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UNITED STATES DEPARTMENT OF ENERGY ECOLOGICAL RESEARCH DIVISION CARBON AND NITROGEN ISOTOPE STUDIES IN AN ARCTIC ECOSYSTEM

to

FINAL REPORT

by

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SUMMARY

The dynamics of carbon fixation and storage in tundra soils has received considerable attention with respect to global carbon cycling. Recent findings by investigators using chamber measurements of fixation/respiration rates in arctic tundra have led to the conclusion that tundra is no longer storing carbon but is instead a source of carbon dioxide to the atmosphere (Oechel et al. 1992). These studies are based, however, on short-term measurements and do not account for interannual variability in temperature, moisture or herbivory. We have sought to test these conclusions and to determine methods by which the long-term accumulation or loss of carbon in tundra can be determined. Little is known, however, of the processes that control storage and the current rates of carbon fixation and peat formation in arctic Alaska. This project focused on several aspects of carbon dynamics and the roles of decomposition and herbivory at the DOE research site at Imnavait Creek, Alaska (68° 41' N, 149° 20' W). Through the use of natural abundance stable and radioisotope techniques, several conclusions emerged:

Peat carbon continues to accumulate in wetter areas of foothill valleys and on the coastal plain of arctic Alaska. Radiocarbon profiles of bomb ^{14}C were used to date layers of vegetation and litter to obtain decomposition rates and to extrapolate these values to intersection with the permafrost horizon where further decomposition is assumed to cease. Carbon storage in riparian moss at Imnavait Creek was estimated at 3 g C/m²-yr. Profiles of ^{137}Cs closely matched those of ^{14}C (Grebmeier et al., in press) and may provide a more expeditious means of assessing recent carbon accumulation rates in tundra.

Carbon and nitrogen stable isotope ratios in tundra vegetation vary markedly over hydrologic gradients in apparent response to changing growth rates and sources of nitrogenous nutrients. Within a taxon, $\delta^{15}\text{N}$ values varied by several ‰ over a tens of meters distance. This in apparent response to the recycling of nitrogen and the loss of nitrogen back to the atmosphere through denitrification. The isotopic discrimination during denitrification is large and can account for the variability in isotope ratios in vegetation over the hydrologic gradients.

Differing morphological forms of plants showed wide variation in $\delta^{15}\text{N}$ values in apparent response to nitrogen sources. Graminoids, lichens, mushrooms and forbs were more enriched in ^{15}N than shrubs and $\delta^{13}\text{C}$ values tended to correlate with $\delta^{15}\text{N}$. It is not known why the large differences (>3‰) exist but the trends were consistent in all sites samples.

Caribou, the most important herbivore in the tundra ecosystem, show seasonal cycles in $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ content as recorded in hoof keratin. Experiments on captive

animals reveals that hoof growth rates vary seasonally with the fastest rates occurring in summer. Over 14 months temporal record is present in the length of a hoof. Matching isotope ratios in rumen contents, hoof and muscle tissues with tundra vegetation allowed approximation of forage importance and revealed marked seasonal dependencies on differing forage types. For the years investigated, mushrooms apparently constitute a large fraction of high quality food intake in late summer. Changes in range quality are also evident in long-term isotope ratio trends in hoof keratin collected over several years.

The results of data collection over the duration of this project have been reported in manuscripts by the PI and collaborators. The raw data has been incorporated into the NSF-Arctic Long Term Ecological Research data base and are accessible through the program via the Ecosystem Center, Marine Biological Laboratory in Woods Hole Massachusetts. The findings have been incorporated into a thesis by Bruce Barnett and several manuscripts are currently in preparation for the open literature based upon this study.

PROJECT RESULTS

The data and conclusions obtained in this study are presented below in a series of manuscripts in draft, reviewed and published form. Most work will be in press by the end of 1994 as the reviewer modifications are incorporated into draft manuscripts. The conclusions are summarized here.

The role of arctic peatlands in terrestrial carbon dynamics

Increased photosynthesis in response to elevated carbon dioxide concentrations is a likely sink for this carbon but the constraints imposed by C:N:P ratios in vegetation and heterotrophic controls on nutrient recycling complicate the scenario. Several researchers on arctic tundra carbon fixation (Rastetter et al., 1992; Shaver et al., 1992) have concluded that the photosynthesis and carbon storage are largely determined by the nutrient supply and recycling rates in the ecosystem. Oechel and Billings (1992) review many of the conflicting results of studies regarding carbon storage in tundra and conclude that long-term carbon storage would probably require conversion of tundra vegetation to more shrubby or forest species. We agree with this scenario only with respect to short-term carbon storage. Although nutrient inputs and recycling strongly affect photosynthetic rates, they also tend to synergistically stimulate respiratory processes. For

effective carbon storage on a long-term basis, heterotrophy and transport of carbon from the system must be maintained at a lower rate than photosynthesis. In itself, carbon storage in natural systems is relatively independent of nutrient supply; indeed, application of nutrients to tilled lands tends to deplete organic carbon as heterotrophic processes and leaching increase. Exposure of peat soils to drainage or tilling has been shown to convert them from carbon sinks to sources (Bramryd 1979, Silvola, 1986). The critical variable, however, for carbon storage, tends to be soil moisture for active heterotrophy is dependent upon aerobic conditions. Billings et al. (1982) have stated that the soil moisture level is one of the major controlling factors in determining carbon accumulation or ablation in the Arctic. We believe that it is the primary control on carbon storage. Bog and tundra ecosystems with very low productivity will nevertheless accumulate peat if the water table and catotelm are maintained close to the growing plants. Our data for arctic tundra have shown that only those environments with saturated soils (flood plains, bases of footslope and flat coastal tundra) are accumulating peat (Schell and Barnett, in press). Many questions concerning water retention and nutrients in peat must be answered before effective modeling of ecosystem responses can occur.

The role of moisture in the dynamics of carbon storage is critical. At a Department of Energy workshop (Post, 1990), an attempt was made to quantify the rates of carbon dioxide production that would result from subjecting tundra ecosystems to a warmer drier climate. An overall warming was assumed and accompanied by a deepening of the active layer and a 10 cm depression in the water table. This increase in acrotelm depth would result in faster peat oxidation and, assuming no net increase in primary production, a loss of ~1.3 Gt C/yr from the system as carbon dioxide. This quantity is in the same magnitude as that projected from tropical deforestation and could potentially show a positive feedback in that the faster warming might lead to a steadily increasing acrotelm depth. These effects were contingent on a warming accompanied by no increase in rainfall. In contrast to a warmer drier scenario, some climate model predictions show an increase in precipitation accompanying warming in the Arctic with increased cloud cover. If rainfall increased markedly, the catotelm could rise as detrital vegetation accumulated and there might be no net loss of carbon or perhaps more important, an increased storage.

Peat accumulations imply that primary production and the production of dead vegetation has been in excess of consumptive (respiratory) demands and active transport from an ecosystem. Clymo (1984) argues that although the respiration of peat carbon is low in saturated soils, the production of carbon dioxide does not stop altogether. This implies that there is a finite upper limit to peat accumulation which he estimated to be in the order of 5-10 m for non-frozen peat bogs.

In permafrost soils, however, there are no constraints on maximum peat depths and in coastal arctic Alaska, basal peat ages indicate that peat has accumulated since revegetation occurred after the Pleistocene. Schell and Ziemann (1983) and Schell and Barnett (in press) estimated, for example, that about 7 - 10 g C/m²-yr was accumulating in the coastal plain peatlands of the Alaskan North Slope. Nevertheless, peat accumulation represents only a few percent of the original primary production and it is difficult to measure current formation rates with short-term techniques because of the heterogeneity of the tundra vegetation. Recent data on the fine-scale distribution of ¹⁴C in the uppermost vegetative layer (see below) shows that peat formation is still occurring in the floodplain of Imnavait Creek at rates similar to those projected from profiles of ¹⁴C activities in the deeper layers of the organic soil column.

It has been over 25 years since the inputs of radiocarbon to the atmosphere peaked from nuclear weapons testing in 1963. The vegetation grown since 1958 has contained elevated radiocarbon concentrations in excess of background and at levels which vary year by year as the input to the atmosphere equilibrates with the ocean. The standing dead and detritus derived from primary production in the past three decades contains these characteristic elevated radionuclide compositions whereas all pre-bomb organic matter is losing radiocarbon only by decay from a uniform starting activity.

Decomposition rates vary widely in the floodplain and slope environments of the R4D site. By measuring the stable isotope ratios along individual strands of moss, the annual cycles of carbon fixation are evident as oscillations of $\delta^{13}\text{C}$ and provide a means of aging the moss layer. A series of measurements at one site in the riparian moss revealed that decomposition rates kept up with fast moss growth rates (up to an apparent 13 cm/year) in the streamside community. At 20 cm depth, residual moss carbon was undetectable and ¹⁴C content abruptly dropped to ages equivalent to >500 yrs. B.P. This microenvironment is apparently not currently storing carbon.

In contrast to the rapid decomposition in the streamside moss layer, the $\delta^{13}\text{C}$ data from the vegetation and underlying peat collected in the floodplain further from the banks of Imnavait Creek show much slower decomposition (See manuscript following). The profile of the ¹⁴C activity through the vegetation and detrital matter is remarkably similar to the atmospheric ¹⁴C curve following weapons testing. This close match allowed us to assign probable dates to the individual layers for their deposition and to plot the residual carbon versus year. A log regression through the residual carbon data allows extrapolation to the initial net primary production and to the current rate of peat accumulation at 20 cm depth, the approximate permafrost horizon. The projected peat accumulation rate of 2.7 g C/m²-yr is consistent with long-term accumulation rates

estimated from basal peat ages and carbon standing stocks. Unlike the moss layer at streamside, this vascular plant and moss community is actively accumulating peat. The effectiveness of the bomb ^{14}C as a marker for organic matter accumulated at specific years in the recent past allows a means of estimating peat accumulation rates.

Stable isotope ratios in caribou and forage vegetation

The migratory path of the Central Arctic caribou herd encompasses a range of many hundreds of miles throughout the eastern Brooks Range, the Arctic Coastal Plains and the taiga of the Yukon Territory. This herd, at over 100,000 animals, is the largest in Alaska and traditionally moves northward in the spring to the coast of the Arctic National Wildlife Refuge to bear their young in an environment offering partial relief from the insect hordes of the summer. In passing through the annual migratory range, the forage available changes with lichens and mosses of the taiga being the winter staple and the browse and forbs of the coastal plain supplying the high quality forage in summer. This seasonal shift between forage types in concert with the physiological changes over the seasons causes marked shifts in the stable isotope composition of carbon and nitrogen in the caribou throughout the year. These changes are recorded in the keratin of the continuously growing hooves. Hoof growth rates are fastest during summer months and slow up in the winter but a record of over 14 months is present in the typical hoof. By comparing the isotope ratios along the hooves with forage types, we have been able to validate food source models which relate range quality with reproductive success and body condition.

Topographic effects on isotope ratios in vegetation.

The usefulness of carbon and nitrogen isotope ratios as tracers in natural systems requires that measurable differences exist among primary producers. In the northern foothills of the Brooks Range, Alaska, large differences were measured in the foliar $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values of vascular plants and lichens. Deciduous and evergreen shrubs were depleted in the heavier isotopes of carbon and nitrogen relative to forb and graminoid species. Lichens were generally more enriched in ^{13}C than vascular plants. Lichen $\delta^{15}\text{N}$ values indicated atmospheric sources of nitrogen, more enriched in ^{15}N than shrubs, but less enriched than graminoid and forbs. Variations in foliar $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values were also noted along tundra water tracks, apparently in response to soil moisture conditions and movement of soil nitrogen.

Deliverables

The following manuscripts are in press or as drafts of papers in preparation for the open literature: The primary manuscript on carbon storage in tundra as determined by isotope techniques is attached.

Schell, D. M. and B. Barnett (in press) Carbon dynamics in tundra ecosystems. In J. Reynolds and J. Tenhunen (eds.), Landscape function: Implications for Ecosystem Response to Disturbance., Ecological Studies, Springer-Verlag.

Oswood, M. W., J. G. Irons III, and D. M. Schell. (in press) Dynamics of dissolved and particulate carbon in a tundra stream in arctic Alaska. In J. Reynolds and J. Tenhunen (eds.), Landscape function: Implications for Ecosystem Response to Disturbance., Ecological Studies, Springer-Verlag.

Schell D. M. 1993. Bomb radiocarbon in arctic Alaskan aquatic and terrestrial biota. In: Radioactivity and environmental security in the oceans: new research and policy priorities in the Arctic and North Atlantic (V. Adushkin and G. Krasilov, eds.) Woods Hole Oceanographic Inst. Woods Hole MA. Pp. 135 - 144.

Carbon and Nitrogen Isotope Ratios of Vascular Plants, and Lichens from Northern Alaska Bruce Barnett and Donald M. Schell, Water Research Center, University of Alaska Fairbanks, Fairbanks, Alaska, 99775 Draft manuscript

Carbon and Nitrogen Isotope Ratios of Caribou Tissues from the Porcupine Herd, Arctic Alaska. Bruce A. Barnett and Donald M. Schell, Water Research Center, University of Alaska Fairbanks, Fairbanks, Alaska, 99775. Draft manuscript.

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