



global glimpses

Center for Global Change &
Arctic System Research

Volume 10 • No. 1 • May • 2002

The Center for Global Change – An Update

Patricia Anderson, Associate Director

The UAF Center for Global Change and Arctic System Research (CGCASR) was created in 1990 at a time when campuses nationwide established similar centers to begin to address the problems of climate change and its potential impacts. Faculty felt that there was an unprecedented opportunity for interdisciplinary interaction at UAF that would be facilitated by the creation of the Center. The Center was to provide a campus-wide framework for developing, coordinating, and implementing interdisciplinary research and educational activities that addressed the role of the Arctic in the global earth system.

During the 1990s, many changes occurred at UAF. Other organizations and arrangements for addressing global change developed, and global change research became more widespread and integrated into many departments and institutes. The Arctic Institute of North America established the Arctic Roundtable, an ongoing series of public forums which cover global change and other arctic topics. In 1998, the International Arctic Research Center (IARC), dedicated to global change studies, was created.

Given this changing environment, in late 2001 the Center staff and Science Steering Committee met to discuss the future directions and activities of the Center. In addition to maintaining the Center's basic structure and core activities, the committee recommended:

- Increasing the role of the Center in strengthening social sciences as an integrated part of global change problems, and
- Exploring interactions with the International Arctic Research Center (IARC).

To begin implementing these recommendations, we reconstituted the Science Steering Committee, replacing outgoing members and adding new members to achieve a better balance among physical, biological and social sciences and engineering. The committee comprises 23 UAF faculty (see box at left). Also included are liaisons to the Alaska

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Center for Global Change Science Steering Committee

(asterisks indicate new members)

*Harry Bader	Environmental Law
*Rick Caulfield	Arctic Anthropology/Political Economy
Cary de Wit	Human Geography
Larry Duffy	Environmental Chemistry
Bruce Finney	Geochemistry
Craig Gerlach	Paleoenvironments
Jim Gladden	Political Science
Doug Goering	Fluid Mechanics/Heat Transfer
Will Harrison	Glaciology
*Jay Jones	Ecology
Glenn Juday	Plant Ecology
Doug Kane	Hydrology
*Judy Kleinfeld	Psychology
Jerry McBeath	Political Science
*Nicole Mölders	Atmospheric Science
*Colin Read	Economics
Peter Schweitzer	Anthropology
Glenn Shaw	Atmospheric Science
Elena Sparrow	Earth System Science/K-12 Sci. Ed.
*Alan Springer	Biological Oceanography
David Valentine	Forest Soils
*Tom Weingartner	Physical Oceanography
*Dan White	Environmental Engineering

Ex Officio:

Patricia Anderson	Science Management
*Sarah Fowell	Quaternary Science
Shari George	GIS/Data Management
Gunter Weller	Climatology

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 - ✦ *Harold S.J. Zald, Department of Forest Sciences*
 - ✦ *Jill F. Johnstone, Institute of Arctic Biology*
 - ✦ *Grace Abromaitis, Institute of Marine Science*

Quaternary Center and the Alaska Data Visualization and Analysis Laboratory. Our thanks to outgoing members John Goering, Brenda Norcross, Don Schell and Al Tyler for their many contributions to the Center.

On 12 April, the Center sponsored a one-day workshop on “Human Dimensions of the Arctic System: Opportunities for Collaborative Research Projects Involving Social and Natural Scientists,” chaired by Henry Huntington, Director of the Human Dimensions of the Arctic System (HARC) science management office. A total of 50 UA participants, balanced between social and natural scientists, discussed the challenges involved in interdisciplinary research, as well as specific ideas for interdisciplinary projects. The Center is designing follow-on activities to this workshop.

Both the Center and IARC have global change research, education and outreach as their mission, and we are already closely cooperating. We now jointly fund the Global Change Student Research Grant Competition (see below), and are implementing a similar program for undergraduates. To further strengthen ties between the two Centers, we have agreed that the CGCASR Science Steering Committee will act as an advisory body for IARC in the future, concerning itself with IARC’s global change issues at UAF. The Steering Committee will help IARC in planning and reviewing relevant UAF research and workshop projects, as well as acting as a conduit of information between the two Centers and with the UAF research community. We look forward to the further development of this new relationship.❖

Center Staff Update

Congratulations to **Barb Hameister** (formerly Barb Severin) on her marriage to Jim Hameister on 21 April 2002! Barb is completing her fourth year with the Center as Publications and Meetings Coordinator. She also takes charge of many special projects for the office, and coordinates the UAF Weekly Science Calendar.

Sherry Lynch is the Center’s Administrative Assistant and the Administrator for the Cooperative Institute for Arctic Research (CIFAR). She joined the Center in July 2000. Sherry’s other activities include her work in administering the Arctic Climate Impact Assessment (ACIA) Secretariat.

Leslie Merriman is our most recent arrival. She began working at the Center in April as Travel Coordinator for the ACIA Secretariat.

Patricia Anderson will mark her tenth year as Associate Director of the Center in September 2002. She also serves as Deputy Director of CIFAR and staff for the ACIA Secretariat.

Gunter Weller, founding Scientific Director of the Center and CIFAR, remains at the helm. He is also the Executive Director of the ACIA Secretariat.

2002 Student Research Grant Recipients

This year, the International Arctic Research Center has joined the Center for Global Change in sponsoring the Global Change Student Research Grant Competition. In addition, the Alaska Sea Grant College Program has generously funded two of the awards (Kevin Budsberg and Olav Ormseth). Congratulations to all!

Kevin Budsberg, Department of Biology & Wildlife: *Temperature and salinity tolerance and sequencing of luxRI of the luminous photobacterium *Phosphoreum* isolated from Yukon River salmon*

Dorte Dissing, Department of Forest Sciences: *CAPE and the landscape—A story about the influence of landscape properties on convective available potential energy (CAPE)*

Teresa Nettleton Hollingsworth, Department of Biology & Wildlife: *Predicting the occurrence of black spruce communities in interior Alaska as a function of vegetation, fire disturbance and climate*

Anja Kade, Department of Biology & Wildlife: *Vegetation, soil and cryoturbation responses in Alaskan arctic tundra*

Olav Ormseth, Institute of Marine Science: *The influence of ocean temperature on the biology and ecology of Pacific cod in Alaskan waters*

S. Kalei Shotwell, School of Fisheries & Ocean Sciences, Juneau: *Utility of climate change in forecasting salmon returns*

Jason Vogel, Department of Forest Sciences: *Controls of and contributors to soil carbon dioxide efflux in Alaskan black spruce forests*

Yiming Wang, Department of Geology & Geophysics: *Late quaternary vegetation and paleoclimate evolution of the lake basin, northern Mongolia*

Student Research Grant Reports—Past Recipients

Stable Isotope Analysis of Pacific Salmon Provides Information on Trophic Status and Past Oceanographic Conditions

by *Franklin R. Satterfield IV, Institute of Marine Science, University of Alaska Fairbanks and Amy Hiron, Institute of Marine Science, University of Alaska Fairbanks.*

Introduction

Salmon are anadromous fish, hatching and spending up to the first two years of their lives in freshwater lakes and rivers and then descending streams leading to saltwater. Because salmon spend the majority of their lives in the marine environment, where more than 99% of their growth occurs, it is important to understand marine processes and their influence on salmon growth and survival. Recent research has shown that fluctuations in salmon abundance on interannual and interdecadal time scales are related to changes in the marine environment (Beamish and Bouillon, 1993; Mantua et al., 1997). Understanding such influences on the salmonid ecosystem involves consideration of available resources and salmon forage demands, two factors that affect carrying capacity for salmonids. Food limitation during periods of high salmonid abundance can decrease growth rates. Such limitation may also induce a change in diet. The abundance of salmon prey and potential competitors, as well as marine production and physical processes, can influence the total number of individual salmon that the North Pacific Ocean is able to support (Pearcy et al., 1999). Substantial evidence regarding decreased mean body size at age, as well as increased age at maturity (e.g., Cox and Hinch, 1997), has been collected over the last decade. These observations suggest that the carrying capacity for salmonids may have been approached (Pearcy et al., 1999).

Naturally occurring stable isotope ratios of carbon ($^{13}\text{C}/^{12}\text{C}$) and nitrogen ($^{15}\text{N}/^{14}\text{N}$) are useful tools for ecological studies. “You are what you eat” aptly describes how stable isotopes are established in an organism. Nitrogen isotope ratios increase with every trophic step up the food chain. Carbon isotope ratios are established in the phytoplankton at the base of the food web and are influenced by the environment in which they grow. Both the carbon and nitrogen isotope ratios are passed through a food web as organisms eat and are eaten. Isotope ratios found in muscle tissue tend to be very similar to the isotope ratios of the whole animal, eliminating the need to grind up and analyze entire organisms (Peterson and Fry, 1987). Salmon muscle is not often frozen and saved over the years, but salmon scales are easily preserved, do not require any special preservation, easily air dry, and can then be utilized for stable isotope analyses.

The objectives of this study were to utilize stable isotope ratios to: 1) examine potential competitive overlap among the different species of mature adult Pacific salmon and 2) determine if archived salmon scales could be used to study changes in salmon populations.

Methods

Muscle and accompanying scale samples were obtained from five North Pacific salmon species (*Oncorhynchus* spp.) shortly after the individuals entered spawning streams or hatcheries. Archived sockeye salmon scales (2–6 individuals/year) from Red Lake on Kodiak Island, spanning 33 years (1966–1999), were obtained from the Alaska Department of Fish and Game. Muscle samples were dried and ground, while scales were cleaned and the portion of the scale representing the last marine year’s growth was removed using a micro-scalpel. Samples were prepared and analyzed at the Stable Isotope Facility at the University of Alaska Fairbanks.

Interspecies comparisons and feeding implications

Relationships between $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ isotope ratios for adult salmon muscle tissue from samples collected in 1997 are shown in Figure 1. The stable isotope ratios cluster into three distinct groups, suggesting unique diets for both coho and chinook, and the potential for similar diets among pink, sockeye, and chum salmon. The variability in the isotopic data between species could result from feeding on prey from different trophic levels, from feeding at different locations, or from some combination of these factors.

Stomach content analysis of sockeye, pink and chum salmon from this region suggests that squid and zooplankton are often primary prey items (Burgner, 1991). Assuming enrichment in $\delta^{15}\text{N}$ of 3–4‰ for each trophic level (Wada et al., 1987), the isotopic composition of our sockeye, pink, and chum is consistent with a diet that includes such prey. Interpretation of isotope values of adult salmon is hindered by limited isotopic data on possible prey items in the North Pacific Ocean (Welch and Parsons, 1993). Available data suggest that both carbon and nitrogen ratios in zooplankton increase from the NE Pacific subarctic gyre towards the NE continental margin, and that zooplankton $\delta^{13}\text{C}$ ratios increase relative to those of $\delta^{15}\text{N}$ in regions close to the shelf break

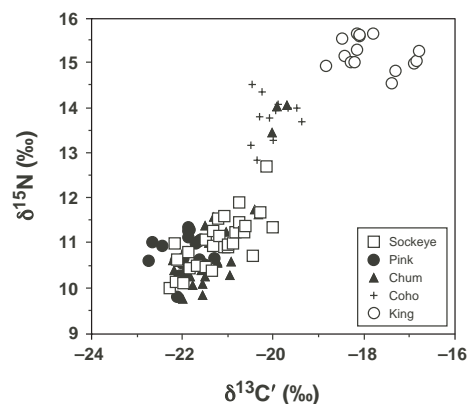


Figure 1. Scatter plot of muscle $\delta^{13}\text{C}'$ (lipid normalized, see text) and $\delta^{15}\text{N}$ stable isotope ratios for 5 species of adult Pacific salmon collected in 1997.

(Wu et al., 1997; Hirons, 2001). We speculate that our chinook may be feeding at a location closer to the margin, relative to the grouping of pink, sockeye and chum, which may partially account for the lower slope in $\delta^{15}\text{N}$ versus $\delta^{13}\text{C}$ than would be expected solely from changes in trophic level. Distributions of chinook in the NE Pacific show closer proximity to the margin relative to the other species (Healey, 1991), consistent with this hypothesis. However, stomach content analyses generally suggest a larger proportion of higher trophic level prey such as fish in the diet of chinook, relative to pink, chum and sockeye (Healey, 1991). Therefore, the between-species relationships in $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ may represent the combined effects of feeding at different locations and trophic levels.

Sockeye time-series and the use of scales as proxies for retrospective studies

The $\delta^{13}\text{C}$ values of the Red Lake salmon scales and muscle tissues differ consistently between the tissues, and $\delta^{15}\text{N}$ ratios of muscle and scale tissues are also strongly correlated. Thus, scales appear to be excellent proxies for retrospective studies. Scale $\delta^{13}\text{C}$ values from Red Lake salmon show some variability over time but no long-term trend (Figure 2a). $\delta^{15}\text{N}$ values, however, show decreasing values from 1972–1982, a generally increasing trend during 1982–1992, followed by fairly constant, but relatively high values during 1993–1999 (Figure 2b). Variation in these isotope ratios through time

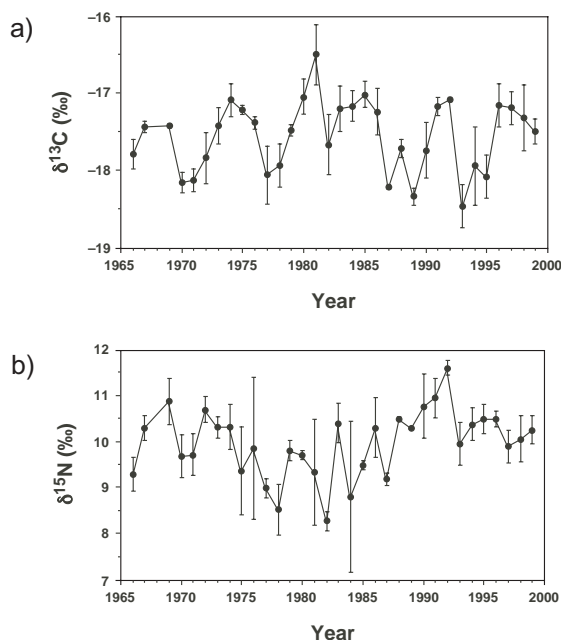


Figure 2. a) Yearly mean $\delta^{13}\text{C}$ (‰) for the last marine year of Red Lake, Alaska archived sockeye scales for the period from 1966–1999. Standard errors are based on analyses of different fish (2–6) for each year. b) Yearly mean $\delta^{15}\text{N}$ (‰) for the last marine year of Red Lake, Alaska archived sockeye scales for the period from 1966–1999. Standard errors are based on analyses of different fish (2–6) for each year.

may result from changes in trophic level of feeding, location of feeding, or isotopic fractionation at the base of the food web (phytoplankton) that is transferred through the food web.

Spatial variability in prey types and prey isotopic composition exist in the North Pacific, but are poorly documented. Limited data suggest that Kodiak sockeye salmon spend their last summer in the Gulf of Alaska gyre (Burgner, 1991), though year-to-year variability in migration routes has not been determined. It is unlikely that the temporal variability in isotopic composition represents significant shifts from open ocean to coastal feeding locations, as such shifts should be accompanied by large changes in $\delta^{13}\text{C}$ (Hirons, 2001). More comprehensive data on isotopic gradients in the North Pacific is required to test additional hypotheses regarding feeding location changes.

If the feeding area and trophic level of a stock of salmon are relatively constant over time, then changes in oceanographic conditions over a large region may be inferred from scale isotope data. Variations in carbon isotope ratios of phytoplankton at the base of the food web may vary due to phytoplankton productivity and species type. Physical processes such as temperature, wind strength and availability of nutrients also play a role in the variation of the carbon isotope ratios. Laws et al. (1995) have shown that phytoplankton $\delta^{13}\text{C}$ increases as algal cell growth rate (i.e., productivity) increases, if factors such as the amount of dissolved carbon dioxide in the water column and the algal cell size remain constant. If that's the case, the Red Lake scale $\delta^{13}\text{C}$ data suggest no long-term trend in North Pacific productivity over the years. This is surprising, as sockeye stocks underwent significant changes in abundance during this period.

Interannual variability in the nitrogen isotope ratios ($\delta^{15}\text{N}$) may reflect changes in the amount and use of nitrogen in the water column. We hypothesize that as the nutrient, nitrate (NO_3^-), an oxidized form of nitrogen, decreases in surface waters of the North Pacific, phytoplankton $\delta^{15}\text{N}$ will increase as they incorporate the nitrate. These isotopic changes will subsequently be transferred up the food chain to salmon. The long-term decline in winter surface nitrate at a sampling location in the northeastern Pacific, Ocean Station Papa (OSP), suggests progressive utilization of the nitrate pool due to a reduction in the strength of wintertime winds (Freeland et al., 1997). These winds generally mix the water column and bring more nutrients, including forms of nitrogen, to the surface where they will be used for food by the phytoplankton. However, if the winds decrease, the phytoplankton in the surface waters will utilize as much of the available nitrate as possible. The general increase in salmon scale $\delta^{15}\text{N}$ from the early 1980s to the 1990s is consistent with the decreasing trend in nitrate. However, the high $\delta^{15}\text{N}$ observed during the early to mid 1970s corresponds with a period of high nitrate concentration, indicating that factors other than changes in nitrate utilization contribute to salmon $\delta^{15}\text{N}$ variability.

Summary

Stable isotope analysis provides a tool with which we can gain a better understanding of Pacific salmon ecosystem processes. Our analyses allow several general conclusions for *Oncorhynchus* spp. First, stable carbon and nitrogen analyses of the five species of mature *Oncorhynchus* show three distinct groupings—chinook have the highest values, followed by coho, with chum, sockeye, and pink salmon together having the lowest values. Differences between the groups may be caused by a combination of factors, including location of feeding and trophic level of feeding. Although detailed data on salmon prey is very limited, isotopic analysis suggests that the diets of the sockeye, pink and chum analyzed are consistent with a diet including open ocean squid and zooplankton. This is in general agreement with stomach content analysis of these fish. Salmon scales incorporate the stable isotopes of carbon and nitrogen in a consistent fashion relative to muscle, and thus scales are suitable tissues for retrospective analyses. The temporal variability in $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ for one sockeye salmon stock (Red Lake, Alaska) was determined for the period 1966–1999. The $\delta^{13}\text{C}$ record exhibits minor variability but no long-term trend. Variability in the $\delta^{15}\text{N}$ values is more substantial, showing marked interdecadal changes. Temporal shifts in isotopic composition at the base of the food web resulting from changes in processes such as primary productivity and nitrate utilization, or in trophic level or location of feeding, may account for these trends, but there is currently insufficient data to evaluate these potential mechanisms. Future studies on the isotopic composition of salmon and their prey, as well as time-series analysis of other stocks and species, should help distinguish between these potential factors.

References

- Beamish, R.J. and D.R. Bouillon. 1993. Pacific salmon production trends in relation to climate. *Canadian Journal of Fisheries and Aquatic Science* 50:1002–1016.
- Burgner, R.L. 1991. Life history of sockeye salmon (*Oncorhynchus nerka*). In: *Pacific Salmon Life Histories*. Eds. C. Groot and L. Margolis. UBC Press, pp. 1–118.
- Cox, S.P. and S.G. Hinch. 1997. Changes in size at maturity of Fraser River sockeye salmon (*Oncorhynchus nerka*) (1952–1993) and associations with temperature. *Canadian Journal of Fisheries and Aquatic Science* 54:1159–1165.
- Freeland, H., K. Denman, C.S. Wong, F. Whitney, and R. Jacques. 1997. Evidence of change in the winter mixed layer in the Northeast Pacific Ocean. *Deep Sea Research* 44(12):2117–2129.
- Healey, M.C. 1991. Life history of chinook salmon (*Oncorhynchus tshawytscha*). In: *Pacific Salmon Life Histories*. Eds. C. Groot and L. Margolis. UBC Press, pp. 311–334.
- Hirons, A.C. 2001. Trophic Dynamics of Pinniped Populations in Alaska using Stable Carbon and Nitrogen Isotope Ratios. Ph.D. thesis, University of Alaska Fairbanks, 143 pp.
- Laws, E.A., B.N. Popp, R.R. Bidigare, M.C. Kennicutt, and S.A. Macko. 1995. Dependence of phytoplankton carbon isotopic composition on growth rate and $[\text{CO}_2]_{\text{aq}}$: Theoretical considerations and experimental results. *Geochimica et Cosmochimica Acta* 59(6):1131–1138.
- Mantua, N.J., S.R. Hare, Y. Zhang, J.M. Wallace, and R.C. Francis. 1997. A Pacific interdecadal climate oscillation with impacts on salmon production. *Bulletin of the American Meteorological Society* 78(6):1069–1079.
- Pearcy, W.G., K.Y. Aydin, and R.D. Brodeur. 1999. What is the carrying capacity of the North Pacific Ocean for salmonids? *PICES Press* 7(2):17–23.
- Peterson, B.J. and B. Fry. 1987. Stable isotopes in ecosystem studies. *Annual Review of Ecology and Systematics* 18:293–320.
- Wada, E., M. Terazaki, Y. Kabaya, and T. Nemoto. 1987. $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ abundances in the Antarctic Ocean with emphasis on biogeochemical structure of the food web. *Deep Sea Research* 34:829–841.
- Welch, D.W. and T.R. Parsons. 1993. $\delta^{13}\text{C}$ – $\delta^{15}\text{N}$ values as indicators of trophic position and competitive overlap for Pacific salmon (*Oncorhynchus* spp.). *Fisheries Oceanography* 2(1):11–23.
- Wu, J., S.E. Calvert and C.S. Wong. 1997. Nitrogen isotope variations in the subarctic northeast Pacific: relationships to nitrate utilization and trophic structure. *Deep Sea Research* 44:287–314. ❖

Simulations of Arctic Cloudiness

by **Cecile Hannay**, IARC-Frontier, University of Alaska Fairbanks (now at the Climate Diagnostic Center, Boulder, Colorado) and **Uma Bhatt**, IARC-Frontier, University of Alaska Fairbanks

Motivation: Global models fail to predict cloud amounts over the Arctic Ocean

Clouds play a fundamental role in the climate system through their impact on radiation (Liou, 1992). Clouds reflect back to space a significant amount of the visible radiation coming from the sun. They also strongly absorb the infrared radiation emitted by the earth. Hence, a high priority in climate modeling is to have an accurate representation of clouds, because it is the key tool for predicting global change. This is especially true over the Arctic Ocean because the magnitude of the surface temperature amplification is inextricably linked both to the ice-albedo feedback and cloud feedback. On one hand, a warmer climate will have less snow cover, resulting in a lower albedo, which in turn causes a further warming. On the other hand, a rise in temperature will lead to an increase of reflective clouds, which in turn act towards cooling the atmosphere.

However, most of the global climate models fail to predict realistic cloud amounts over the Arctic Ocean (Tao et al., 1996). This is an issue for accurate predictions of arctic climate changes. Figure 1 shows the annual cycle of the arctic cloud amount simulated with the Community Climate Model (CCM3), which is a state-of-the-art atmospheric global model designed for global climate research. It is clear that CCM3 is unable to reproduce the arctic cloud amount during the winter and it largely overestimates the observed cloud amount.

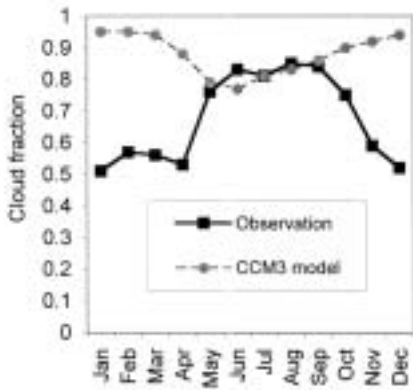


Figure 1. Annual cycle of arctic clouds. The simulated cloud fraction (dashed line) is compared to the observed cloudiness (Clark et al., 1996)

The primary objectives of this work are to answer why the global model CCM3 overestimates arctic cloudiness during winter and how to improve the simulations of wintertime cloudiness.

Method: A single-column model is used to test the cloud parameterization

Cloud processes occur on scales too small to be represented explicitly in global models such as CCM3. Therefore, the overall effect of clouds is included in the governing equations of a global model through what is called the “cloud parameterization.” A parameterization is the way that a global model treats the processes that are not resolvable at the grid scale of the model.

Single-column models are commonly used for testing parameterizations developed for global models (Randall et al., 1996). This is a very economic approach to test parameterizations of large-scale models. The single-column model is essentially a single column of a global model extracted from its environment. Observations are used to specify the conditions in the neighboring columns.

Our simulations were performed with the single-column version of the CCM3 (Hack et al., 2000). For the Arctic, the Surface Heat Budget of the Arctic Ocean (SHEBA) experiment provides a comprehensive observational data set that is

utilized for the initializing, forcing and evaluating of single-column simulations of the Arctic during all phases of the annual cycle (Bretherton et al., accepted; Intrieri et al., accepted).

Result: Accurate temperature and moisture are crucial to predicting arctic cloudiness

Basically, we have performed three types of simulations: the standard simulation, relaxed simulation, and sensitivity studies of the cloud parameterization.

- The “standard simulation” is conducted with the conventional CCM3 parameterization packages. As shown in the upper plot of figure 2, the model overestimates the cloud amount in this case. Moreover, we have shown that the model does not capture accurately the temperature and moisture profiles.

- In the “relaxed simulation,” the temperature and moisture fields are relaxed to the observed values. Relaxation is a common technique used to prevent key variables from drifting too far away from the observations. Relaxing the temperature and moisture profiles to observed values dramatically improves the simulations (lower plot in figure 2). Clouds are reproduced fairly well on a monthly as well as on a daily timescale. This result suggests that the cloud parameterization of CCM3 is suitable for the Arctic as long as the temperature and moisture fields are correctly captured.

- The “sensitivity studies” to the cloud parameterization address the influence of cloud type, ice effective radius and ice liquid ratio. We have shown that the model is not very sensitive to changes in these fields.

Summary

This research has been motivated by the fact that CCM3 significantly overestimates the cloud amount in the Arctic during winter, when compared to observations. Our goal was to understand the deficiencies in CCM3 that led to these errors in arctic cloudiness during winter and how modifications of the cloud parameterization could improve the simulations.

Our study provides a better understanding of why the CCM3 overestimates the arctic cloud fraction during winter.

The CCM3 cloud parameterization works moderately well over the Arctic if the thermodynamic profiles are accurate. More accurate reproductions of the temperature and moisture fields will likely result from changes in the boundary layer parameterization.

Acknowledgments

This project was financially supported by the Frontier Research System for Global Change and by the Center for Global Change and Arctic System Research at the University of Alaska Fairbanks, which are gratefully thanked.

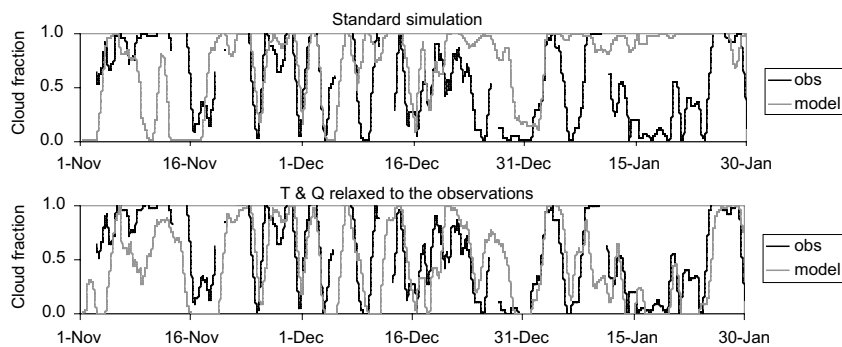


Figure 2. Temporal evolution of the simulated cloud fraction (black) and observed cloud fraction (grey). Standard simulation (upper plot) versus relaxed simulation (lower plot).

References

- Bretherton, C.S., S.R. de Roode, and C. Jakob. A comparison of the ECMWF forecast model with observations over the annual cycle at SHEBA. *Journal of Geophysical Research*, accepted.
- Clark, M.P., M.C. Serreze, and R.G. Barry. 1996. Characteristics of Arctic Ocean climate based on COADS data, 1980–1993. *Geophysical Research Letters* 23:1953–1956.
- Hack, J.J. and J.A. Pedretti. 2000. Assessment of solution uncertainties in single-column modeling frameworks. *Journal of Climate* 13:352–365.
- Intrieri, J.M., C.W. Fairall, M.D. Shupe, P.O.G. Persson, E.L. Andreas, P.S. Guest, and R.E. Moritz. An annual cycle of arctic surface cloud forcing at SHEBA. *Journal of Geophysical Research*, accepted.
- Liou, K. 1992. *Radiation and Cloud Processes in the Atmosphere: Theory, Observation and Modeling*. Oxford University Press.
- Randall, D., K.-M. Xu, R.C. Somerville, and S.F. Iacobellis. 1996. Single-column models and cloud ensemble models as links between observations and climate models. *Journal of Climate* 9:1683–1697.
- Tao, X., J. Walsh, and W.L. Chapman. 1996. An assessment of global climate model simulations of arctic air temperatures. *Journal of Climate* 9:1060–1076. ❖

Physiographic and Reproductive Components of Treeline Response to Climatic Variation in the Alaska Range

by **Harold S.J. Zald**, Department of Forest Sciences, University of Alaska Fairbanks (now at the School of Natural Resources and Environment, University of Michigan)

Introduction

Treeline represents a transitional boundary between the forested ecological system and the treeless tundra. Treeline is also seen as the vegetative result of the boundary between temperate and arctic climatic regimes. The focus on climatic variation and change over recent decades has resulted in increased interest in treeline dynamics by the scientific community. High latitude treelines are of particular interest, since high latitude climates are more variable than those of more temperate regions (Chapman and Walsh, 1993; Cuffey et al., 1995). With varying degrees of uncertainty, climatically induced treeline movements may have significant impacts at multiple spatial scales (Table 1).

Traditionally there has been a strong climatic bias in treeline dynamics research. Temperature has often been used as the primary factor to explain treeline positions throughout

Spatial Scale	Potential Treeline Effects
Local	Local flora and fauna population changes
Regional	Regional flora and fauna changes Changes in wildlife migration patterns
Global	Changes in arctic reflectivity (albedo) Changes in carbon biogeochemical cycling

Table 1. Possible effects of treeline movement at multiple spatial scales.

the world (Grace, 1989; Sirois, 1992). Temperature has also been the primary factor used in ecological models that create potential vegetation patterns at large regional spatial scales over long periods of time (Starfield and Chapin, 1996). By emphasizing temperature in treeline research, an oversimplification has occurred, neglecting the complex ecological components that interact at the forest/tundra boundary.

Landscape ecology and reproductive ecology at treeline

Two disciplines that may be of special importance in understanding treeline dynamics in the Alaska Range are landscape ecology and reproductive ecology. Stan Rowe has eloquently described landscape ecology and landscape ecosystems this way: “Any single perceptible ecosystem is a topographic unit, a volume of land and air plus organic contents extended areally over a particular part of the earth’s surface for a certain time” (Rowe, 1961). One of the central components of landscape ecology is the importance of physiography.

Physiography deals with the configuration of the earth’s surface, and the associated geologic substrate or parent material over a particular spatial scale. Physiography can affect treeline positions and movements in direct and indirect ways. Directly physiography can affect treeline positions and movement by providing suitable physical locations for tree germination, establishment, growth, and reproduction. Physiography can also provide sites unsuitable for trees (talus slopes, frequently flooded sites, etc.), despite suitable climatic conditions. Physiography may also provide topographic barriers for treeline movement, which ecological models have attempted to quantify (Rupp et al., 2001). Physiography may also indirectly affect treeline dynamics by modifying climatic conditions. Just a few examples include cold sinks caused by depression, orographic precipitation caused by mountains, and hot, dry, south-facing landforms that receive higher amounts of solar radiation than their neighboring landforms.

Reproductive ecology is also essential to understanding treeline spatial responses to climatic change. In the Alaska Range, white spruce (*Picea glauca*) is the overwhelmingly dominant treeline species. White spruce reproduces by seed, so sexual reproduction is a prerequisite for treeline altitudinal or latitudinal movement. Without viable seed, treeline positions will not move upward or northward, regardless of how favorable the climatic regime may be for the growth of existing trees. White spruce displays periodic seed crops (bumper crops of high seed production) over 11- to 13-year cycles across much of its geographic range in North America (Zasada et al., 1978). Research in interior Alaska suggests that multiple warm springs and early summers with abundant moisture are required for excellent quantity and quality seed crops (Alden, 1985; Zasada et al., 1992).

The roles of physiography and reproductive ecology were the focus of my research. It was the purpose of this research to discover if there are patterns of treeline position and movement that are based on physiography and reproductive ecology.

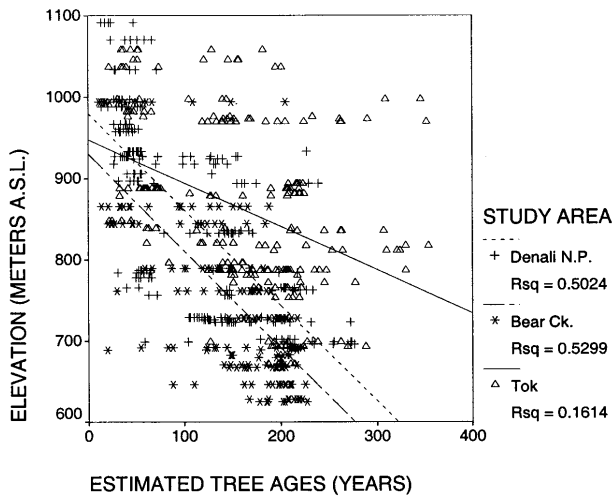


Figure 1. Relationship between estimated tree ages and elevation of study areas.

Study locations and methods

Three study areas were identified in the eastern half of the north slope of the Alaska Range. The study areas were located in Denali National Park, along the Trans-Alaska pipeline south of Delta Junction, and along the Tok cutoff of the Glenallen Highway south of Tok. In each study area three physiographic units (P.U.s) were sampled (north-facing slopes, south-facing slopes, and drainage landforms). In each physiographic unit one transect was established along an elevational gradient from closed canopy forest to the highest elevation of tree establishment. Tree cores were taken from white spruce trees along these transects and aged. A total of 750 tree cores were collected, and 681 were of suitable quality for aging (90.8 percent). Regression models were used to analyze the relationships between tree ages, elevations, physiographic units, and study areas. The steeper the regression line, the more rapidly treeline moved up in elevation for that particular land unit being analyzed.

Physiographic and study area trends of treeline

Analyses show that treeline positions and movements are different between study areas (Figure 1). Comparisons of all physiographic units (P.U.s) suggest that treelines on north- and south-facing slopes are similar, but treelines in drainage landforms are significantly less sensitive (Figure 2). However, this can be misleading. In analyses not included in this article, south-facing slopes are more sensitive to elevation when each study area is examined independently. This suggests that the landscape may influence treeline movement at a spatial scale larger than the individual physiographic units sampled. South-facing physiographic units displayed the steepest regression slopes, implying that they have the most rapid treeline movement. This is likely the result of the higher amount of solar radiation that they receive compared to the other units studied. North-facing units and drainages had significantly flatter regression lines. Reduced solar radiation and local moderating effects caused by permafrost

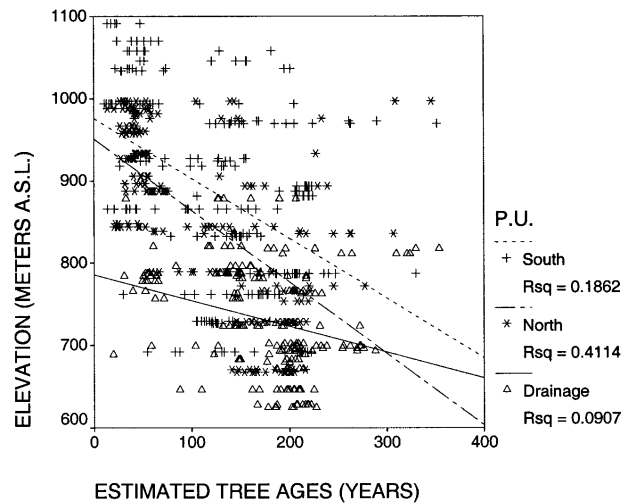


Figure 2. Relationship between estimated tree ages and elevation of all physiographic units (P.U.s).

may suppress treeline movement in response to climatic change. Drainage units' regressions are likely to be caused by a variety of physiographic effects. Drainages tend to serve as sinks for cold air, creating colder conditions than those found on adjacent uplands. The geological processes of sediment erosion, transport, and deposition may also restrict treeline movement by providing unstable physical sites for tree establishment.

Even at the highest elevations in all study areas there is a wide age range for trees, suggesting multiple recruit periods at treeline. Age distributions also suggest periodic recruitment patterns that may be the result of periodic seed crop production. This is supported by a loose correlation between age distribution and a 200-year reconstruction of early season growing conditions based on tree growth and existing temperature data from Fairbanks, Alaska (Figure 3).

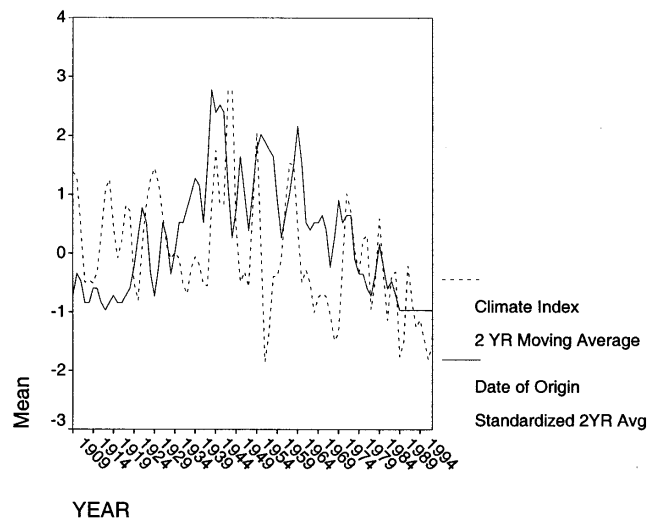


Figure 3. Relationship between estimated tree age distributions and early season temperature and precipitation (climate index).

What does it all mean?

The results of this research suggest that we need to view treeline ecology for what it is, a diverse ecological system with many interacting abiotic and biotic components. In order to better understand treeline ecology we must employ a wide variety of techniques that come from multiple disciplines. Landscape ecology and reproductive ecology represent a few of the disciplines, but are far from the only ones. The use of a more complete multi-factor approach to treeline dynamics will greatly improve ecological modeling precision and validity, as well as increase our basic understanding of treeline ecology in general.

Acknowledgments

This research was funded by a student grant through the Center for Global Change and Arctic System Research. Professor Glenn P. Juday of UAF's School of Agriculture and Land Resources Management provided valuable information about white spruce and treeline ecology that benefited this research greatly. Professor Ed Packee, also of UAF's School of Agriculture and Land Resources Management, provided assistance in study area locations. I am also most grateful to Dan P. Coles for his work as my field assistant during the summer of 2000, and the University of Michigan's School of Natural Resources and Environment for continued support during my graduate education.

References

- Alden, J. 1985. Biology and management of white spruce seed crops for reforestation in subarctic taiga forests. AFES. School of Agriculture and Land Resources Management. University of Alaska Fairbanks, Alaska. Bulletin 69.
- Chapman, W.L. and J.E. Walsh. 1993. Recent variations of sea ice and air temperatures in high latitudes. *Bulletin of the American Meteorological Society* 74:33–47.
- Cuffey, K.M., G.D. Clow, R.B. Alley, M. Stuiver, E.D. Waddington, and R.W. Saltus. 1995. Large arctic temperature change at the Wisconsin-Holocene glacial transition. *Science* 270:455–458.
- Grace, J. 1989. Treelines. *Philosophical Transactions of the Royal Society of London* B324:233–245.
- Rowe, S. 1961. The level-of-integration concept and ecology. *Ecology* 42:420–427.
- Rupp, T.S., F.S. Chapin III, and A.M. Starfield. 2001. Modeling the influence of topographic barriers on treeline advance at the forest-tundra ecotone in northwestern Alaska. *Climatic Change* 48:399–416.
- Sirois, L. 1992. The transition between boreal forest and alpine tundra. In *A Systems Analysis of the Global Boreal Forest*, H.H. Shugart, R. Leemans, and G.B. Bonan, Eds. Cambridge University Press, Cambridge, pp. 297–315.
- Starfield, A.M. and F.S. Chapin III. 1996. A dynamic model of arctic and boreal vegetation change in response to global changes in climate and land-use. *Ecological Applications* 6:842–864.
- Zasada, J.C., M.J. Foote, F.J. Deneke, and R.H. Parkerson. 1978. Case history of excellent white spruce cone and seed crop in interior Alaska: cone and seed production, germination, and seedling survival. U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest Experiment Station, General Technical Report PNW-65.
- Zasada, J.C., T.L. Sharik, and M. Nygren. 1992. The reproductive process in boreal forest trees. In *A Systems Analysis of the Global Boreal Forest*, H.H. Shugart, R. Leemans, and G.B. Bonan, Eds. Cambridge University Press, Cambridge, pp. 85–125.❖

How do Interactions between Fire and Vegetation Affect Boreal Forest Response to Changes in Climate?

by *Jill F. Johnstone*, Institute of Arctic Biology, University of Alaska Fairbanks

Introduction

Fire affects many aspects of boreal forest ecosystems, such as landscape structure, community composition, and ecosystem processes. Many boreal regions, including western Canada and Alaska, are likely to experience an increase in fire activity as a result of global climate change (Flannigan et al., 1998). This increased activity is likely to complicate the response of vegetation to climate change, as post-fire vegetation composition is sensitive to variations in both fire and climate conditions (Sirois and Payette, 1991; Payette et al., 2000). Changes in vegetation composition can, in turn, influence fire behavior by altering fuel characteristics (Cumming, 2001; Hély et al., 2001). The potential for multiple interactions between vegetation, fire and climate suggests that the response of boreal forest landscapes to climate change may be complex and difficult to predict. In particular, interactions between vegetation characteristics and disturbance may play important roles in developing alternative states in forest ecosystems and could strongly affect ecosystem response to climate change.

Effects of fire severity and climate variation on post-fire tree establishment

This research examines the response of tree seedlings to variations in fire severity and climate conditions, with an overall aim of understanding how variations in fire and climate affect patterns of post-fire succession. In the summer of 2000, experiments were initiated to investigate the effects of fire severity on seedling establishment in four recent (1998–1999) burn scars in Yukon Territory and Alaska. At each site, experiments were set up to compare tree seedling establishment across natural or manipulated levels of soil burn depth. At one intensive site near Delta Junction, Alaska, open-topped greenhouses were included in the experiment to test the effects of summer warming on seedling establishment. The greenhouse treatments increase mid-day air temperatures by 1–5 °C, depending on weather conditions.

The primary objective of these experiments is to examine how variations in fire severity, expressed as soil burn depth, affect post-fire seedling establishment patterns when seeds are freely available. Replication of experiments across several sites permits an assessment of how regional variability in soil or climate factors may affect the strength or direction of this relationship. Drought-stress has been

suggested to be the main factor controlling seedling establishment rates on organic soils (Zasada et al., 1983). Based on this hypothesis, it is expected that the effects of burn depth will be greatest at the drier sites, and that small-seeded tree species will be most sensitive to burn depth because of their more limited capacity for rapid root growth. Warming should further decrease seedling survival if it increases the number or severity of drought periods.

At each of the four sites, seed germination and seedling growth were monitored across two severity levels: lightly-burned soils with an intact organic layer, and severely-burned soils with exposed mineral soil. All experimental plots received equivalent seeding treatments of four tree species: trembling aspen (*Populus tremuloides*), black spruce (*Picea mariana*), white spruce (*Picea glauca*), and lodgepole pine (*Pinus contorta*). One-meter-diameter circular plots were divided into 0.25-m² sub-plots and randomly assigned to a seeding treatment or a non-seeded control. Seeds were sown in June and September of 2000. In order to obtain measurements of seedling growth in plots with low rates of establishment, small established seedlings were transplanted into the experimental plots in June 2001 (n=3/sub-plot). The experiment will be terminated in August 2002, and all the seedlings will be harvested to obtain measurements of total biomass and nutrient concentrations.

Observations from the second year of the experiments show seedling establishment patterns that are generally consistent with the hypotheses stated above. At each of the four experimental sites, seedling establishment rates were substantially higher for seeds sown on severely burned substrates compared to lightly burned, organic soils (Figure 1). Trembling aspen showed the greatest sensitivity to burn severity, as it had the lowest germination and highest mortality rates on organic soils. Black spruce, white spruce, and lodgepole pine showed a slightly greater ability to germinate on organic soils. These three species have seeds that are many times larger than those of aspen. Lodgepole pine, whose seeds are similar in size to white spruce and twice the size of black spruce, had the highest rate of germination on organic soil (Figure 1). Pine also had the lowest mortality rate of the four species, which averaged 20, 40, 55 and 85 percent for pine, black spruce, white spruce, and aspen, respectively. These patterns suggest that, in comparison with deciduous species, large-seeded conifers are more successful at establishing on organic soils, but among the conifers, other factors affect relative establishment success. In particular,

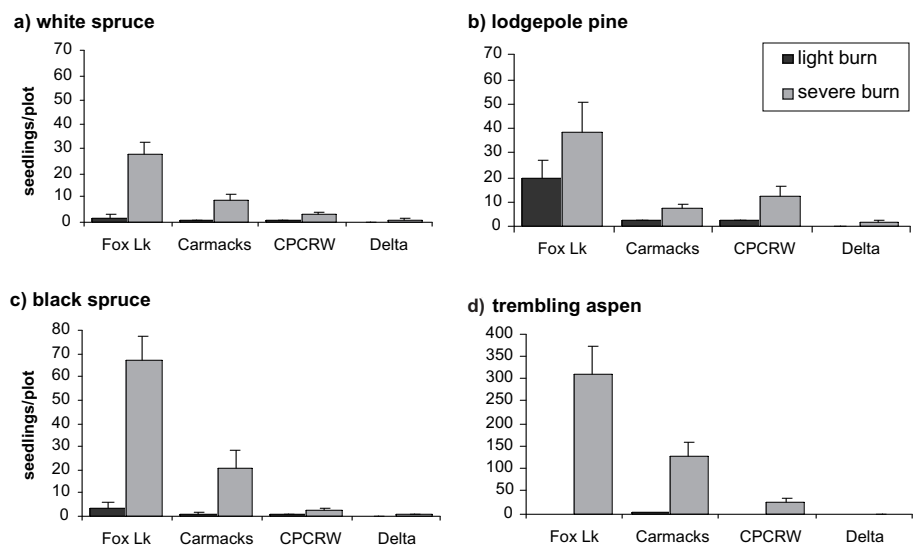


Figure 1. Average seedling germination per plot (± 1 SE) for four boreal tree species (in order of seed size): a) white spruce, b) lodgepole pine, c) black spruce, and d) trembling aspen. Values represent total cumulative germination, measured during 2000 and 2001, and do not include mortality. All plots received a standard sowing treatment for a given species. Note the y-axis scales vary among the graphs.

black spruce does not appear to have a clear advantage in establishing on organic soils, despite its tendency to dominate on sites characterized by thick organic layers (Van Cleve and Viereck, 1981; Van Cleve et al., 1991).

Total germination rates varied widely among the sites in this study (Figure 1). Germination was highest at sites with greater moisture availability, a pattern that supports the idea that drought stress is a key factor limiting post-fire seedling establishment. Total germination was lowest at the Delta Junction site, which is located on well-drained soils. Unfortunately, the low establishment rates at this site precluded detection of any effect of experimental warming on seedling establishment. Future measurements obtained from transplanted seedlings will hopefully provide an estimate of the effect of warming on early seedling growth and survival.

Implications

The high sensitivity of boreal tree regeneration to soil burn severity suggests that changes in fire regime could have strong effects on patterns of forest succession. Many northern boreal forest stands possess thick organic soils that undergo conifer-to-conifer successional replacement after fire (Van Cleve and Viereck, 1981). The results of this study indicate that this dominance cycle is primarily maintained by reproductive strategies such as cone serotiny (cones that remain fused until heated) that allow trees to disperse large quantities of on-site seed, thereby overcoming low establishment rates on organic seed beds. An increase in the proportion of deep-burning fires that expose mineral soil surfaces would reduce the relative advantage of serotinous species such as black spruce and lodgepole pine, and allow species dispersing seeds from outside a fire area to become established. Once present, fast-growing, non-serotinous deciduous

species such as birch and aspen will compete with conifers for light and nutrients, and delay the development of a conifer canopy. Deciduous species may be maintained in a forest stand through multiple disturbance cycles because of their capacity for dense re-sprouting from stumps and roots after fire (Greene et al., 1999). Deciduous trees also produce large amounts of high-quality litter that stimulates soil decomposition and restricts moss growth, causing slower rates of organic layer accumulation that favor their subsequent re-establishment (Mann and Plug, 1999). In this fashion, changes in climate that alter patterns of fire severity could result in rapid changes in the composition of forest landscapes. These altered communities may then be maintained through successive disturbance cycles by positive feedbacks between recruitment, vegetation characteristics, and ecosystem processes. Alterations in the dominant community state across a landscape may affect many aspects of ecosystem functioning, and could create additional feedbacks to climate, through changes in surface albedo, evapotranspiration and ecosystem carbon storage (Chapin et al., 2000).

References

- Chapin F.S. III, A.D. McGuire, J. Randerson, et al. 2000. Arctic and boreal ecosystems of western North America as components of the climate system. *Global Change Biology* 6:211–223.
- Cumming, S.G. 2001. Forest type and wildfire in the Alberta boreal mixedwood: what do fires burn? *Ecological Applications* 11:97–110.
- Flannigan, M.D., Y. Bergeron, O. Engelmark, and B.M. Wotton. 1998. Future wildfire in circumboreal forests in relation to global warming. *Journal of Vegetation Science* 9:469–476.
- Greene, D.F., J.C. Zasada, L. Sirois, D. Kneeshaw, H. Morin, I. Charron, and M.-J. Simard. 1999. A review of the regeneration dynamics of North American boreal forest tree species. *Canadian Journal of Forest Research* 29:824–839.
- Hély, C., M.D. Flannigan, Y. Bergeron, and D. McRae. 2001. Role of vegetation and weather on fire behavior in the Canadian mixedwood boreal forest using two fire behavior prediction systems. *Canadian Journal of Forest Research* 31:430–441.
- Mann, D.H. and L.J. Plug. 1999. Vegetation and soil development at an upland taiga site, Alaska. *Ecoscience* 6:272–285.
- Payette, S., N. Bhiry, A. Delwaide, and M. Simard. 2000. Origin of the lichen woodland at its southern range limit in eastern Canada: the catastrophic impact of insect defoliators and fire on the spruce-moss forest. *Canadian Journal of Forest Research* 30:288–305.
- Sirois, L., and A. Payette. 1991. Reduced postfire tree regeneration along a boreal forest–forest–tundra transect in northern Quebec. *Ecology* 72:619–627.
- Van Cleve, K., and L.A. Viereck. 1981. Forest succession in relation to nutrient cycling in the boreal forest of Alaska. In: *Forest Succession, Concepts and Application*. Eds. D.C. West, H.H. Shugart, and D.B. Botkin. Springer-Verlag, New York, pp. 184–211.
- Van Cleve, K., F.S. Chapin III, C.T. Dyrness, and L.A. Viereck. 1991. Element cycling in taiga forest: State-factor control. *BioScience* 41:78–88.
- Zasada, J., R.A. Norum, R.M. Van Veldhuizen, and C.E. Teutsch. 1983. Artificial regeneration of trees and tall shrubs in experimentally burned upland black spruce/feather moss stands in Alaska. *Canadian Journal of Forest Research* 13:903–913. ♦

A Retrospective Assessment of Primary Productivity in the Bering Sea as Indicated by Sea Bird Isotope Ratios

by **Grace Abromaitis**, *Institute of Marine Science, University of Alaska Fairbanks.*

Background

The Bering and Chukchi Seas have undergone major marine mammal and seabird declines in recent years (Loughlin et al., 1984, 1992; York, 1990; Sinclair et al., 1997). A major shift has occurred in the physical environment of the region, with marked effects on the biota (Whitney et al., 1998). Years prior to 1976 were characterized by more extensive ice cover in the winter and colder average temperatures, whereas subsequent years were warmer and characterized by shifts in the species composition of benthic fishes and invertebrates (Niebauer, 1988; Ebbesmeyer et al., 1991; Anderson et al., 1997). Recent compilations of historical nutrient and weather data indicate that mixed layer depths and nitrate supply to the euphotic zone in the North Pacific Ocean have decreased (Freeland et al., 1997). Schell (2000) reported a decrease of 2.7‰ in the $\delta^{13}\text{C}$ values of bowhead whale baleen from 1966 to present, and ascribed the decrease to changes in phytoplankton $\delta^{13}\text{C}$ values. I analyzed isotope ratios in thick-billed murres to independently observe changes in $\delta^{13}\text{C}$ values in the same geographic region.

Isotope ratios in murres (apex predators) integrate the seasonal isotopic signal of primary production. Nitrogen isotope ratios reveal trophic position and food web interactions. The primary producers at the base of the food chain set carbon stable isotope ratios. Phytoplankton $\delta^{13}\text{C}$ values depend on cell size, growth rate, nutrient supply, and carbon dioxide reduction (Laws et al., 1995; Popp et al., 1998). Therefore, phytoplankton $\delta^{13}\text{C}$ values reflect seasonal growing conditions. Use of nitrogen and carbon stable isotope information thus gives a multi-dimensional view of the system.

This project used archived muscle and feather samples from thick-billed murres and described temporal changes in isotope ratios in the Bering Sea over the past four decades (Abromaitis, 2000). In addition, blood, feather, and feces samples from captive pigeon guillemots were taken to investigate isotope incorporation during feather synthesis.

Climatic influence on thick-billed murre isotope ratios

Mean annual thick-billed murre muscle $\delta^{13}\text{C}$ values were correlated with the Pacific Decadal Oscillation values (Mantua et al., 1997) of the previous year (Spearman's Test, $p = 0.0015$). However, they were not correlated with annual sea ice extent or with annual flow through Bering Strait (Roach et al., 1995; Niebauer, 1998). Thick-billed murre $\delta^{13}\text{C}$ values followed trends seen in bowhead whale baleen

(Schell, 2000) (Spearman's Test, $p = 0.03$). These results suggest that primary productivity (as reflected in murre carbon isotope ratios) is affected by climatic shifts.

Feather enrichment over muscle varied between years for carbon, resulting in no direct correlation between feather values and muscle in murre. Since feathers incorporated carbon and nitrogen only during growth and were then biologically inert, the $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ of feathers reflected the diet during molt. Muscle continually metabolized carbon and nitrogen, and thus the $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values of muscle reflected diet close to the time of sampling. Variability in feather enrichment may have resulted from a change in molt location or isotope ratios at the molt location between years.

Isotope ratios during feather synthesis in captive pigeon guillemots

Captive pigeon guillemots were dosed with labeled glycine, which passed rapidly through them and was only partially assimilated. However, the labeled glycine was used in feather synthesis, as evident by carbon and nitrogen enrichment in samples taken from the base of growing feathers. After dosage, secondary feather shafts tended to be more enriched in carbon and nitrogen than were their vanes. Also, some secondary shafts were enriched while vanes did not show any enrichment, indicating blood access to the shaft after the vanes had completed formation (Lucas and Stettenheim, 1972). When the $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ of unlabeled pigeon guillemot feathers were compared to the birds' diet, fractionation values within the range found in prior studies of falcons, chickens, quail, gulls, and cormorants (0.2–4‰ in carbon and 1.6–3‰ in nitrogen) were evident (Mizutani et al., 1991; Hobson and Clark, 1992). Feather enrichment was consistent among birds, as expected, because the birds were fed a consistent (known) diet while growing new feathers.

Summary

The correlation between the Pacific Decadal Oscillation, thick-billed murre muscle, and bowhead whale baleen carbon isotope ratios suggests that primary productivity in the Bering Sea has been affected by climatic shifts. Stable isotope ratios in feathers and muscle represented different dietary periods in thick-billed murre and were not directly comparable. However, pigeon guillemot feathers that were actively growing did directly reflect the isotopic signature of the bird's diet. It is likely that murre feathers and muscle tissue would also be comparable when the birds were molting. Future studies may reduce the variability in isotope ratios between tissues by focusing on collecting birds during the molt season. Such studies could also clarify the relationship between diet, feather growth, and isotopic incorporation into feathers and muscle tissue.

References

Abromaitis, G.E. 2000. A Retrospective Assessment of Primary Productivity on the Bering and Chukchi Sea Shelves using Stable Isotope Ratios in Seabirds. MS Thesis, University of Alaska Fairbanks. 79 pp.

- Anderson P.J., J.E. Blackburn, and B.A. Johnson. 1997. Declines of forage species in the Gulf of Alaska, 1992–1995, as an indication of regime shift. In: *Forage Fishes in Marine Ecosystems. Proceedings of an International Symposium on the Role of Forage Fishes in Marine Ecosystems*. Alaska Sea Grant Report 97-01. University of Alaska, Fairbanks, Alaska, pp. 531–544.
- Ebbesmeyer, C.C., D.R. Cayan, D.R. McLain, F.H. Nichols, D.H. Peterson, and K.T. Redmond. 1991. 1976 step in the Pacific climate: Forty environmental changes between 1968–1975 and 1976–1984. In: *Proceedings of the Seventh Annual Pacific Climate (PACCLIM) Workshop, April 1990*. California Department of Water Resources, Interagency Ecological Studies Program Technical Report 26, pp. 115–126.
- Freeland, H.K., C.S. Denman, F.W. Wong, and R. Jacques. 1997. Evidence of change in the winter mixed layer in the Northeast Pacific Ocean. *Deep-Sea Research* 44:2117–2129.
- Hobson, K.A., and R.G. Clark. 1992. Assessing avian diets using stable isotopes. II: Factors influencing diet-tissue fractionation. *The Condor* 94:189–197.
- Laws, E.A., B.N. Popp, R.R. Bidigare, M.C. Kennicutt, and S.A. Macko. 1995. Dependence of phytoplankton carbon isotopic composition on growth rate and $[\text{CO}_2]_{\text{aq}}$: theoretical considerations and experimental results. *Geochimica et Cosmochimica Acta* 59:1131–1138.
- Loughlin, T.R., D.J. Rugh, and C.H. Fiscus. 1984. Northern sea lion distribution and abundance, 1956–80. *Journal of Wildlife Management* 48:729–740.
- Loughlin, T.R., A.S. Perlov, and V.V. Vladimirov. 1992. Range wide survey and estimation of total abundance of Steller sea lions in 1989. *Marine Mammal Science* 8:220–239.
- Lucas, A.M., and P.R. Stettenheim. 1972. *Avian Anatomy Integument*. United States Department of Agriculture, Washington, D.C., 720 pp.
- Mantua, N.J., S.R. Hare, Y. Zhang, J.M. Wallace, and R.C. Francis. 1997. A Pacific interdecadal climate oscillation with impacts on salmon production. *Bulletin of the American Meteorological Society* 78: 1069–1080.
- Mizutani, H., Y. Kabaya, and E. Wada. 1991. Nitrogen and carbon isotope compositions relate linearly in cormorant tissues and its diet. *Isotopenpraxis* 4:166–168.
- Sinclair, E.H., Ed. 1997. *Fur Seal Investigations 1996*. NOAA Technical Memorandum NMFS-AFSC-87. 115 pp.
- Whitney, F.A., C.S. Wong, and P.W. Boyd. 1998. Interannual variability in nitrate supply to surface waters of the Northeast Pacific Ocean. *Marine Ecology Progress Series* 170:15–23.
- York, A.E. 1990. Trends in numbers of pups born on St. Paul and St. Georges Islands, 1973–88. In: *Fur Seal Investigations, 1987 and 1988*. Ed. H. Kajimura. NOAA Technical Memorandum NMFS F/NWC-180, pp. 31–37. ♦

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