EVOS ANNUAL PROJECT REPORT

Project Number: ***G-030649***

Project Title: ***Reconstructing Sockeye Populations in the Gulf of Alaska over the Last Several Thousand Years: The Natural Background to Future Changes***

PI Name: Mann and Finney

Time Period Covered by Report: Year II ending 30 September 03

Date of Report: September 5, 2003

A. Introduction

Our study has three overall 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 to changes in the ocean/climate system in order to better understand how environmental changes affect salmon populations. Finally, through this retrospective ecological study, we will identify the bounds of natural variation in salmon populations using the last 10,000 years as a yardstick for comparison. In what follows we describe our progress in achieving these general objectives.

B. 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 $\delta^{15}N$.

We have retrieved a series of sediment cores out of Eshamy Lake, Upper Russian Lake, and Karluk Lake. We have obtained sediment cores taken by other investigators from Skilak and Hidden Lakes. So far, we have completed analyses at 1-cm intervals of organic carbon, magnetic susceptibility, $\delta^{15}N$, C, and total N from two cores from Eshamy Lake. The same suites of analyses are nearly completed for two cores from Upper Russian Lake, from a long core from Karluk Lake, and from the Hidden and Skilak cores. In the Eshamy Lake cores, we have obtained AMS-radiocarbon age control at millennial intervals. Dating of the Upper Russian, Karluk, Skilak, and Hidden Lake cores is still in progress.

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 $\delta^{15}N$ 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.

The figures that accompany this report show preliminary results from Eshamy, Upper Russian, and Karluk Lakes. The results are exciting for several reasons, but they also give rise to several new challenges. Major results and challenges are as follows.

Result 1: Lakes in southern Alaska provide detailed archives of lake history, including $\delta^{15}N$ records that describe the prehistoric dynamics of salmon populations (Fig. 1, 2, 3, 4). Rapid sedimentation rates and the presence of marker horizons formed by widespread volcanic ashes 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 $\delta^{15}N$ (Fig. 5, 6). 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.

Challenge 1: The challenge here is twofold: first to identify which time scales are of greatest practical interest for deciphering climate-fish interactions, and second, to find lakes whose sedimentary processes minimize bioturbation and permit fine scale sampling.

Result 2: N stable isotope stratigraphy in Eshamy, Karluk, and Upper Russian Lakes indicates that these limnic systems were progressively enriched in pelagic N during the Holocene (Fig. 5). This suggests that salmon run size has, in general, been increasing steadily in these systems. In Upper Russian Lake (Fig. 3), organic C also has been increasing over the last 10,000 years.

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? Results from control lakes on Kodiak Island and the Kenai Peninsula should help test these hypotheses.

Result 3: Our new time series of $\delta^{15}N$ in Eshamy and Karluk Lakes display similarities in the history of salmon abundance in the two systems over the past 6500 years (Fig. 5). Finney already has noted rough synchrony between lakes on Kodiak Island and between Kodiak lakes and Lake Iliamna. However, there are time periods within all these records when the $\delta^{15}N$ concentrations diverge. Specifically, in Eshamy Lake there was no $\delta^{15}N$ rise after 1000 yr B.P. like there was in Karluk Lake (Fig. 5).

Challenges: Accurate chronologies are critical for detecting synchrony between different lake records. Radiocarbon dating requires destructive sampling of cores to obtain terrestrial plant macrofossils whose ages are unaffected by the numerous fractionation artifacts that affect the radiocarbon ages of organisms that obtained their C through aquatic food chains. 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 (e.g., Fig. 2, 3, 4 illustrating the multiple cores from Upper Russian Lake). The bottom line is that the need for precise chronologies requires more work and hence higher laboratory costs than what we originally anticipated.

The second challenge involves how to compare different time series in a statistically valid manner. We are currently talking with a statistician about appropriate methods.

Finally, what are some reasonable hypotheses about why different lakes occasionally diverge in their salmon run sizes? One hypothesis is that subregions within the GOA responded differently to climate forcing in the past, just as the GOA and California Current regions responded differently during the 20th century. Alternately, perhaps divergent run histories result when ecological feedbacks within individual lakes become so powerful that they obscure the effects of climate forcing.

Result 4: So far the most detailed $\delta^{15}N$ record that we have comes from the 2001 core from Eshamy Lake. Here 1.6 m of sediment accumulated in just 3500 years. Analysis of this core at 1 cm intervals (Fig. 6) reveals a cyclical pattern involving crashes that followed immediately after peaks in $\delta^{15}N$, followed by slow recovery along "ramps" of increasing $\delta^{15}N$. We are puzzled by this data. It could be that this pattern is an artifact of sedimentation processes, perhaps by periodic increases in the input of terrestrial C that somehow skew the ^{15}N. Alternatively, this cyclic pattern could relate to the self-organization of the lake ecosystem involving positive and negative feedbacks between salmon-derived nutrients, plankton, and predator-prey cycles within the nursery lake.
Challenges: We have already reanalyzed the ^{15}N from part of the 2001 Eshamy core to check for analytical errors. There were none. Removal of terrestrial organic matter by fine sieving also failed to remove the cyclic pattern. We are currently analyzing the new Karluk core at 1 cm intervals looking for patterns similar to those in the high-resolution Eshamy Lake core. We need to obtain a core spanning the entire Holocene from the site in Eshamy Lake that yielded this interesting record. At present, we lack a coring apparatus capable of doing this.

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 started looking for interactions between climate and salmon abundance by comparing "wiggle" plots of $\delta^{15}N$ 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 (Fig. 7, 8). Closer to home, there are hints from the high resolution Eshamy core that crashes in salmon abundance there coincided with transitions between dry and wet intervals in northwest Alaska (Fig. 9). We are using our previous work on the Kobuk sand dunes to provide a proxy record for aridity (Mann et al., 2000). A comparison between the Red Lake $\delta^{15}N$ record (Finney et al., 2000) and the $\delta^{18}O$ 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 (Fig. 10). However, the advent of intensive commercial fishery on Kodiak around A.D. 1900 limits any conclusions from these short (300 year) time series. Thompson's ongoing work on Mount Logan ice cores promises new, longer ^{18}O time series for comparisons with out salmon chronologies.
Challenges: 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. We are now exploring the tree-ring database, though initial impressions are pessimistic due to the relatively short records they

cover. The available glacial record is promising, though the well-dated portion of this time series is brief, only spanning the past several millennia. Furthermore, the glacial record is full of holes and hindered by the nonclimatic responses of tidewater glaciers. The ongoing impacts of human fisheries hinder a statistical analysis of salmon escapement and the instrumental record in terms of environmental controls.

1. ***Future Work:***

Analysis of the new cores from Eshamy and Karluk Lakes is near completion. Isotope samples from Upper Russian Lake are now at the mass spectrometer laboratory, and we are preparing samples from Skilak and Hidden Lakes. Pb210 samples are ready to submit for dating the upper parts of each core. We plan on obtaining gravity cores from Delight and Desire Lakes in September 2003. Contingent on further EVOS funding, in 2004 we plan on obtaining a high-resolution core from Eshamy Lake that spans the last 10,000 years and a similar high-resolution core from Red Lake.

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 July that would add another year to our project at the current year's funding level. What was to be our FY 2004 budget would then become the FY 2005 budget. We feel this additional year's funding is necessary in order to bring our research product to market in an optimal way. 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.

Prepared By: D. H. Mann ***Project Web Site Address:*** NA

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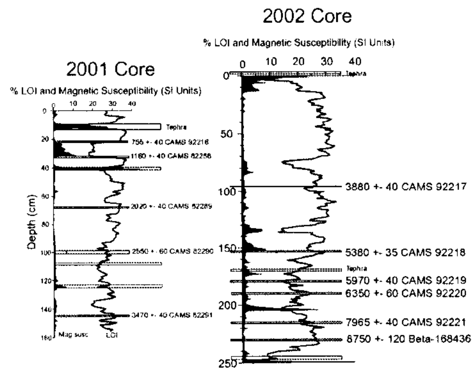

Figure 1. Loss on ignition and magnetic susceptibility measurements in Eshamy Lake cores. Magnetic susceptibility records differences in the concentration of mineral material susceptible to retaining a magnetic field. Loss on ignition (LOI) is a proxy for the amount of organic material in a sediment sample. Radiocarbon ages obtained on terrestrial plant fragments are shown along the left-hand edge.

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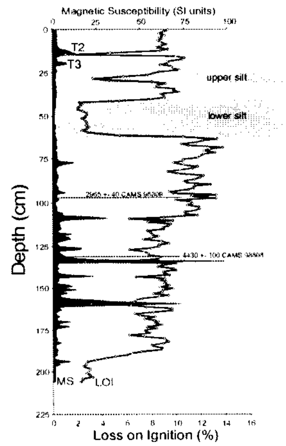

Figure 2. Loss on ignition and magnetic susceptibility in core A1 from Upper Russian Lake.

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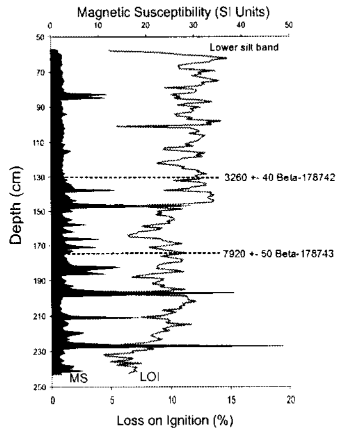

Figure 3. Magnetic susceptibility, loss on ignition, and radiocarbon age control on core B1 Upper Russian Lake

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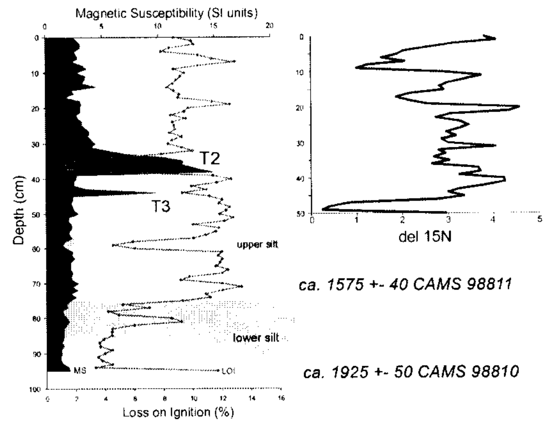

Figure 4. Loss on ignition, magnetic susceptibility, and del 15N in core A2 from Upper Russian Lake. The two 14C dates bracket the lower silt band in core B3, which we have not yet analyzed.

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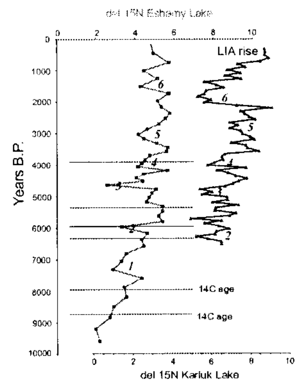

Figure 5. Comparison of millennial records of del 15N in Eshamy and Karluk Lakes. Levels of 14C age control show my horizontal lines. Note the trend towards 15N enrichment in both basins. Possible correlated lows in salmon abundance are numbered. Offsets may be due to the preliminary age control over sedimentation in Karluk Lake. Note the absence of a Little Ice Age low in 15N in Eshamy Lake. Rember that Eshamy dates are uncalibrated and will shift to slightly older ages.

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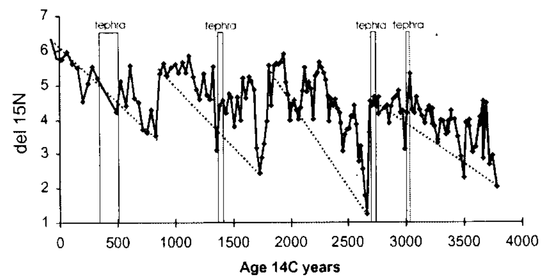

Figure 6. del 15N record from the 2001 Eshamy Lake core. Dashed lines denote apparent "ramps" in 15N input to lake sediments. The 1000-year time scale of this behavior does not correspond with any known climate driver and may be evidence for some sort of cyclic, self-organized behavior in the lake-salmon system.

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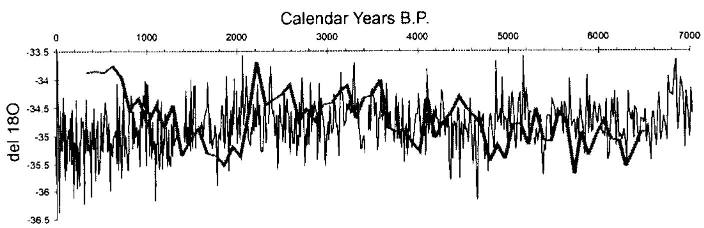

Figure 7. Comparison between Karluk 15N record and the 18O record from GISP2 ice core from Greenland.

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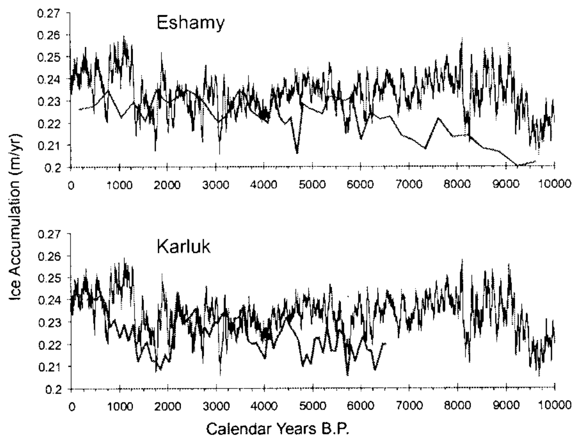

Figure 8. Comparisons between del 15N records from Eshamy and Karluk Lakes with the ice-accumulation rate in the GISP2 core from the Greenland Ice Sheet (Cuffey and Clow, 1997; Cuffey et al., 1995). Remember that the Eshamy age control is uncalibrated and so is shifted slightly left in the diagram.

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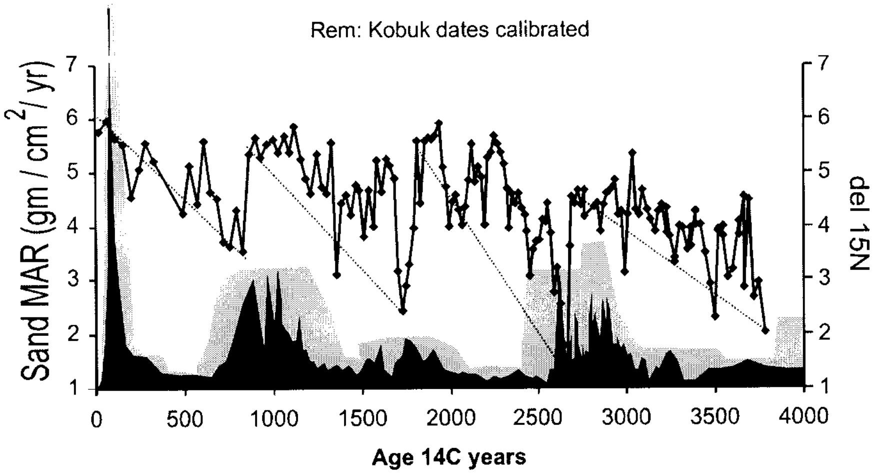

Figure 9. del 15N record from Eshamy Lake (2001 core) compared to the activity of the Kobuk sand dunes, which is primarily a record of changing soil moisture conditions.

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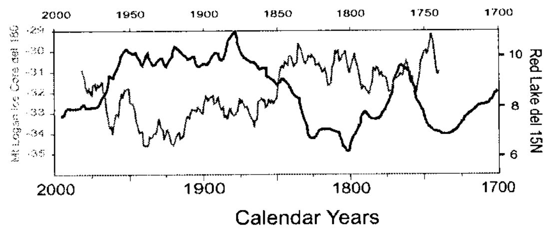

Figure 10 . Comparison between Red Lake del 15N record (black) for the past 300 years and the 180 record from the Mount Logan Ice core(red line) (Moore and Holdsworth, Nature 42, 401).

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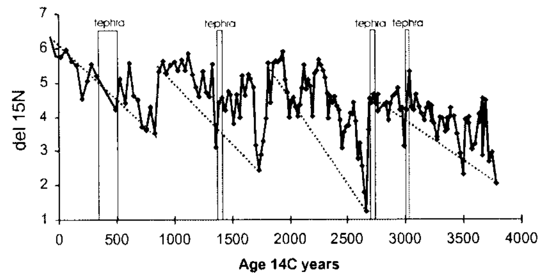

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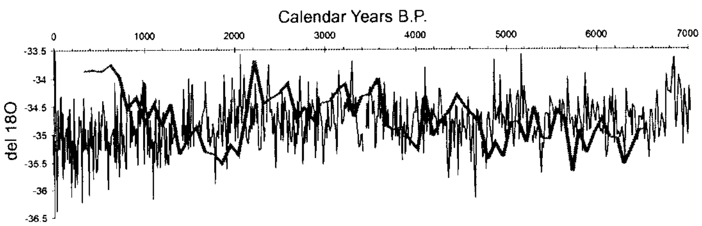

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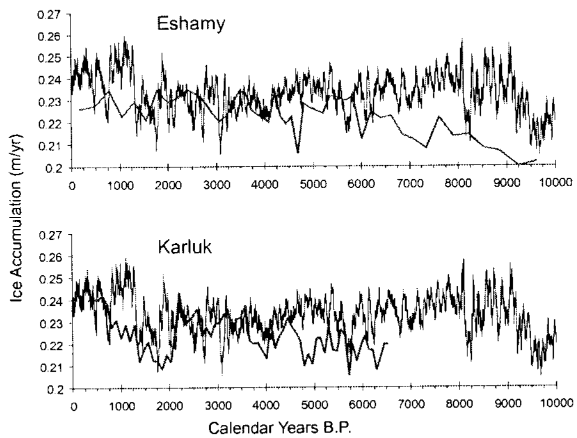

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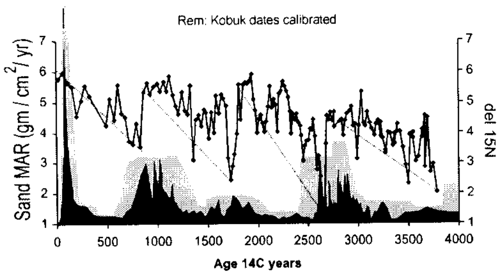

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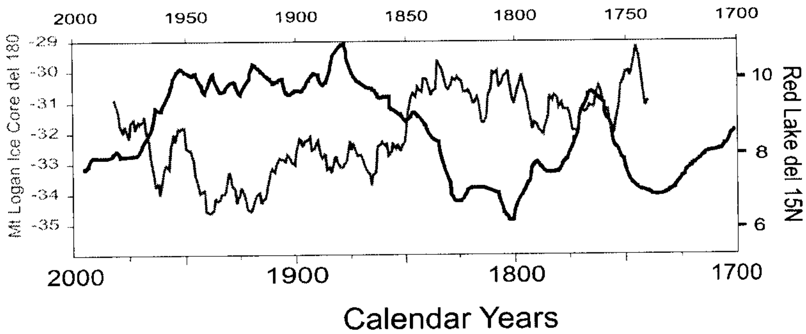

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