EVOS ANNUAL PROJECT REPORT

Project Number: **040649**

Project Title: Reconstructing Sockeye Populations in the Gulf of Alaska over Millennial Time Scales: The Natural Background to Future Changes

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Time Period Covered by Report: Year III ending 30 September 04

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A. Introduction

Our study has three goals. The first is to reconstruct sockeye salmon abundance over time scales of millennia in multiple lakes in southern Alaska using isotope analysis of lake-bottom sediments. Our second goal is to compare the reconstructed fluctuations in salmon populations with changes in the ocean/climate system in order to better understand how natural environmental changes affect salmon populations. Finally, through this retrospective study, we seek to identify the natural bounds of variation in salmon populations over the last 10,000 years. What happened in the past can be used to judge the normalcy of future changes in salmon populations as they respond to human impacts and climatic changes. Here we describe our progress in achieving these objectives.

B. Field Methods

The laboratory methods we use are standard techniques, but there are some interesting field methods developed in the course of this project. We accessed the study lakes in April using a Robinson helicopter out of Girdwood. Multiple cores were taken from each lake basin. We purposefully tried to core near areas of rapid deposition such as delta fronts as well as in isolated basins where deposition is slower. The idea is to get cores with higher temporal resolution from areas of high deposition rates. Distal basins hopefully will yield records extending throughout all of postglacial time. The trick is to arrive at a lake while temperatures are above freezing but while the ice is still thick. If temperatures are below freezing, the cables and ropes freeze, which makes everything more difficult. If you get to a lake too late in the spring, deep slush covers the ice (Fig. 1) and there are obvious safety concerns. We use two types of corers. Reconnaissance is done with an 8-foot, 2.5” diameter, clear plastic tube that attaches to a plastic head with a one-way valve. This valve allows water to pass upwards through the head as the corer is pounded into the sediment with a 10-pound slide hammer. The preferred, final core was taken with a 3-inch diameter, clear PVC pipe that is driven with a heavy slide hammer. This larger corer has a piston that is held stationary as the coring tube is driven downwards. Use of the piston minimizes compression of soft sediment, which sometimes occurs with the reconnaissance corer (Fig. 2). One disadvantage of both these corers is that we can take only a single drive. Because the study lakes are deep, it is not practical to use casing. Our way around this limitation is to use long (up to 20’) lengths of clear PVC pipe. The sediments of Karluk Lake are rich in volcanic ash, which makes the sediments very stiff. Rapid sedimentation of stiff sediments in Karluk has so far frustrated our attempt at retrieving the entire postglacial (ca. 14,000 year) record of ^{15}N from that lake. Back in the laboratory, the cores are split using a small skill saw and a garrote. One half of the core is archived, and the other used for analytical samples. Cores are photographed (Fig. 3) and a detailed lithostratigraphic log is made. Volumetric samples are removed from the active half of each core for measurements loss on ignition, magnetic susceptibility, water content, biogenic silica, and isotope analysis. The remaining sediment is sieved at half- or one-centimeter intervals to obtain plant macrofossils for radiocarbon dating. A macrofossil is a plant part, usually a seed, twig, bark fragment, or leaf. We use only macrofossils from terrestrial plants to avoid contamination of radiocarbon samples with either "old" carbon originating from detrital C (e.g., peats and soil organics) or carbon depleted in ^{14}C during fractionation within the water column (i.e., we never date aquatic plant remains). It takes 2-3 spruce needles to make a large enough sample for a precise accelerator mass spectrometer radiocarbon (AMS) age determination. Dating is critical and it becomes more problematic as the lake increases in size and the core site gets further from the lake shore. From the point of view of age control, the ideal study lake would be hundreds of meters deep and <100 m in diameter. Karluk Lake, for instance, is proving difficult to date accurately due to the scarcity of terrestrial plant macrofossils deposited in the deep basins of this large lake.

C. Specific Objectives and Results to Date

1) Develop sediment-core chronologies and measure downcore changes in lake-productivity indicators (organic C and C/N ratios) as well sedimentary $\delta^{15}N$.

Result 1: We have retrieved a series of sediment cores from Eshamy, Upper Russian, and Karluk lakes. In addition, we have obtained sediment cores taken by other investigators from Skilak and Hidden lakes. So far, we have done lithologic descriptions and completed analyses of organic carbon, magnetic susceptibility, $\delta^{15}N$, $\delta^{13}C$, and total N from two cores from Eshamy Lake, and one core each from Upper Russian, Skilak, Hidden, and Karluk lakes. In the Eshamy Lake cores, we have obtained AMS-radiocarbon age control at millennial intervals between 5000 and 9000 yr B.P. (Before Present). The age control on the Upper Russian cores includes six dates; the Karluk core has two ^{14}C dates. Lead 210 dating of the Upper Russian, Karluk, Skilak, and Hidden Lake cores is still in progress due to delays in the laboratory we have subcontracted to perform this analysis.

Challenges: The sediment cores we have recovered are both longer and contain more detailed records of $\delta^{15}N$ than we anticipated at the beginning of this project. Also, we have discovered that the sedimentation rates of mineral material (e.g., glacial silts in Upper Russian Lake) and nitrogen (e.g., the micro-ramps of ^{15}N in Eshamy Lake) change rapidly up-core. This makes more precise age control a necessity. To achieve better age control, we must spend additional time sieving cores to obtain more radiocarbon samples and spend more money on additional AMS dates.

2) Compare sediment data corresponding to the past few decades (e.g., the period of intensive investigations by ADF&G) to salmon population statistics. We then will develop calibration relationships between $\delta^{15}N$ and salmon numbers.

This task has been partly completed in work by Finney compiling statistics on the escapement from Karluk and Red Lakes. We are currently assembling escapement data from the Kenai River system.

3 and 4) Reconstruct paleolimnologic changes in each lake over the past several thousand years using the results of Objectives 1 and 2. Compare δ^{15}N records from PWS and the Kenai Peninsula to Finney's published and ongoing work on Kodiak Island. Compare retrospective data on changing salmon abundances to environmental changes and infer causative relationships.

Specifically, we have analyzed all the sediment cores for organic carbon, $\delta\ ^{13}$C, and magnetic susceptibility, in addition to measuring δ^{15}N levels. The figures that accompany this report show results from Eshamy, Upper Russian, and Karluk lakes. The results are exciting for several reasons, but they also give rise to several new challenges.

<u>Result 1</u>: Lakes in southern Alaska provide detailed archives of lake history, including δ^{15}N records that describe the prehistoric dynamics of salmon populations (Fig. 3, 4). Rapid sedimentation rates and the presence of marker horizons formed by widespread volcanic ashes (Fig. 2) make these lakes excellent sites for this type of work. The large degree of detail contained in these lake sediment records has been a surprise. For instance, we have yet to achieve a degree of sampling precision that captures the shortest time scales of fluctuations in δ^{15}N (Fig. 3,4). When we began this study, we naively thought that the major shifts in ^{15}N stratigraphy would occur at time scales of centuries to millennia. This new data shows that major shifts occur at annual to decadal scales as well.

<u>Challenge 1</u>: The challenge here is threefold: first to identify which time scales are of greatest practical interest for deciphering climate-fish interactions; second, to find lakes whose sedimentary processes minimize bioturbation and permit fine scale sampling; and third to actually find terrestrial macrofossils to date at the critical depths in the cores. In practice, obtaining fine enough dating control takes precedence over the other two challenges. Already we have sacrificed the archived half of the Karluk core in sieving for more datable macrofossils. Currently we are sieving archived splits of the Upper Russian and Eshamy cores in order to estimate sediment age more precisely.

<u>Resul</u>t 2: All the study lakes whose records extend into the early Holocene show a gradual "ramping up" of δ^{15}N during postglacial times (Fig. 3,4). Immediately after deglaciation, Eshamy and Upper Russian lakes were relatively poor in ^{15}N. In Upper Russian Lake, ^{15}N levels seem to have fluctuated wildly in the first few millennia of organic-dominated sedimentation (Fig. 3). The ramping up of deep sea-derived nitrogen reached a peak around 3000 ^{14}C yr B.P. in Upper Russian and Karluk lakes. Interestingly, 3000 yr B.P. is generally accepted as the beginning of the Neoglacial interval in southern Alaska, a period that saw repeated glacial advances and retreats on the northern shores of the Gulf of Alaska. Note that although red salmon colonization of newly deglaciated lakes can occur rapidly (over several decades), as Alexander Milner has shown in Glacier Bay, maximum run size may take many thousands of years to develop.

Challenge 2: Are these general shifts in C and N in fact the result of salmon fertilization of lake ecosystems, and/or caused by some process of diagenesis in the sediment column, and/or caused by processes of eutrophication that would occur without the influence of salmon, and/or caused by long-term changes in the North Pacific climate system during the Holocene? Another possibility is that sedimentation rates of mineral material increased during the Holocene and progressively diluted the concentrations of fish-born elements. We are confident that diagenetic artifacts are not to blame; and increasing mineral dilution seems unlikely. Control lakes on Kodiak Island and Dan Engstrom's study of lake ontogeny around Glacier Bay suggest that eutrophication is probably not the cause either. We are still puzzling about whether the salmon are gradually enriching their own spawning watersheds through some combination of increasing nutrient levels in lake sediments and in the soils of the surrounding landscape or if Holocene climate somehow shifted unidirectionally in such a way as to favor red salmon escapement.

Result 3: Both Karluk and Upper Russian lakes show marked shifts in the numbers of salmon dying in these lakes between 2000 and 1500 14C yr B.P. (Fig. 3). This period immediately precedes the Medieval Warm Period, a time of warmer, drier conditions that occurred in some regions of the northern hemisphere (including Alaska) ca. 1400-900 ^{14}C yr B.P. The pre-1000 yr B.P. glacial record from southern Alaska is unfortunately somewhat hazy. We were lucky in Upper Russian Lake to find the distinct signature of ice advance during the same period that the salmon populations declined both there and in Karluk Lake (Fig. 2, 3). This glacial marker is a band of grey clay that indicates the inflow of glacier meltwater. We think the silt layer records a brief (ca. 500 yr) period when ice was thick enough to send meltwater across a low divide into the Upper Russian watershed. Higher in the Upper Russian core, a thinner band of clay marks another incursion of glacial meltwater into the lake around 1000 ^{14}C yr B.P. This early Little Ice Age silt layer also accompanies a decline in δ^{15}N in Upper Russian Lake. We hypothesize that salmon populations declined just prior to and shortly after the Medieval Warm Period in response to climatic conditions conducive to glacier expansion in the Gulf of Alaska region..

Challenge 3: The decline of δ^{15}N in Upper Russian Lake at times when glacial silts were being deposited could be an artifact of increased sedimentation rates. More precise dating is required to detect changes in sedimentation rates. Nonetheless, we suspect this is a real effect for the simple reason that Karluk Lake shows a synchronous dip in δ^{15}N just prior to the Medieval Warm Period (Fig. 3), and there are no glacial sediments dating to this time in the Karluk record. Accurate chronologies are critical for documenting sedimentation rates properly and for detecting synchrony between different lake records. Radiocarbon dating requires destructive sampling of cores to obtain terrestrial plant macrofossils. To precisely date a lake record, we must retrieve multiple cores from each basin. In the laboratory, these multiple cores must be stratigraphically correlated, and this requires intensive analyses of C and magnetic susceptibility. The bottom line is that the need for precise chronologies requires more work and hence higher laboratory costs than what we originally anticipated.

Result 4: Eshamy Lake is different. We re-cored Eshamy Lake because our first core produced a δ^{15}N history that seemed quite different from Upper Russian or Karluk lakes (Fig. 4). The new Eshamy core seems to match the original one from there. Like Karluk and Upper Russian, the new Eshamy core shows a gradual "ramping up" of δ^{15}N over the last 10,000 years. But it lacks the pre-Medieval Warm Period dip in δ^{15}N that is seen in the other lakes. Also, both Eshamy cores contain evidence for "micro-ramps," intervals of about one millennium when slow recoveries to higher δ^{15}N values follow abrupt drops. The new Eshamy core is analyzed in less detail than the old core but it too shows evidence of this micro-ramping pattern.

Challenge 4: What are some reasonable hypotheses about why lakes differ in their history of salmon runs? If regional climate and oceanography were the primary drivers, then all lakes should show similar histories. Certainly Karluk and Upper Russian lakes display similarities in their post-3000 yr B.P. histories. One explanation is that red salmon in Prince William Sound responded differently to climate forcing in the past, just as (at a much larger spatial scale) salmon in the Gulf of Alaska and in the California Current region responded differently during the 20th century to the shifting phases of the Pacific Decadal Oscillation. Alternately, perhaps divergent histories result when ecological feedbacks within individual lakes become so powerful that they obscure the effects of climate forcing. Or perhaps there are lake-specific events having nothing to do with internal feedbacks or climate forcing. Maybe there is some tectonic influence over how accessible Eshamy Lake is to red salmon. It is interesting that the time scale of the micro-ramps in Eshamy Lake (ca. 1000 years) is similar to the periodicity of large earthquakes in Prince William Sound.

5) Compare reconstructed sockeye population fluctuations with published data sets on paleoclimatic changes in the GOA region. These data sets include tree rings, glacial records, and pollen records of vegetation change. From these comparisons, we will develop a series of hypotheses about how changes in the atmosphere/ocean system affect salmon populations.

Result 1: We have been looking for interactions between climate and salmon abundance by comparing "wiggle" plots of δ^{15}N versus various proxy data sets. Some (e.g., Karluk) but not all (e.g., Eshamy) show that salmon abundance changed across the time-stratigraphic boundaries of the Medievil Warm Period and Little Ice Age (see Finney et al., 2002). No apparent correlation exists between the new Karluk and Eshamy Lake records with climate proxy data from the Greenland ice sheet. We have been patiently waiting for publication of new δ^{18}O records from the ice cap of Mount Logan in the St. Elias Mountains. These new records are expected to be out soon in the scientific literature. A comparison between the Red Lake δ^{15}N record (Finney et al., 2000) and the existing δ^{18}O record from Mount Logan (Moore and Holdsworth, 2001) suggests a negative correlation, with warmer intervals on Mount Logan coinciding with a decline in salmon run size. However, the advent of intensive commercial fishery on Kodiak around A.D. 1900 limits any conclusions from this short (300 year) time series. Thompson's ongoing work on Mount Logan ice cores promises new, longer ^{18}O time series for comparisons with our salmon chronologies. There are few other climate-proxy data from the GOA region that have sufficient temporal resolution to make them useful to our study. The tree-ring record is short and is primarily a function of summer temperature. Winter storminess is probably more relevant because of its implications for windiness and ocean circulation in the Gulf of Alaska. The glacial record is also too short (<1000 years) to be very useful. The ongoing impacts of human fisheries hinder a statistical analysis of salmon escapement and the instrumental record in terms of environmental controls.

Challenge 1: The bad news is that we need more time-series that serve as proxy records for different aspects of the ocean/atmosphere system in the Gulf of Alaska and Bering Seas. The good news is that we think we may have figured out a way to reconstruct a time series of snow avalanche magnitudes in Prince William Sound. We are presently trying to assemble a preliminary record of avalanche frequency, which relates to winter storminess in the GOA.

1. **Future Work:**

Laboratory work is now concentrating on sieving remaining core samples for additional plant macrofossils for further dating control. Pb210 samples have been submitted to an out-of-state laboratory for analysis and we are waiting for results.

2. **Coordination/Collaboration:** NA

3. **Community Involvement/TEK & Resource Management Applications:** NA

4. **Information Transfer: List (a) publications produced during the reporting period, (b) conference and workshop presentations and attendance during the reporting period, and (c) data and/or information products developed during the reporting period.**

Finney gave several talks during the reporting period. During the 2002 EVOS Workshop, he gave 2 invited talks entitled:
1) “Historical Linkages between Marine Environments and Watersheds”
2) “Paleolimnological Evidence for the Influence of Salmon-derived Nutrients in Alaskan Lakes”
During the American Quaternary Association’s biennial meeting in Anchorage in August 2002, Finney gave an invited talk entitled:
3) “Paleoenvironmental Change in the Interior and South Coastal Regions of Alaska since the Last Glacial Maximum”
During the EVOS/GEM/GLOBEC/NPRB workshop in Anchorage in January 2003, Finney gave an invited talk entitled:
4) “Past and Present Fluctuations in Fish Stocks: What do they mean for Management Today?”
As far as submitting a paper for publication, we have been delayed by an over abundance of data and by the desire to figure out a set of defensible hypotheses before we present our results.

5. **Budget:**

We submitted a proposal to GEM in March that would add another year to our project to enable us to complete the write-up stage of this project in the detail these interesting results deserve. For the reasons detailed above in the “Challenges” sections of this report, both the laboratory and field work portions of this study have proven more costly than we originally thought. This is good news in that the quality, detail, and applicability of the data we are producing promises to be greater than originally envisioned.

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Figure 1. Coring in early April at Upper Russian Lake, Kenai River watershed. The person is laying out the cable that works the slide hammer and the static line that pulls the corer up after it is filled with lake mud. A come-along hangs from the aluminum tower. The corer itself has sunk into a slush pool. The lake ice was only 25 cm thick and melting rapidly.

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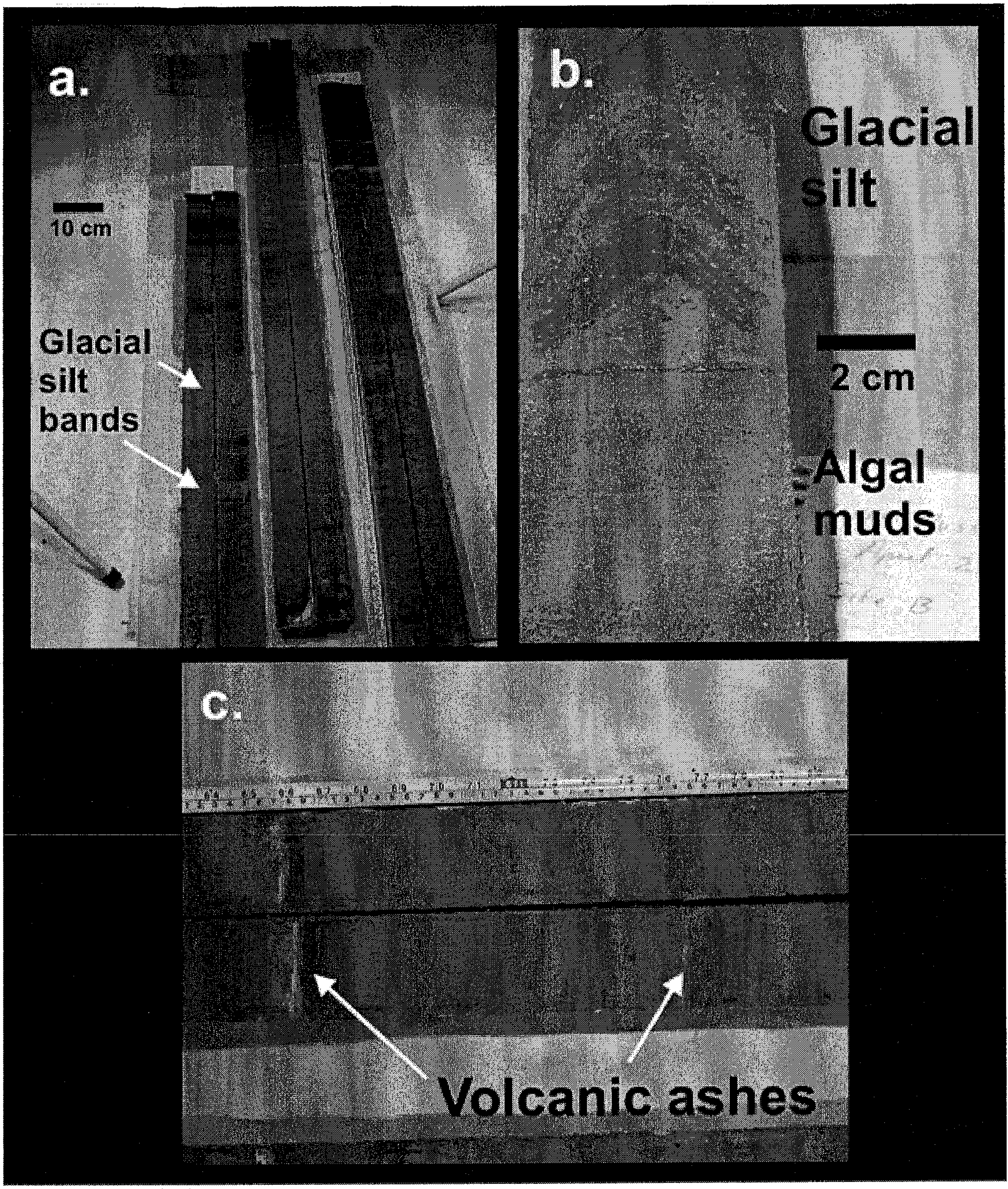

Figure 2. Views of cores from Upper Russian Lake.
A.: Oblique view of split cores showing bands of glacial silt.
B: closeup of lower boundary of glacial silt band showing contrast between underlying algal muds and laminated silts. Arching of the grey silts is caused by drag from the sidewalls of the non-piston corer.
C: Both halves of split core showing thin layers of volcanic ash, probably from volcanoes in the Cook Inlet area.

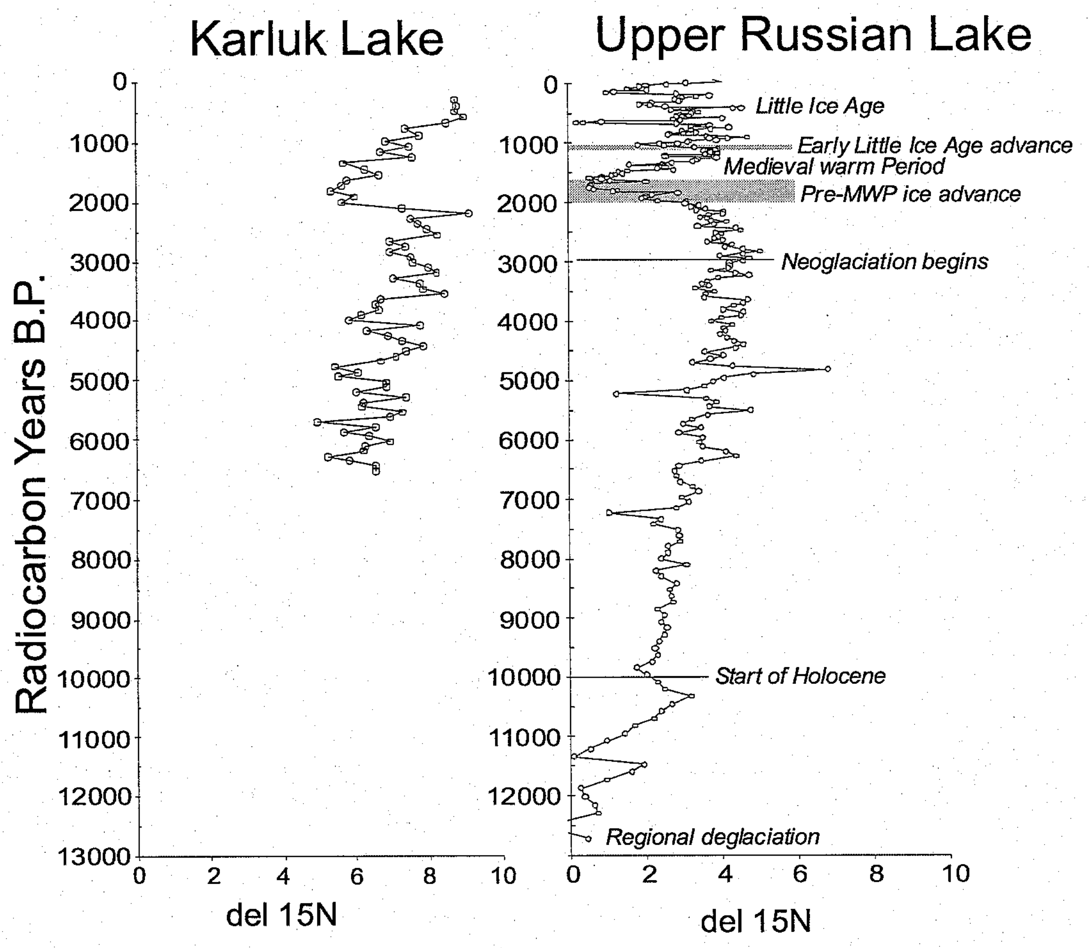

Figure 3. delta 15N in sediments of Karluk Lake (Kodiak Island) and Upper Russian Lake (Kenai River watershed). Vertical scale is in radiocarbon years before A.D. 1950. Note the gradual ramping up of del 15N to circa 3000 yr B.P., when values begin a fluctuating downward trend. In both these lakes there is a striking decline in del 15N values between about 2000 and 1500 yr B.P. during a period of glacier advance. One of the subsequent dips in 15N in Upper Russian Lakes corresponds to another, more brief glacier advance occurring around 1000 B.P. During the beginning of the Little Ice Age.

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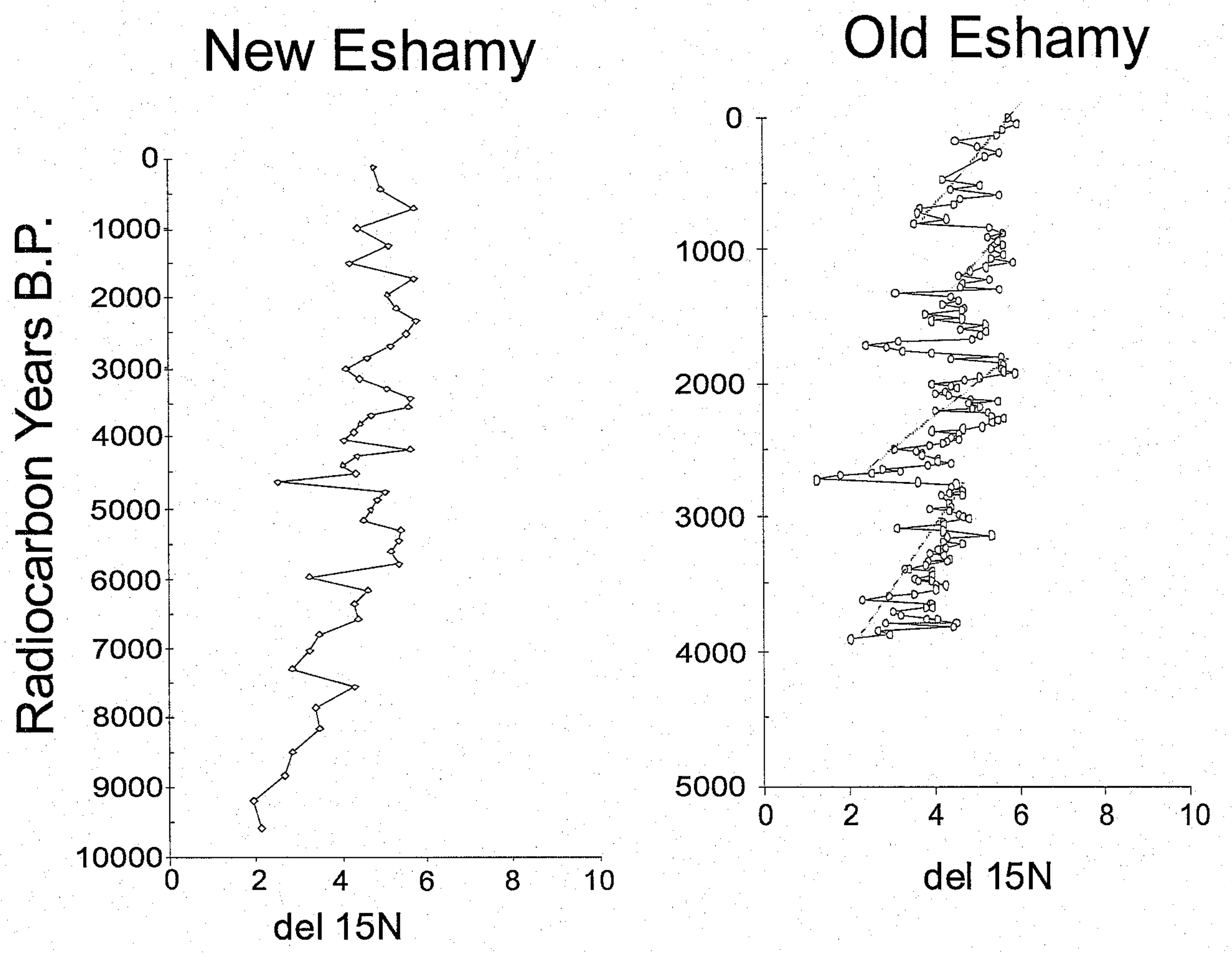

Figure 4. delta 15N in Eshamy Lake, Prince William Sound. Both records show gradual ramping up to ca. 2000 yr B.P. The higher resolution, old Eshamy core also shows ‘micro-ramping” of unknown origin. Neither of these cores show the distinct, pre-Medieval Warm Period dip in del 15N values as seen in Upper Russian and Karluk lakes.

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