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Mercury in Alaska: The Need for Monitoring

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Metals appear in all arctic ecosystems and high concentrations of metals can have obvious impacts on the local environment. Plants and animals, including humans, usually have time to adapt over many generations. When natural erosion and transport of metals occurs as natural sources change with time, populations can continue to change because, on a relative time scale, these physical processes are slow enough to allow biochemical adaptation or behavioral modification to compensate. Anthropogenic pollutants associated with global climate change will have a major impact on local environments by changing the natural biogeochemical cycle. Moreover, impacts from human activities usually occur over a much shorter time scale, and biological adaptation may not be able to keep pace with these rapid environmental changes. Thus, a rapid increase in toxic metals can threaten the physical health of both plant and animal species, as well as human populations that depend on these species for their subsistence.

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Ecosystem Element	Assessment Endpoint	Line of Evidence
Fish	Reduction in species diversity, population numbers or increased frequency of pathology in the fish community.	Survey data, Hg exposure data, and biomarkers such as heat shock proteins.
Piscivorous Wildlife	Reduction in abundance or production of piscivorous mammal or bird population resulting from Hg toxicity; increase in pathology.	Hg levels in fish, Hg exposure data, and biomarkers such as metallothionein.
Humans	Hg transport in food chain.	Hg levels in subsistence food.

Table 1. Possible endpoints in ecological assessment for mercury in Alaska.

Mercury is a natural element occurring in both terrestrial and aquatic ecosystems in Alaska. In the lower 48 states, atmospherically deposited mercury (resulting in 159 tons emitted annually) is mainly from coal-fired electric utilities (33%) or waste incinerators (33%). In the Arctic National Wildlife Refuge (ANWR), scientists have reported low levels of mercury in snow samples and higher mercury concentrations in the surface sediments of ANWR lakes than those reported for comparable Canadian lakes. More data on actual concentrations in both the physical environment and wildlife are needed. For humans, public health officials are concerned about synergistic effects of mercury and polychlorinated biphenyls (PCBs). PCBs in the environment may enhance the actual toxicity of mercury, that is, lower its effective concentration close to observed levels in Alaskans. While these levels are far from life threatening, they may have long-term effects on an individual's cognitive ability. Only recently have ecological and human assessments been proposed in a comprehensive way for Alaska (Table 1).

Mercury Effects are Biomagnified

Bioaccumulation is the process of concentrating metals within the body regardless of whether the metals are directly absorbed or ingested with food. The term bioconcentration describes the direct uptake from the environment, while

(Continued on p. 2)

biomagnification means the accumulation of metals via the food web. Mercury is methylated by organisms in fresh and marine water and, by becoming more lipid-loving, mercury is quickly concentrated through the food chain. Both mercury and methylmercury (MeHg) are toxic, but MeHg has been shown to cause neurological and developmental disorders in humans. The risk of fetal brain damage increases when the mercury concentration in maternal hair exceeds 10–20 µg/g. This threshold was based on studies of ingested mercury-contaminated grain, but long-term effects can be noticed at half that level, especially in complex neurological functions such as language. Elevated mercury concentrations have been reported in rural Alaskans who have a significant amount of fish in their diet. Alaska’s short linear food chains make higher exposures more likely.

Using Sentinel Species to Monitor Transport

River otters have been routinely used as an indicator of pollution from chemicals introduced into the environment. In Alaska, we found that mercury in river otter hair ranges from 2 ppm to as high as 18.8 ppm. In Prince William Sound, population means for river otters ranged between 4 and 10 ppm, while in the Yukon-Kuskokwim (Y-K) Delta area the

mercury levels in river otter hair averaged 2.7 ppm (Table 2). The biomagnification factors between river otters and fish in Alaska are in a range between 10 and 100. Studies in Prince William Sound also showed that analysis of river otter hair could distinguish whether the otter was eating freshwater or marine fish. Other mammals and birds should be developed as indicator species in order to better follow the effects of climate change on arctic ecosystems. A current unanswered question is whether biogenic transport of mercury is more significant than chemical-physical transport in the Arctic.

Mercury in Fish

Because of the importance of fishing, both commercial and subsistence, to Alaska’s economy, contaminants in fish have become a focus of research interest. In a recent study sponsored by CIFAR and NIEHS on subsistence fish in the Y-K Delta area of Alaska, the mean level of total mercury in all fish sampled was 0.368 ppm. This is above the conservative EPA-recommended level of 0.2 ppm. When species of fish were compared, mercury levels were highest in pike, a freshwater fish. Figure 1 illustrates this transportation up the food chain from grayling to pike to river otters.

(Continued next page)

Area	Comments	Liver	Kidney	Brain	Muscle	Fur	Author
Georgia	Clay soils Low clay					15.9 (3) 37.6 (6)	Cumbie 1975
Quebec					1.99 (2)		Desai-Greenaway and Price 1976
Georgia	Ware Co. Echols Co. Piedmont	9.16 (6) 5.11 (4)			4.62 (56) 4.23 (32) 1.48 (34)	25.55 (55) 22.95 (36) 15.24 (34)	Halbrook 1978
Ontario		2.973 (4)	1.046 (4)		0.889 (4)		Wren et al. 1980
Connecticut and Massachusetts	Males Females	4.28 (14) 2.24 (14)					O'Connor and Nielsen 1981
Wisconsin		3.34 (49)	8.47 (49)	0.74 (49)			Sheffy and St. Amant 1982
Manitoba	Duck Mountain Wekusko Whiteshell Winnipeg River	2.11 (2) 1.75 (17) 2.27 (6) 3.67 (13)	2.58 (2) 1.07 (17) 1.66 (6) 2.37 (13)	0.48 (2) 0.28 (17) 0.38 (6) 0.91 (13)			Kucera 1983
Alaska	Herring Bay ('96) Herring Bay ('97) Jackpot Bay ('96) Jackpot Bay ('97) Bethel					5.2 (20) 9.20 (13) 8.3 (19) 10.17 (10) 2.7 (3)	Duffy et al. (unpublished)
Michigan	Upper Pen. Lower Pen.	1.95 (17) 2.36 (21)	1.58 (16) 1.58 (12)				Ropeh and Neely 1993

Table 2. Mercury levels (micrograms per gram wet weight) in tissues of otter reported by various authors (number of samples in parentheses; based on Kucera, 1983).

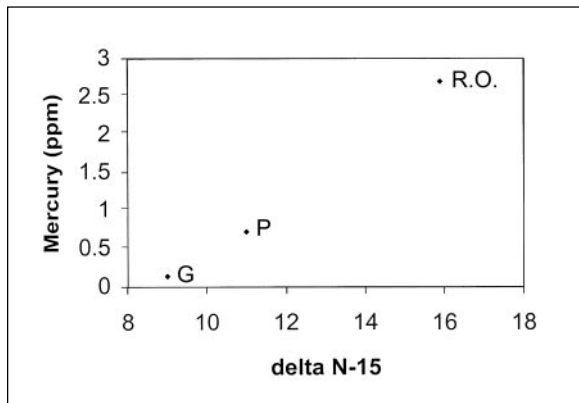


Figure 1. Mercury concentration vs. delta N-15 in the Yukon-Kuskokwim River delta, Alaska. G=grayling, P=pike, R.O.=river otters.

Fish as Monitors of Development and Global Climate Change

As development proceeds and global climate change affects both natural deposits of mercury such as cinnabar and former disturbed sites such as abandoned mines and military areas, increased transport into river systems might occur. Also, it is known that the removal of mercury from the atmosphere is driven by temperature-dependent photochemical processes, which create water-soluble reactive species. Increased mobilization of mercury may convert some areas in the Arctic from being a sink to becoming a source. Continuing to observe and monitor mercury levels in rivers and wildlife should become a basic part of research on global climate change. The data from these monitoring activities will be useful in testing the validity of competing global climate change models.

Environmental Justice

In the past, rural and indigenous populations were rarely consulted or invited to participate in the research on contaminants that could not only affect their health but their culture. The local communities, especially elders (see inset; Bradley, 1999), must be included in all parts of the research: planning, performing and dissemination of the results. In Alaska, fish and wildlife are not just a sports industry but the “totem” of individual and cultural spirituality.

What Next?

We have just begun to address the questions about mercury in Alaska. In a few cases such as river otters and marine mammals, biomagnification of mercury was observed, but with the short linear food chains in Alaska, more animals

need to be studied. We know that mercury has an increased residence time in cold water and that aquatic systems are most affected by atmospheric deposition of mercury. However, there are few measures of aqueous or atmospheric levels of mercury in Alaska. Most of our limited knowledge is based on spotty sediment analysis which cannot truly address real-time fluxes. As we gather data, mercury research in Alaska will contribute to important scientific and health questions such as “What is the relative importance of physical or biological transport mechanisms in the redistribution of mercury?” This is a key question, since global climate change scenarios suggest an increase in severe storms which could re-suspend mercury—as was seen recently in the mercury contamination of the Carolinas by hurricane-generated river flooding of industrial storage sites. Mercury studies are needed in Alaska not only to determine the safety of our subsistence food but also as a biogeochemical focus of global climate change research.

Acknowledgements

This material is based on ideas of many colleagues and students at the Institute of Arctic Biology, especially Dr. R. Terry Bowyer and Dr. Merav Ben-David. This work was funded in part by the Institute of Arctic Biology, the Cooperative Institute for Arctic Research (CIFAR), a NOAA-sponsored program, and a NIEHS pilot grant from the University of Washington’s Center for Ecogenetics. I also appreciate the help of Senka Paul, Tauni Rodgers, and the Yukon-Kuskokwim Delta Health Corporation leadership and community members. Current studies on the Bering Sea ecosystem are supported by a NOAA grant to Sathy Naidu, John Kelley, and Doug Dasher at the Institute of Marine Science, University of Alaska Fairbanks.

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Man sometimes thinks he’s been elevated to be the controller, the ruler. But he’s not. He’s only part of the whole. Natural Law prevails everywhere. It supersedes Man’s Law. One of the Natural laws is that you’ve got to keep things pure. Especially the water. Keeping the water pure is one of the first laws of life. If you destroy the water, you destroy life. Another of the Natural laws is that all life is equal... You have to respect life—all life, not just your own. Unless you respect the earth, you destroy it.

— Oren Lyons
Onondaga

2000 Student Research Grant Recipients

The following students are recipients of this year's Student Research Grant Awards from the Center for Global Change and Arctic System Research. The Alaska Sea Grant College Program joined as a partner this year and is funding the first two of these awards:

Grace Abromaitis, Institute of Marine Science, School of Fisheries and Ocean Sciences

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

Monica Bando, Institute of Marine Science, School of Fisheries and Ocean Sciences

Developing a Nutritional Model of Kodiak Island's Steller Sea Lions

Andrew Borner, Department of Biology and Wildlife, Institute of Arctic Biology

Combining Plant and Nutrient Phenology to Make Predictions about Plant Species Responses to Climate Change

Richard Brenner, Department of Biology and Wildlife, Institute of Arctic Biology

*Integrating Nitrogen Sinks and Losses with Belowground Carbon Cycling in Stands of White Spruce (*Picea glauca*) and Balsam Poplar (*Populus balsamifera*) on the Tanana River Floodplain, Interior Alaska*

Kurt Galbreath, Department of Biology and Wildlife, Institute of Arctic Biology

*Interpreting Paleoenvironmental Change through Phylogenetic Analysis of *Spermophilus parryii* and its Cestode Parasites*

Cecile Hannay, Department of Physics and the International Arctic Research Center

Evaluation of Microphysical Processes in a Single Column Model Simulation of Arctic Clouds

Jill Johnstone, Department of Biology and Wildlife, Institute of Arctic Biology

The Role of Climate, Fire Severity and Vegetation Composition in Post-fire Boreal Forest Vegetation Succession

Kevin Petrone, Department of Biology and Wildlife, Institute of Arctic Biology

Dissolved Inorganic Carbon Dynamics in Boreal Forest Watersheds: The Influence of Fire and Permafrost

Harold Zald, Department of Forest Sciences, School of Agriculture and Land Resources Management

Response of Treeline Forests to Climatic and Physiographic Variation, Alaska Range

Sarah Zimmermann, Institute of Marine Science, School of Fisheries and Ocean Sciences

Ocean and Atmospheric Interannual Variability in the Southern Barents Sea from 1970 to 1990

Research Grant Reports—1997 Recipients

Paleoenvironmental Changes at Treeline during the Late Holocene in Central Alaska

by Melanie Rohr, Department of Geology and Geophysics, University of Alaska Fairbanks

Climate is expected to change rapidly within the next century and, according to global circulation models, the most severe effects will occur in high latitude regions. There is a great uncertainty about how and at what rate terrestrial ecosystems may respond to future climatic shifts projected by current model simulations. Vegetation ecotones such as treeline are considered to be especially sensitive to such changes and serve as an important indicator of global climate change. Although changes in treeline dynamics in some parts of the Arctic and sub-Arctic have been discussed extensively in the past few years, little is known about treeline history in Alaska.

I present here a record of fossil pollen, spruce macrofossils and stable isotopes from lacustrine sediments of two

Central Alaskan lakes. Swampbuggy Lake (official name; N63½41', W147½40') and Nutella Lake (informal name; N63½23', W147½25') are located in the central portion of the Alaska Range slightly below and above treeline, respectively. Swampbuggy Lake is surrounded by open forest while Nutella Lake lies in open shrub-tundra.

The main focus of this study is to reconstruct the Mid- to Late Holocene climate history of this region and associated changes of treeline vegetation. Previous records show a trend towards moister and colder climate in Alaska during the Late Holocene (4,000 years BP until present). Advances of Alaska's mountain glaciers occurred throughout the latter part of the Holocene but were most pronounced during the Little Ice Age (13th to 19th century AD). Tree-ring records from Alaska and elsewhere in North America confirm episodes of cooler climate during the Little Ice Age. A warming trend has occurred over the last century.

Sediment cores of approximately 180cm and 200cm length, respectively, were retrieved during summer of 1996

and sampled at high resolution. The cores represent a time interval spanning the Mid Holocene to present.

The age at the base of the Swampbuggy Lake core was extrapolated to be approximately 5,200 years ^{14}C BP. An age-depth chronology was established using ^{210}Pb dating near the core top and AMS radiocarbon dates of spruce needles and pollen. A prominent tephra layer located midway through the core, the so-called Jarvis Ash, serves as stratigraphic marker and age control.

Stable isotope analysis shows significant fluctuations of carbon isotope ratios during the past 5,000 years. Isotope ratios ($\delta^{13}\text{C}$) are relatively high (~ -23 to -22‰) in the bottom half of the core but begin to gradually decline between 4,200 and 3,650 yrs BP. Isotope values drop to around -26‰ and remain low until approximately 2,300 yrs BP. A short interval of carbon ratios is followed by another decline around 900 yrs BP (~ 1000 AD). The isotopic signature near the top shifts again to high values similar to those at the bottom of the core. Fluctuations in carbon isotope ratios are a function of paleoproductivity changes. Low ratios are to be expected when climate is colder and wetter, as productivity declines and surface run-off into the lake increases.

Changes in spruce pollen percentages and the abundance of spruce macrofossils (stomates, needles) are synchronous to the events recorded by the stable isotope record. The relative abundance of spruce pollen is relatively low until approximately 4,000 yrs BP and is characterized by a dominance of *Picea glauca* (white spruce). After 4,000 yrs BP spruce pollen percentages rise gradually to about 60% while the composition shifts to a dominance of *P. mariana* (black spruce). A rise in spruce pollen percentages is found in the top levels of the core although these trends require further confirmation. Spruce needles are most frequent at levels with high spruce pollen percentages. *Picea* stomates do not follow this trend but the appearance of stomates is generally more frequent in the lower half of the core.

Current analysis does not show any significant changes in isotopes or pollen during the same period at Nutella Lake. The setting and basin characteristics of the lake provided isotopic ratios that were not of pure aquatic origin and therefore rendered it difficult to interpret in terms of climate change. It can be assumed, however, that the climate signals seen at Swampbuggy Lake were of regional scale and that the same climate signals were experienced at both lakes. At Nutella Lake biotic response may have been too subtle to be picked up by pollen analysis.

I hypothesize that the observed changes in stable isotope ratios between 4,200 and 2,300 yrs BP are the result of a significant shift towards cooler and wetter climate and are evidence for Neoglacial cooling at the onset of the Late Holocene period. Our pollen data suggest increased density of spruce, specifically black spruce, around Swampbuggy Lake. Spruce needles found during this interval indicate the local presence of trees and imply that our pollen record was not distorted by an increased influx of black spruce from the

lowlands. Further fluctuations of carbon isotope values in the upper half of the core suggest a recurrent episode of climate cooling during the Little Ice Age shortly followed by a warming trend during the 20th century.

This study shows the complex response of treeline to climatic forcing. The deterioration of climate in the magnitude of Late Holocene cooling may not necessarily result in overall movement of treeline but rather in an adjustment of tree population density and composition. ♦

Development of a Remote Sampling Technique for Aerosol Phase Sulfur

by Dennis Nicks, Jr., Department of Chemistry and Biochemistry, University of Alaska Fairbanks

Climate and climate change phenomena have become important topics within the scientific community and general public. Much of the research so far has focused on the role of greenhouse gases such as CO_2 and CH_4 and the consequences of atmospheric accumulation of these gases since the industrial revolution. The earth's climate is a complex nonlinear system, with numerous parameters controlling the heat balance including systems that are affected by a change in climate. These parameters, known as feedbacks, are very complex and important to study. Recently, attention has been given to the role that sulfur gases and aerosols may have in governing climate. Aerosol impact on climate occurs directly, by scattering solar radiation, and indirectly, by changing the optical properties of clouds. The largest natural source of reactive sulfur gases on earth is a by-product emitted by oceanic phytoplankton, dimethyl sulfide (DMS). Measurements of DMS from the Gulf of Alaska and the Chukchi Sea have demonstrated that Arctic and sub-Arctic regions may be a significant source of this aerosol precursor. The oxidation of this reduced sulfur species in the atmosphere produces hygroscopic aerosols that can act as cloud condensation nuclei (CCN). These CCN can be activated in clouds to form cloud droplets which can change the albedo (or reflectivity) of the area covered by clouds, possibly reflecting more solar radiation back into space.

The Arctic landmass covers a large geographical area, making it difficult to obtain direct measurements of the chemical composition of atmospheric aerosols. Most of the information obtained is from remote sampling techniques. Traditional remote aerosol sampling and analysis techniques require a long sampling period, typically one or two days in an unpolluted air mass. Thus the chemical composition measured would be the average over that sampling time. The focus of this research has been on the development of a remote aerosol sampling technique that uses the Aerosol-Sulfur Chemiluminescence Detector (SCD) instrument, which is being developed in our laboratory. This technique is as easy to use as existing techniques, with the added advantage of a shorter sampling time (better temporal resolution). High time-resolved measurements give a better understand-

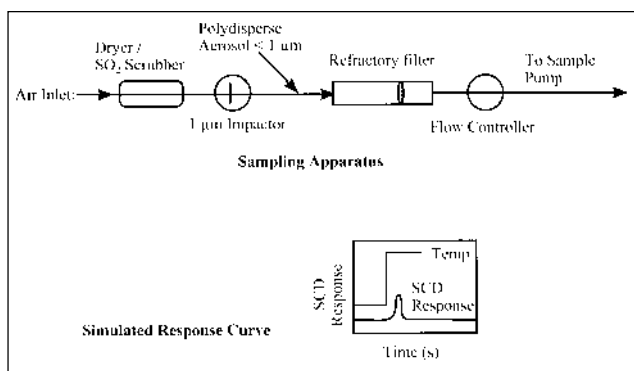


Figure 1. The aerosol phase sulfur remote sampling apparatus.

ing of atmospheric phenomena such as gas-to-particle conversion and cloud processing. The shorter sampling time would also be advantageous when used on a moving platform, such as a ship.

A schematic diagram of the aerosol phase sulfur remote sampling apparatus is shown in Figure 1. A pump with a constant volumetric flow draws sample air through a dryer and sulfur dioxide (SO_2) scrubber. This eliminates water vapor and SO_2 that can interfere with the aerosol measurement in the Aerosol-SCD technique. The sample air then passes through a one- μm impactor, which eliminates the larger aerosol particles from sample air. Finally, the resulting aerosol sample is collected on a 0.2- μm filter, which is housed in a filter holder designed and custom built at the Geophysical Institute at the University of Alaska Fairbanks. Once the aerosol sample is collected on the filter, the filter housing is capped off and sent to the University of Alaska Fairbanks for analysis.

When the sample is received, the filter housing is interfaced to the Aerosol-SCD. The filter housing is heated rapidly, vaporizing the sample into the SCD. This event is recorded on the response curve shown in Figure 1. The peak shown in the response curve can be calibrated for the sulfur mass of the collected aerosol sample. Once proper temperature control of the vaporization phase is achieved, it may be possible to differentiate individual sulfur compounds based on volatilization temperature and sulfur mass.

The Aerosol-SCD and remote sampling technique are still in the early stages of development. The results thus far look promising for obtaining high time-resolved measurements of the sulfur composition of Arctic aerosols. Information from this research will lead to a better understanding of the chemical and physical processes that are involved in gas-to-particle conversion, particle growth and coagulation and ultimately cloud formation. Further findings could be incorporated into global climate models, help in the interpretation and prediction of weather systems, and improve pollution dispersion models. Understanding the chemical and physical processes involved in cloud formation and any impact that anthropogenic activity has had on that system is crucial to the Earth System Sciences. ❖

Assessing the Paleolimnological Sediment Record of a Southeast Alaska Sockeye Salmon Nursery Lake

by David L. Barto, School of Fisheries and Ocean Sciences, University of Alaska Fairbanks; now at Alaska Department of Fish and Game, Douglas, AK

A number of recent studies indicate that Pacific salmon transport significant quantities of nutrients derived from marine sources into freshwater systems when they return to spawn and subsequently die. The marine-derived nutrients (MDN) released from spawning adult salmon can be important nutrient sources to oligotrophic lakes and streams. The anadromous sockeye salmon is the only Pacific salmon with a life cycle that requires an extensive freshwater period in a lake environment. Nutrient loading investigations of coastal Alaskan lakes indicate that decaying sockeye salmon carcasses can be the source of >50% of phosphorous and other nutrient inputs annually. Therefore, returning adult salmon have the potential to significantly affect the productivity of the freshwater environment through annual variability and natural population cycles.

The variability of salmon abundance has been well documented in the relatively short history of the commercial fishing industry in Alaska. In terms of ex-vessel value, sockeye salmon are the most important species to this industry, but the lack of adequate long-term historical fish production data has provided a challenge to fishery managers in their attempt to forecast annual variability and natural population cycles.

This investigation was designed to assess the paleolimnological sediment record of Chilkat Lake by reconstructing time series data of in-lake productivity influenced by inputs of MDN. It is believed that changes in nutrient inputs to the lake are strongly related to the magnitude of sockeye salmon spawning populations (escapement). It is further hypothesized that changes in nutrient input to the lake would depress or enhance salmon production and add to the natural population fluctuations that are also influenced by predictable climatic cycles.

Recent studies suggest that changes in nutrient inputs to the lake are directly related to the magnitude of the annual spawning population (escapement), and can be quantified by sediment stable isotope analysis of nitrogen (^{15}N) and carbon (^{13}C). Nitrogen supplied by the adult salmon is enriched in marine ^{15}N relative to the other main source of nitrogen in freshwater salmon systems, atmospheric N_2 ($\delta^{15}\text{N}=0\%$). Since salmon populations fluctuate annually, the resulting MDN inputs and the resulting freshwater $\delta^{15}\text{N}$ will also fluctuate.

A nutrient mass balance analysis was completed for Chilkat Lake using data from recent limnological investigations and 26 years of annual escapements. The results indicate that the input of sockeye salmon-derived phosphorous and nitrogen accounts for up to 84% and 59% respectively of annual elemental inputs to Chilkat Lake.

Lake paleoproductivity and paleoescapement trends were documented using two separate sediment cores (Core #1 and

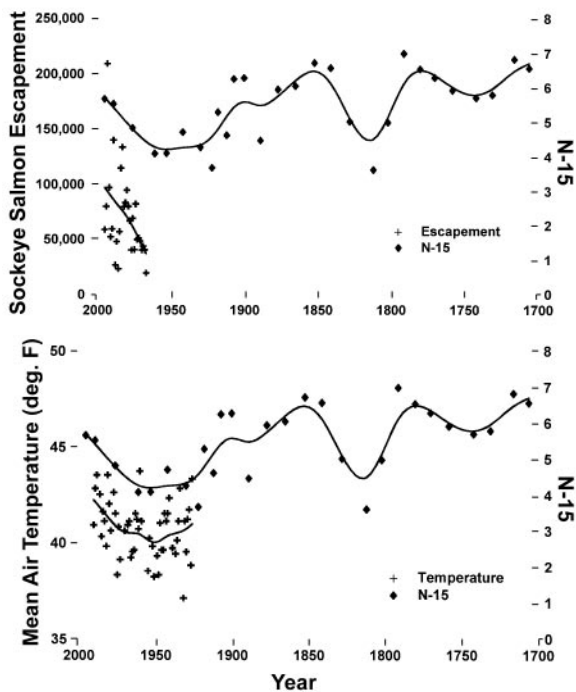


Figure 1A. Comparison of Core #1 sediment nitrogen 15 ($\delta^{15}\text{N}$) to escapement (spawning sockeye salmon population) and mean air temperature ($1/2F$).

Core #4) collected from the same area of the lake. Dating control was established using Cesium-137 and Lead-210 radioisotope analysis. These dating results indicate that this lake has a relatively slow sedimentation rate of 1.2 mm/yr.

The sedimentary $\delta^{15}\text{N}$ analysis of Core #1 represents the most recent 300-year period. These results indicate a good correlation with the existing escapement (26-year) and mean annual air temperature data (70-year) (Figure 1A).

The results of the lake paleoproductivity analysis of Core #4 represent the last 1400 years. These paleoproductivity trends were estimated using organic carbon, biogenic silica and organic ^{13}C proxies in the sediment core. Organic carbon and biogenic silica results are inversely correlated with periods of high concentrations of sedimentary CaCO_3 (Figure 1B). These CaCO_3 inputs are believed to be the result of the intrusion of glacial melt-water from the Tsirku River. The increased turbidity caused by these intrusion events would have dramatically changed the lake rearing environment and reduced in-lake productivity through increased sediment inputs. These inputs would result in a decrease in euphotic zone depth, water temperatures and, through food web interactions, the subsequent production of sockeye salmon. These periods of glacial water inputs are generally believed to coincide with climatic conditions of low rainfall and elevated air temperatures.

The sedimentary $\delta^{15}\text{N}$ levels follow the paleoproductivity trends exhibited by the organic carbon and biogenic silica accumulation and are also inversely correlated to the periods of high concentrations of sedimentary CaCO_3 (Figure 1B). These $\delta^{15}\text{N}$ results also indicate a large decrease that coin-

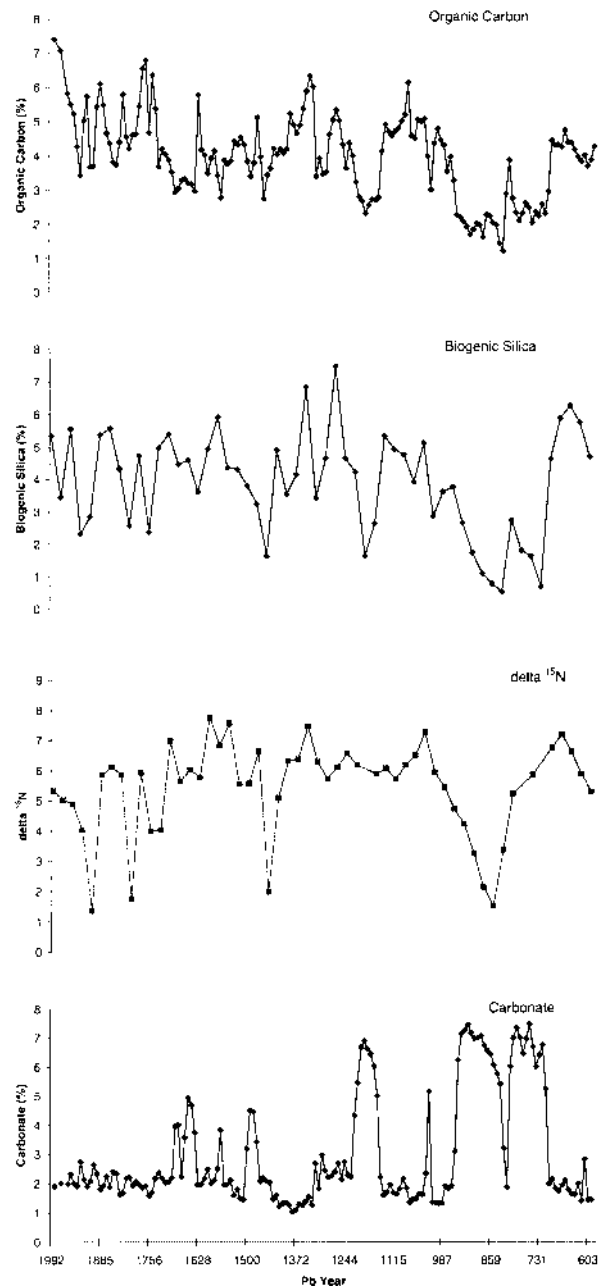


Figure 1B. Comparison of sediment Core #4 paleoproductivity indicators for organic carbon, biogenic silica, nitrogen 15 ($\delta^{15}\text{N}$) and carbonate

cides with several large-magnitude CaCO_3 events during 700 to 1200 AD. This 500-year period is generally recognized as the period of “Medieval Warming.”

The frequency and duration of these glacial water intrusions are believed to be climate related. The resulting cyclic annual inputs of MDN are believed to influence the overall sockeye salmon production from this lake. Information generated from long-term changes in fish abundance can provide insight into natural ecosystem variability, the impact of human disturbance and data necessary for sustained management. ♦

***Assessing the Consequences of Climate Change for Alaska
and the Bering Sea Region***

Proceedings of a Workshop
University of Alaska Fairbanks
29–30 October 1998

Impacts of Global Climate Change in the Arctic Regions

Report from a Workshop on the
Impacts of Global Change
25–26 April 1999
Tromsø, Norway

***Preparing for a Changing Climate:
The Potential Consequences of Climate Variability and Change***

A Report of the Alaska Regional Assessment Group
for the U.S. Global Change Research Program

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