoundment may change the insect community structure in roadside areas with food web impacts and subsequent changes in usage by shorebirds and waterfowl species. Although it is unlikely that this (or any other study) can produce data that will allow definitive prediction of developmental effects on the ecosystem, it is hoped that synthesis of the data acquired, along with that for supporting studies, will serve as an effective management tool for minimizing adverse impacts.

INTENSIVE SITE RECOMMENDATION

The tasks outlined will require a logistic base that will be available on a year-round basis and convenient to the central arctic coastal plain and the Colville River system. Based upon past experience under NOAA-OCSEAP contract and facilities available, we propose using the support services of J. Helmericks in the Colville River delta. This site has year-round lodging for up to 15 personnel, electric power and is the home base for an air taxi service. It is close to Kuparuk Center which would allow easy transfer of equipment and personnel. The family conducts a commercial fishery operations during summer and can provide valuable sample and sample collection services throughout the year. They are used to, and patient with, the idiosyncrasies of scientific field operations. Aircraft support available consists of a Cessna 206 on floats or wheels and several smaller aircraft on either skis, floats or wheels. The location in the Colville delta provides ready access to small tundra streams such as Kachemach and Kalubik creeks via riverboat. Colville River fishes can be collected via netting at the camp. Float plane access to the major lakes near Teshekpuk is within an hour's flight. Per diem rates and aircraft charter costs for past operations have been more reasonable than those available at Prudhoe Bay service facilities. Additionally, they are located close to the U.S. Fish and Wildlife Service Colville Delta field camp and provide logistic support for them. The personnel of USFWS have offered to assist in collection and provision of bird and fish specimens for this project.

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