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ENERGY FLOW IN AN ARCTIC AQUATIC ECOSYSTEM

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PROJECT OVERVIEW

This component of the terrestrial-aquatic interaction (TAI) group seeks to use the natural stable carbon isotope ratios and radiocarbon abundances to trace the movement of photosynthate from the terrestrial environment to the stream system at MS-117. In addition to estimating the total flux, we will also attempt to describe the relative fractions derived from modern primary production and that derived from delayed inputs of eroded peat. We will also seek to determine the coupling efficiency of these energy sources to the invertebrate faunal populations in the tundra soils and streams.

CARBON FLUXES IN THE MS-117 STREAM

Transfer of energy from tundra to stream and subsequent export from the study area will be assessed by a variety of techniques designed to quantify both the dissolved and particulate fractions and to differentiate between modern and delayed export of carbon from the tundra. Since the radiocarbon content of modern production is above background (pre-1950) levels, it should be possible to determine if the loss of carbon from the tundra is derived primarily from plant materials grown in the past few years or from peaty detritus accumulated over many years past. By collecting particulate and dissolved organic matter from water track weirs and stream weirs over the course of the summer, the seasonal variation in relative exports will also become evident. In addition, direct estimates of primary production within the ponds will be made using C-14 bicarbonate uptake rates. Whole pond productivity will be estimated using oxygen curves and compared to a darkened pond to measure respiration rates.

The direct inputs to the stream system due to bank erosion and thaw of ice wedges are more difficult to obtain, but it may be possible to measure high water erosive events through the careful marking and documentation of stream bank morphology and observing the changes arising from storm inputs of high water and spring breakup in 1987. Particulate detritus in the bottoms of the ponds will also be compared with the particulate matter derived from the water track weirs for radiocarbon dissimilarity which would also indicate whether inputs were primarily from runoff or erosion of banks.

PROCESS STUDIES

We plan to test the hypothesis that the critical link governing the movement of both peat carbon and modern plant detritus into the food web is the consumption and conversion of organic detritus and microflora to insect biomass. Specific detrital components - lignins, cellulose, etc, will be synthesized with radiolabeled carbon and used in tracer experiments to determine the role of specific invertebrate taxa in mobilizing those fractions of the detrital pool. These experiments, which will be conducted in the laboratory, will be used to verify and detail the energy transfer pathways inferred from MS-117 as a result of the natural isotopic abundance data. I will be relying on Mark Oswood for the identification and collection of macroinvertebrates from the stream system.

The success of this project will depend on close interaction with the rest of the TAI group. Mark Oswood's program will be cooperating through the collection of stream particulate and dissolved fraction samples which will be split for both nutrient data and isotope abundance data. Mass transfer data, although not a primary focus, will be obtained in order to estimate the importance of allochthonous inputs to the nutrient budgets of the stream.

To measure the shifts in recent versus old (peat) carbon inputs to fauna arising from perturbations to the stream ecosystem such as added nutrients, we are planning a 1987 experiment similar to that performed by Petersen et al., (1985) on the Kuparuk River. They found that by adding phosphorus to the severely nutrient limited stream caused a shift from heterotrophy to autotrophy in a 3 km stretch. Details of the experiment will be worked out in consultation with Bruce and will probably require a more integrated participation among TAI group PI's.

OBJECTIVES

This study is an integrated component of the Terrestrial - Aquatic Interaction (TAI) Working Group and aids the R4D program in two distinct and complementary modes. First, in conjunction with the stream invertebrate studies, it will attempt to separate modern from delayed (peat) energy inputs to the stream and serve to validate energy models for the beaded pools of the MS - 117 site. Second, this study will support Mark Oswood's program on the energetics of the system and will aid in establishing the nutrient and carbon budgets. The isotopic techniques employed can be used very effectively with a minimal sampling effort and thus very reasonable logistic requirements.

The specific objectives for summer 1986 and beyond include:

1. Use the natural carbon isotope abundances of the stream organic matter to determine the relative energy inputs arising from terrestrial runoff and litterfall, in situ primary production, and erosion of peat from the stream banks. Additionally, these techniques will be used to determine if primary production beneath melting snow is a significant input of photosynthate to the annual cycle.

2. Collect insect and other stream invertebrates from the intensive site stream in conjunction with the aquatic energetic study of M. Oswood. These samples will be measured for C-14 content to estimate the role of peat in nutrition of various insect species and crustaceans.

2. Assist in the measurement of nutrient spiraling and carbon dynamics in the stream at MS-117 with M. Oswood, through field and laboratory experiments using radiolabeled tracers.

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 the drainage stream.

BACKGROUND

In spite of an extremely harsh environment, the lakes and ponds of the Alaskan arctic coastal plain support abundant aquatic fauna and associated avifauna. In situ primary production is sufficient, however, 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 assumed, therefore, 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 alternate potential source of carbon is the peat which underlies the vegetative mat, but the highly degraded nature and ubiquitous presence of this substance suggested that this material was resistant to microbial usage (Hobbie, 1980). The overall energy source allocations have remained an uncertain aspect of arctic freshwater foodwebs, especially with regard to the full annual cycle during which energy dependencies may shift completely in response to the changes in ice cover and daylight.

The principal investigator became involved in foodweb studies in the Arctic first with the IBP Tundra Biome and then with the NOAA/OCSEAP studies of the nearshore marine ecosystem. In the coastal waters, many of the same species present in tundra lakes--oldsquaws, loons, phalaropes, ciscoes, whitefishes and arctic char -- were also using the food resources of the marine environment. Some species such as the oldsquaw (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 lagoons to feed in the summer and return into the freshwater drainages to overwinter and spawn. 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 primary production, fluvial inputs of "new" terrestrial vegetation and peat.

Assessing the role of peat in the trophic energetics of the system presented a problem in that feeding studies on the major invertebrates would be tedious and ran the risk of being inconclusive because of the temporal constraints. 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 about the respective roles of modern terrestrial vegetation versus peat in the detritus. However, through the use of both C-14 and C-13 natural abundances, the terrestrial fraction could be separated into a peat fraction and a modern vegetative detrital fraction. Once representative carbon isotope abundances were known for the source materials, the role of the sources in supporting given organisms could be estimated at any trophic level regardless of the complexities of the pathways transferring the carbon to the organism.

The results of these initial studies have been published in Schell (1983) and Schell and Ziemann (1983) and include the following findings:

1. Peat is consumed by microorganisms in marine waters but does not contribute significantly to the requirements of nearshore 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 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 consumers by which peat is transferred to higher organisms.

This study seeks to estimate the role of peat carbon versus primary production by living plants in the overall energy budget of the freshwater ecosystem. This "delayed production" of consumers from peat may be critical to the overwintering success of resident fauna and to migratory waterfowl which rely heavily on tundra pond invertebrates for feeding their young and accumulation of fat reserves for the fall migration. The overall goal of the project is to provide an estimate of the large scale energy fluxes in the MS - 117 stream complex and the energy source variability over the seasonal extremes. As the relative importance of the various energy inputs becomes evident, the research effort will adapt to the emerging lines of study.

PROPOSED EIGHTEEN MONTH RESEARCH PLAN -- AUG. 1986 - JAN. 1987

The research plan for this continuation as outlined above is still being worked out at the time of this proposal writing. At the San Diego coordination meeting in April 1986, the supportive role that this PI will provide to others in the integrated study will be refined. Although past effort has been spread between the intensive site and coastal plain locations, this proposal is for work solely at the MS - 117 site.

Field Studies

In the nearby Kuparuk River Petersen, et al, (in press) found that the inputs of detrital carbon as particulate and dissolved organic matter are much greater than those from in situ primary production. This situation is also very likely for the stream at MS-117. We intend, therefore, to quantify the inputs as carefully as possible and to determine the fate of this material in the aquatic environment.

Particulate carbon in runoff water will be collected over the spring breakup to document the concentration and carbon isotope abundances. Following the return to low water conditions after snowmelt, the particulate matter from water track weirs and from the stream channels will be collected at one week intervals unless major storms warrant event sampling when rapid rises in the stream are evident.

Since the loss of dissolved organic matter from growing plants and from freeze lysing of cells may be an important organic matter input mechanism during the pre-breakup period, we intend to estimate the photosynthetic activity of plants beneath the snow. Fungal oxidation of standing biomass results in high partial pressures of C-13 depleted carbon dioxide beneath the snow canopy which may be used for photosynthesis by plants growing on light penetrating the snow during melt. If appreciable photosynthesis occurs by either algae, mosses or overwintering green tissue in vascular plants, the usage of the C-13 depleted carbon dioxide will result in a greatly enhanced heavy isotope depletion in the plant reducing the gas. We will collect samples of the carbon dioxide beneath the snow for isotope ratio mass spectrometry and will compare the isotope ratios in plant tissue collected near the start of the growing season with that collected later when the snow cover is gone. Since light intensities beneath the snow cover will determine the energy available for photosynthesis, a Li-cor photometer is being requested for this facet of the project.

The partitioning of allochthonous carbon inputs to the stream will be accomplished through the use of natural abundances of radiocarbon in the organic fractions. Samples of the particulate matter will be sized by screening through a 1 mm mesh to separate the fine fraction from the coarser twigs and grass particles. Dissolved organic matter will be obtained by evaporating the filtrate or by concentration of humic acids onto ion exchange resins. The individual samples will then be analyzed for radiocarbon activity using standard carbon dating techniques and the fractions derived from modern plant material and from peat approximated by comparing the activity of each fraction against that of the "end member" materials -- either clipped modern plant matter or the activity of a vertical section of peat.

The rationale for this approach depends upon the large amounts of bomb C-14 that has entered the biological material during the past twenty years or so. Figure 1 illustrates the radiocarbon activities in plant tissue in the northern hemisphere following the onset of thermonuclear weapons testing in the atmosphere and the decline in activity since the partial test ban treaty became effective. Each megaton of weapon explosive yield contributed about 4 kg of ^{14}C to the atmosphere as carbon dioxide and this was rapidly dispersed around the northern hemisphere by tropospheric and stratospheric circulation (Nydal, et al, 1980). The result of this large input is that each year's primary production since 1967 carries a distinctive C-14 content depending upon the source of carbon dioxide used in photosynthetic carbon fixation. Among vascular plants on the arctic tundra, atmospheric carbon dioxide appears to be essentially the sole source and the radiocarbon content is accurately reflected. Samples of willow leaves, twigs and multiyear-old stems collected at MS-117 contained radiocarbon concentrations very close to the amounts expected from the chronological dates of fixation.

In contrast to the relatively high radiocarbon concentrations in the modern photosynthetic products, the particulate

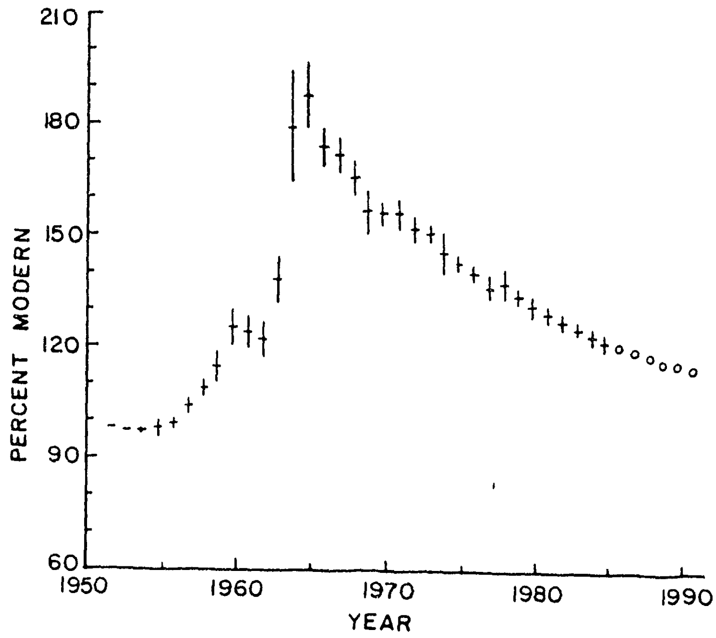

Figure 1. Radiocarbon activities (1950 = 100 percent) in North American agricultural products. Data show the dilution of atmospheric background by fossil fuel carbon dioxide prior to 1954 and the subsequent rapid addition of C-14 by nuclear weapons testing. The Partial Test Ban Treaty took effect in August 1963. Curve is from Swan, Kreuger, and Sullivan (unpublished data).

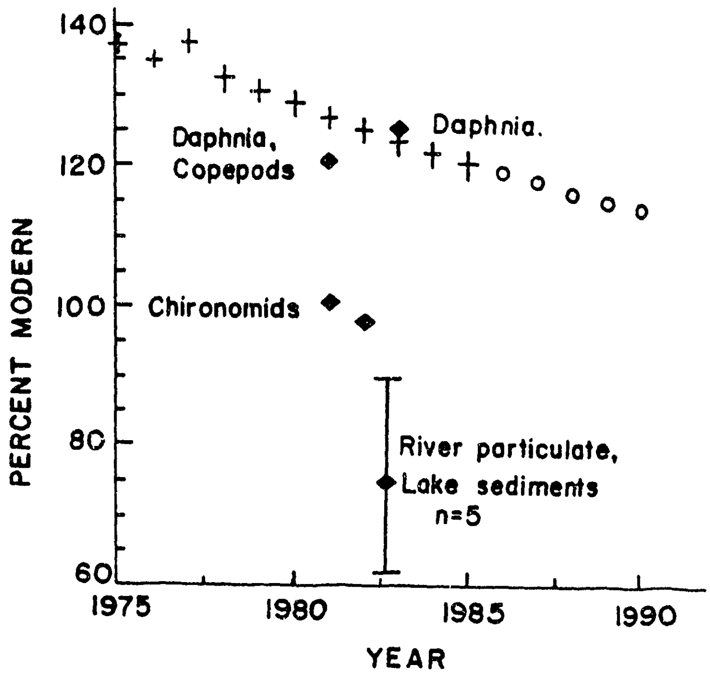

Figure 2. Radiocarbon activities in North Slope invertebrates and detrital matter (diamonds) and atmospheric background (crosses are measured data, open circles are projected values). Daphnia and copepods rely almost entirely on modern algal production whereas chironomids show a major fraction of their energy supply from peat. Atmospheric data from Swan, Kreuger and Sullivan, (unpublished).

organic matter collected from the larger rivers of the coastal plain in the past contained very depressed radiocarbon activities (Figure 2). The large erosional inputs of peat into the fluvial system overwhelms the modern inputs and the mean radiocarbon activity is close to that of the average activity of an undisturbed profile of the peat layer (Schell, 1983). Figure 2 also shows the radiocarbon activity in two important invertebrate prey types found in the streams and ponds. The daphnia and copepods are known to be part of an algae-based food chain in the water column. Their radiocarbon activities are close to modern and indicate a nearly complete reliance on modern production. Chironomids, in contrast, live in the sediments and feed in the detritus layer. The radiocarbon activity of these organisms indicates that peat carbon is a major component of the energy budget. It follows that any higher predator feeding on chironomids is going to acquire the radiocarbon depletion proportional to their dependence on chironomids.

At a small drainage such as MS-117, no data are available on the relative inputs of modern detrital matter entering the aquatic system versus that derived from peat. This information is essential in assessing any anthropogenic impacts on the aquatic ecosystem for it has been shown that peat carbon is a major source of energy to top consumers in the larger rivers and lakes (Schell, 1983) and must be included in energy supply budgets when considering carrying capacities or seasonal requirements of wintering populations of anadromous or resident fish.

Field processing of samples for radiocarbon analysis requires that no contact be made with trace amounts of artificial radiocarbon. Since primary productivity measurements at Toolik Lake camp may have inadvertently contaminated some of the laboratory buildings, we are planning to complete all of the preparatory work at the field site. For most particulate samples, this consists of bagging and packing the samples and storing in new shipping containers. The dissolved fractions may require elution from ion exchange columns or evaporation and this will be accomplished at the IMS trailer at the MS-117 site. Samples for radiocarbon analysis will be prepared at our "clean" laboratory in Fairbanks and subsamples for stable carbon analysis will be combusted and purified for mass spectrometry at the Institute of Marine Science.

Laboratory studies

Specific components of the detrital carbon fraction will be tested for microbial lability and assimilation by insect larvae through the use of radiolabeled substrates. Radiolabeled cellulose and glucose will be supplied to chironomid and tipulid larvae alone and progressively diluted by peat and the rate of carbon dioxide liberation followed with time. Total radiolabel incorporated into the insect tissue will be determined after incubation by oxidation of the insects to carbon dioxide using a Harvey Biological Oxidizer and recovery of the label in scintillation fluid. Radiolabeled lignin will be prepared by incubation of willow twigs with radiolabeled phenylalanine solution followed by maceration and isolation of the lignin fraction. This label will also be supplied to insect larvae in the presence of peat to test for the mobilization of the peat lignin fraction. Controls of peat inoculated with pond bacteria and autoclaved samples will test for the oxidation rates due to microbiota and abiotic processes respectively.

The above experiments will be coordinated with M. Oswood's total microbial respiration measurements to give a more comprehensive picture of stream microbial processing of organic matter and the seasonal activity of the microfloral-meiofaunal components.

ANTICIPATED RESULTS

The experiments outlined above should provide a good understanding of the processes active in the stream ecosystem at MS-117 which govern the secodary productivity of small stream environments. Specifically we should have insight into:

a. The magnitude and seasonality of carbon inputs to the stream environment and the rate of throughput.

b. The distribution of organic matter source material between modern primary production and that derived from peat accumulated over hundreds of years.

c. The rate of decomposition of relatively refractory organic matter under natural arctic conditions and the extent of microbial activity in the ponds.

d. The efficiency of coupling to macrofaunal components of the various organic matter inputs and the potential for transfer of these energy sources to food webs supporting higher organisms

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