Exxon Valdez Oil Spill
Gulf Ecosystem Monitoring and Research Project Final Report

A 6,300-Year-Old Window into the Past: Retrospective Analysis of Nearshore Marine Communities Based on Analysis of Archeological Material and Isotopic Analysis

GEM Project 030656/A
Final Report

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Study History: Project 030656/A was the second year of this project, a retrospective analysis of nearshore marine systems through analyses of archeological material. In its first year this project was 02656.

Abstract: Natural stable isotope analysis of bivalve midden material from the Mink Island site (XMK-030) in the Shelikof Strait of the Gulf of Alaska contrasted with comparable analyses of modern material from the same site has revealed marked differences in ocean conditions through time. These differences are reflected in variation in both delta-13Carbon ($\delta^{13}C$) and delta-18Oxygen ($\delta^{18}O$) isotope ratios from shell carbonates sampled at high resolution across individual shells of the butter clam, *Saxidomus giganteus*, and mussel, *Mytilus trossulus*. Modern material shows relatively close association of ocean temperature, as indicated by $\delta^{18}O$, and productivity, as suggested by the $\delta^{13}C$ values. In the Little Ice Age, both summer and winter ocean temperatures were cooler than those observed today. Additionally, productivity was depressed and did not track ocean temperature closely. During the latter stages of the Hypsithermal, by contrast, productivity was high, and ocean temperature was cool. Differences in productivity probably reflect variation in sun and cloud cover between these two periods. Analysis of shells dating from the Medieval Warm Period reveal yet different patterns with the most striking aspects being no decline in winter productivity in *Saxidomus* shells, and peaks of productivity in the spring and fall.

Key Words: retrospective, climate, ocean, natural stable isotope, Holocene, archeology, Katmai National Park, Gulf of Alaska, bivalves, mollusks, clam, mussel, *Saxidomus giganteus*, *Mytilus trossulus*, Carbon-13, Oxygen-18

Project Data: The data involved in this project include: 1) synthesis of midden shell data; 2) natural stable isotope analyses of selected bivalve material; 3) natural stable isotope analyses of modern seasonal water samples and bivalves. Gail Irvine is the custodian of the data (U.S.Geological Survey, Alaska Science Center, 1011 E. Tudor Road, Anchorage, AK 99503, phone 907-786-3653, fax 907-786-3636, email gail_irvine@usgs.gov).

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Executive Summary

The focus of this study has been the reconstruction of past ocean conditions and climate from an analysis of archeological midden materials. The Mink Island site (XMK-030), part of Katmai National Park and Preserve, is located in the Shelikof Strait and has been occupied from 6,300 years ago to at least 400 years before the present (BP). The extensive bivalve midden material at this site, coupled with its excellent preservation and reference to known occupation surfaces (dated via Carbon-14 analyses), has created a wonderful and rare opportunity to create a picture of past ocean climate and conditions over this long time span. In addition, the use of micro-sampling of bivalve shells, has allowed extremely high-resolution (weekly to bi-weekly) depiction of annual ocean climate patterns and productivity. This type of data has heretofore not been generated for Gulf of Alaska retrospective studies.

Natural stable isotope analysis of bivalve midden material from the Mink Island site contrasted with comparable analyses of modern material from the same site has revealed marked differences in ocean conditions through time. These differences are reflected in variation in both delta-13Carbon ($\delta^{13}C$) and delta-18Oxygen ($\delta^{18}O$) isotope ratios from shell carbonates sampled at high resolution across individual shells. Most analyses were conducted on shells of the butter clam, *Saxidomus giganteus*, but analyses were also conducted on mussel (*Mytilus trossulus*) shells. Modern material shows relatively close association of ocean temperature, as indicated by $\delta^{18}O$, and productivity, as revealed by the $\delta^{13}C$ values. Freshwater input can also influence the $\delta^{18}O$ values, and this is discussed in the interpretations. During the Little Ice Age (540 years BP), both summer and winter ocean temperatures were cooler than those observed today. Additionally, productivity was depressed and did not track ocean temperature closely. During the latter stages of the Hypsithermal (5,750 years BP), by contrast, productivity was high, and ocean temperature was cool. Differences in productivity probably reflect variation in sun and cloud cover between these two periods. Analysis of shells dating from the Medieval Warm Period (850 years BP) reveal yet different patterns, with the most striking being no decline in winter productivity in *Saxidomus* shells, and peaks of productivity in the spring and fall.

The different patterns described above provide us with detailed insight into the patterns of ocean temperature/salinity and productivity over the last 6,000 years. Deviations from expected values (such as the lower ocean temperatures in the Hypsithermal) may reflect the combination of factors that produce climate (e.g. differences in insolation, glacial melt, and precipitation). These latter factors could also influence the strength of coastal currents in the Gulf of Alaska.

The comparison of these prior ocean climate patterns with modern ones allows us to place modern conditions in a much broader framework, and facilitates our ability to predict what types of changes may occur in ocean systems with changes in climate, including global warming.

Introduction

Changes in marine ecosystems occur on multiple scales of space and time. In the near-term, recent biological information suggests that patterns in the abundances of marine organisms and productivity of their associated systems may change in a low-frequency cyclical manner (e.g., regime shifts; Francis et al., 1998; Hare and Mantua, 2000), or may undergo longer-term directional change (e.g., Bering Sea; Schell, 1998, 2000). Long-term changes may reflect changes in climate that have spanned decades, centuries or millenia. Such changes are known for coastal regions from a variety of data. Within Alaska, the coastal paleoenvironments and climate of the late Pleistocene and Holocene have been reviewed by Mann and Hamilton (1995) and Mann et al. (1998).

Long-term changes in marine ecosystems are difficult to investigate, and the entrees into such data are limited. Sediment cores, isotopic analyses, pollen-grain analyses, tree-ring data, and archeological investigations have been used to examine long-term biological data. A combination of data may provide a multi-faceted approach that allows integration and interpretation of changes and processes occurring in nearshore marine environments.

A tremendous opportunity to gain long-term perspective on biological change in nearshore marine communities bordering the Gulf of Alaska is afforded by recent excavations of an archeological site along the Katmai National Park and Preserve coast. This exceptionally rich island site, excavated by a team lead by Dr. Jeanne Schaaf, has midden material dated to at least 6,300 radiocarbon years before present (BP). This site is unusual in its long history, excellent organic preservation, and well-defined stratigraphy, the latter allowing layers to be related to dated occupation surfaces. The site appears to have been occupied rather continuously over the last 6300 years except for a gap from approximately 2,000 to 4,000 years before present. This same gap has been noted from other sites across the whole region (the northern Alaska Peninsula and Kodiak). What sets this site apart from other sites along the Kenai Peninsula coast and southeast Alaska is the abundance of the biological material and its excellent preservation. It is both the oldest identified and most extensively excavated site along the northern Alaska Peninsula.

In addition to the suite of ^{14}C values from the site, there are at least 50 other values from the Katmai coastal area that provide a broader context for the site. Paleoclimate data have been collected in nearby areas, including analysis of a peat deposit that spans 10,000 years and that contains a tephra (volcanic ash) stratigraphy and vegetational history of the entire Holocene (Hilton, 2002). The combination of radiocarbon dates and paleoclimate information provides a context within which a more detailed analysis of midden materials can be made.

We present data from our isotopic analyses of midden material that illustrates long-term patterns in nearshore productivity and their relation to climate change.

Objectives

The Gulf Ecosystem Monitoring Program (GEM) is focused on monitoring species and processes in order to describe and understand changes in the oceanic and nearshore environments of the Gulf of Alaska. As an early part of the program, it has espoused the need for retrospective analyses in order to enrich our understanding of long-term changes in this region. The shorter-term cyclical patterns in species abundances and climate that are a focus of much of GEM, must be understood against the broader spectrum of truly long-term (century to millenial) changes and more directional climate change (e.g., global warming). Retrospective analyses of archeological sites may allow development of such a perspective. The objectives of this project are to:

1. Reconstruct long-term patterns in nearshore ocean temperature and productivity via isotopic analysis of shells of selected invertebrate taxa found in different, dated layers of middens.
2. Relate these changes to the ocean/climate systems that occurred at the same time in order to better understand the factors associated with climate change and that drive nearshore productivity.

Through these analyses and investigative comparisons we hope to identify the bounds of natural variation in nearshore productivity and climate over the last 6,300 years. Our specific hypothesis is that changes in nearshore productivity, as evidenced by isotopic signatures of invertebrate shells, have changed in relation to major climate periods or trends in the Holocene.

Study Site and Its Physical Setting

The Mink Island site is located within the Takli Archeological District on the Katmai National Park and Preserve coast (Figure 1). This exposed and severely eroding site is the oldest known site along the Katmai coast. Four seasons of data recovery excavations were completed in 2000. The well-preserved stratigraphy, including occupation floors and a rich faunal record dating from 6,300 years ago to 500 years ago, is enabling definition of the cultural history for the Katmai coast. The non-mixed nature of the material contributes to the clarity of the stratigraphy. in the site sediments. Unusually well-preserved vertebrate and invertebrate assemblages are found at the site. The results of the excavations of the younger midden deposits, postdating 2000 years ago are the subject of a dissertation (Hilton, 2002). Eighty radiocarbon dates have been run from the site, making it the most well-dated site in Alaska.

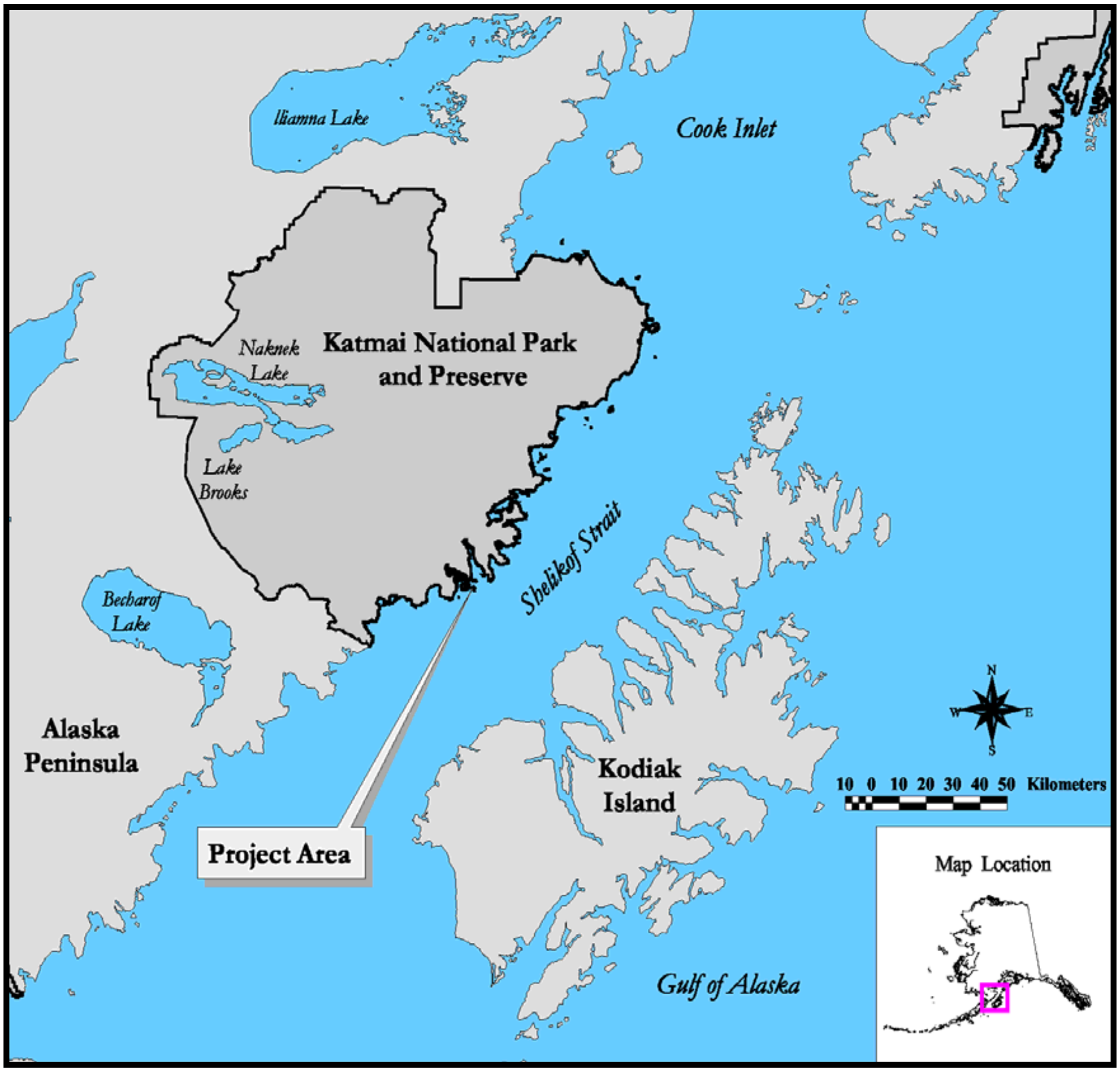

Figure 1. Map of southwestern Alaska and project vicinity. The boundaries of Katmai National Park and Preserve are indicated. Note that the island is located in Shelikof Strait.

The island containing the site is positioned offshore, subject to the oceanographic conditions of the Alaska Coastal Current. The direction of flow is southwest down the Shelikof Strait, with 1976-77 data from a more offshore mooring in the Shelikof indicating a winter flow of 26.7 cm/s (Figure 2; Reed and Schumacher, 1986). The Alaska Coastal Current is a wind- and buoyancy-forced current (Royer, 1982; Weingartner et al., 2003), whose flow is fueled by the wind and precipitation/runoff provided by low pressure systems (storms).

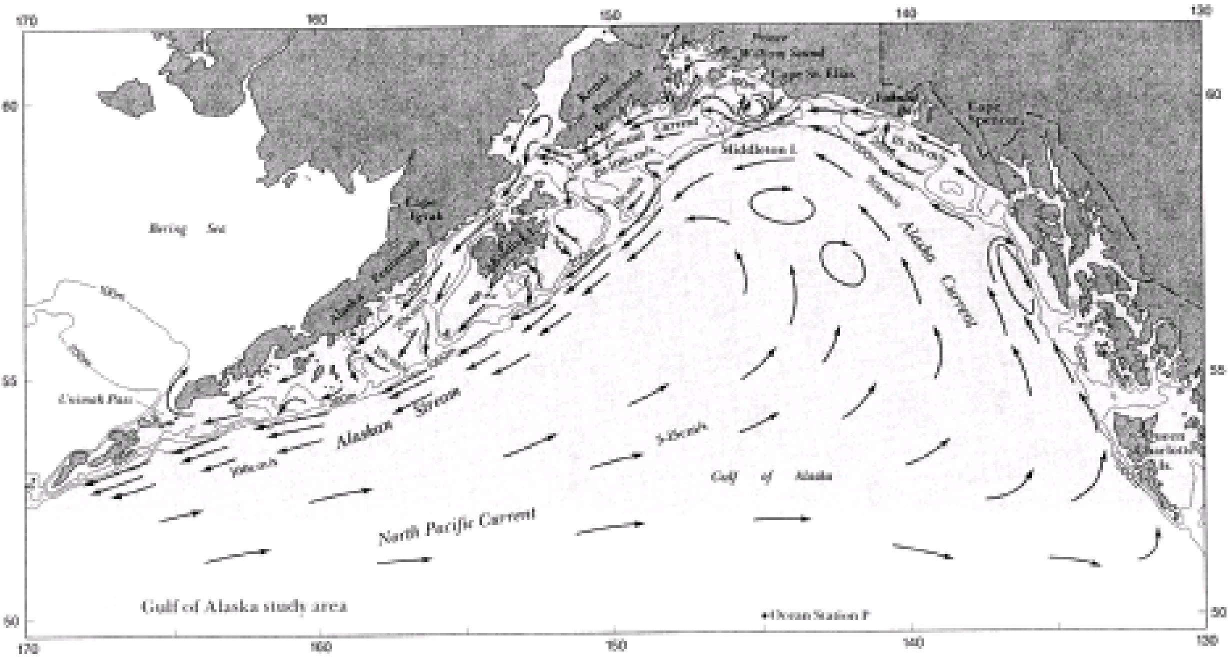

Figure 2. Depiction of the major currents in the Gulf of Alaska. From Reed and Schumacher, 1986.

The Shelikof Strait is a storm-wave environment subject to high winds originating both from high pressure cells over the continental interior and from passing cyclonic storms (Overland and Heister, 1980). During the autumn and winter, storms typically affect the Alaskan coast at intervals of 48 hours or less (Hare and Hay, 1974). The routes taken by storms across the North Pacific are predictable and have consequences for regional climatic patterns. Cyclones generated off the coasts of Siberia and Japan typically track northeastwards, crossing south of the Aleutian Islands towards the coast of North America. Their repeated passages create a region of semi-permanent low pressure, the Aleutian Low (Wilson and Overland, 1986). The Aleutian Low exists approximately 25% of the time, making it an integral part of weather patterns in southern Alaska throughout the year.

Wind intensity in the Gulf of Alaska is greatest between October and April (Overland and Heister, 1980). In the western Gulf, predominate winds are from the west (Wilson and Overland, 1986). Nearshore winds are highly variable due to the presence of high mountains that block onshore flow. On the shorelines of the Shelikof Strait, high winds are variable in direction, coming from the north during times of high pressure in the Bristol Bay region, from the northeast when large cyclones are passing east of Kodiak Island, and from the southwest when large storms cross the Aleutian Island chain further to the west. Gradients of pressure and temperature between relatively warm air over the Gulf of Alaska and cold air over the Bering Sea and continental interior frequently lead to katabatic flow. Katabatic winds channel through mountain passes into fjords along the coast. Another type of nearshore wind occurs when a cyclone abuts a narrow strait bordered by high mountains. The normally clockwise, geostrophic winds are blocked, creating a gap in the cyclone's wind field that is compensated by low level winds blowing along and perpendicular to the regional pressure gradient. This results in strong, localized winds blowing down straits such as the Shelikof Strait (Overland, 1984).

Storm frequency decreases during springtime in the Gulf of Alaska. Winds speeds also decrease to a low in mid-summer when the northeastern Pacific High is usually strongest. Summer winds are characteristically light except when a storm enters the region (Brower et al., 1977). The Gulf of Alaska is usually cloudy, the result of the near-continental passage of storms through the region (Brower et al., 1977). Clouds are also generated by the flow of cold, interior air out over the warm waters of the Gulf in winter. While the east Pacific High is dominant in the summer, fog and stratus clouds are frequent in a low-level temperature inversion created over the relatively cool waters of the Gulf (Wilson and Overland, 1986).

Though weather stations are widely scattered, precipitation along the southern coast of Alaska appears to be highly variable. A maximum of 800 cm/year falls in the coastal mountains (Royer, 1983), and a minimum of 59 cm/year falls at Larsen Bay, located in the rainshadow of the mountains of Kodiak Island (Karlstrom, 1969; AEIDC, 1977). In general, the Katmai coast is drier than areas in the eastern Gulf of Alaska. Large portions of the coastline between the Copper River delta and the Alaska Peninsula receive 200 cm/year (Royer, 1983). Precipitation away from the coast, over the Gulf of Alaska is approximately 100 cm/yr (Wilson and Overland, 1986). Near sea level, most precipitation falls as rain, even in winter (Brower et al., 1977).

Temperatures along the coast of southern Alaska are relatively cool in summer and warm in winter when compared to stations at similar latitudes in the continental interior. Mean annual temperature ranges from 2.2° C at Valdez to 5.4°C at Cape Hinchinbrook. Mean annual precipitation ranges from a low at Larson Bay of 59 cm to 460 cm at Cordova

Methods

Selection of Material for Isotopic Analysis

We selected bivalve shells to analyze for natural stable isotopes ($\delta^{13}C$, $\delta^{18}O$) based on their association with radiocarbon dates (Hilton, 2002; Schaaf, pers. comm.) from major climate periods (Figure 3, Mann et al., 1998). The well-defined stratigraphy of the Mink Island site, coupled with the abundance and fine-preservation of the material makes possible analytical approaches that tie ^{14}C dates closely to biological material. Bivalve material is extremely abundant through time. Only bivalve shells tightly associated with the targeted radiocarbon dates were analyzed. During the excavation of the Mink Island site, fine-grained recovery techniques were used to ensure that the occupation surfaces were linked to the faunal refuse outside the lived-upon surfaces. All excavation surfaces, artifacts, and select faunal elements were 3-point provenanced for tight control, leading to an extremely well-defined stratigraphy. In addition to the archeological material, live *Saxidomus giganteus* and *Mytilus trossulus* were collected from the intertidal of Mink Island on several trips. During these trips seasonal water measurements were made (e.g., temperature, salinity) and water samples were taken for reference isotopic analysis.

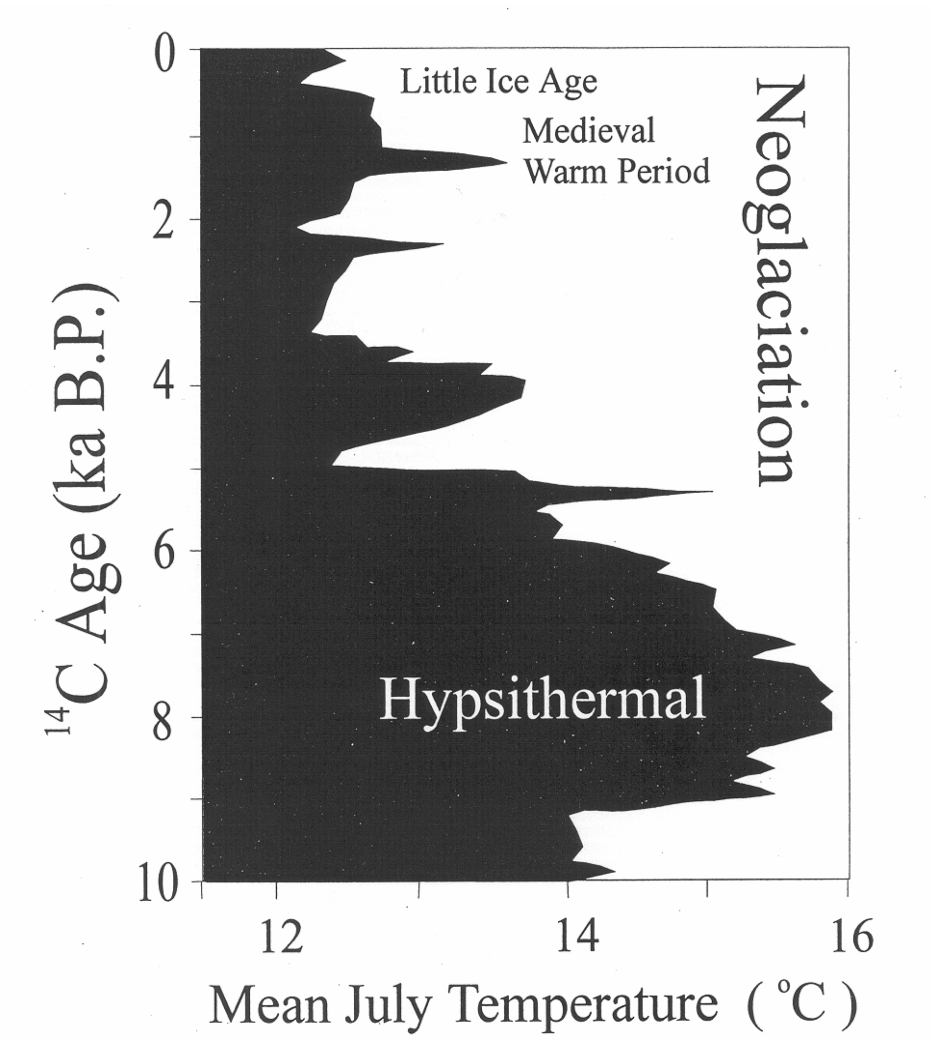

Figure 3. History of summer temperature in southern Alaska during the Holocene inferred from pollen transfer functions (redrawn from Heusser et al. 1985, as reported by Mann et al., 1998).

Analytical Facilities

Isotopic analyses have been conducted at the University of Iowa's Paul H. Nelson Stable Isotope Laboratory (PHNSIL), which houses a Finnigan-MAT 252 isotope ratio mass spectrometer (IRMS) equipped with the following peripheral devices: 1) a Kiel III automated carbonate device (for the analysis of carbonate micro-samples); 2) a Gas Bench II for a variety of analyses including $\delta^{13}C_{DIC}$, $\delta^{18}O_{H2O}$ values; a Hydrogen Device for measuring δD values of water samples; and a Costech Elemental Analyzer with a low blank autosampler for determining $\delta^{13}C$ and $\delta^{15}N$ values of a variety of organic materials (and C, N contents). All peripheral devices are automated and are on-line with the mass spectrometer. The PHNSIL also houses high vacuum gas extraction lines for the preparation of a variety of materials (waters, organic matter, gases, etc.).

Sampling of carbonates has been conducted using the micro-sampling and image analysis equipment housed in the PHNSIL. This equipment consists of a Nikon SMZU zoom microscope equipped with a Hitachi CCD video camera (720 line resolution) and a frame capture card. Optimas Image Analysis software is available for on-screen analysis and digitization. Image analysis is conducted using Optimas software. An automated Nikon 35 mm camera system and a Sony 5.24 Megapixel digital camera (DSC-F707) are also available. High-resolution micro-sampling of skeletal carbonates is conducted on a fully automated, precision Newport 462 X-Y-Z stage equipped with Newport 850B servo-motor actuators (capable of one inch of travel distance) that are controlled by Parker-Compumotor software and hardware (in conjunction with Optimas Software). Together with a Brasseler UP-200 controller and a UG-12 precision handpiece and assorted bits and burs, this equipment allows manual and automated micro-sampling of mineral phases from polished rock slabs, thick sections, etc. at 15 μm increments (Carpenter, 1996; Frappier et al., 2002).

Carbonate Micro-sampling Methodology

Micro-samples of carbonate are milled from the surface of biogenic carbonate (e.g., mollusk shells) using a Brasseler UP 200 controller and a UG-12 precision handpiece fitted with a variety of tungsten carbide dental burs and bits with observation under a Nikon SMZU microscope. Sampling transects are typically conducted perpendicular to visible growth bands of each shell. Routine micro-sampling of shell material is conducted manually using the Brasseler UG-12 precision handpiece fitted with a faceted tungsten carbide scribing tool. This sampling permits sample collection at approximately 0.15 mm increments. Depending on shell growth rates, this type of sampling permits collection of geochemical data with weekly to bi-weekly temporal resolution.

Carbonate powders (typically 0.05 mg $CaCO_3$) are loaded into stainless steel vessels and placed in numbered stainless steel carriers and then desiccated. Desiccated sample powders are then loaded into individual borosilicate reaction vessels used in the automated Finnigan Kiel III Carbonate Device on line with a Finnigan-MAT 252 IRMS. In the Kiel device, carbonate samples are reacted with 2 drops of anhydrous H_3PO_4 at 75ºC (using an acid fractionation factor of 1.008675). Resultant water and CO_2 are cryogenically separated and pure CO_2 is transferred to a micro-volume for introduction to the Finnigan-MAT 252 IRMS for analysis. Analytical precision is monitored through the daily analysis of NIST powdered carbonate standards (NBS-18, 19 and 20 and other in-house carbonate standards) and is better than ± 0.1 ‰ for both carbon and oxygen isotope ratios. $\delta^{13}C$ and $\delta^{18}O$ values are reported relative to V-PBD.

Results and Interpretation

Modern shells – Collected alive from Mink Island (10/7/02)

Modern specimens of *Saxidomus giganteus* and *Mytilus trossulus* collected alive from Mink Island have been micro-sampled using techniques capable of measuring carbon and oxygen isotope ratios of shell carbonate at sub-monthly resolution (Figures 4, 5). In some cases, better than weekly resolution has been attained in fast growing portions of shells (e.g., *Mytilus trossulus*; Figure 5). These modern data allow direct comparison of analogous data collected from ancient shell materials. The data from modern *Saxidomus* and *Mytilus* specimens indicate that there are two periods of low $\delta^{18}O$ values during each year of growth.

Today, surface waters in the Gulf of Alaska are influenced by springtime melting of coastal glaciers and late summer-early fall rainfall adding freshwater to coastal marine waters. Silvestri (1997) measured coastal glaciers near Prince William Sound and found that glacial meltwaters have $\delta^{18}O$ values of ~ -14 ‰ (Standard Mean Ocean Water = SMOW). Addition of these meltwaters during the early spring produces a negative shift in the seasonal $\delta^{18}O$ value sinusoid (Figures 4, 5). Rainfall in the late summer-early fall and higher surface water temperatures at this time (due to insolation) yield a second inflection in the seasonal $\delta^{18}O$ value sinusoid. Today, these events create the asymmetric saw-tooth $\delta^{18}O$ value patterns in Figures 4 and 5 where $\delta^{18}O$ value minima in the fall are followed immediately by winter cold intervals ($\delta^{18}O$ value maxima).

Stable isotope data from these modern specimens allow comparison of analogous data from ancient specimens. In addition to the analysis of modern *Saxidomus giganteus* and *Mytilus trossulus* from Mink Island, analysis of modern weathervane scallops (*Patinopecten caurinus*) from the nearby Shelikof Strait and Kodiak Island allow an understanding of the $\delta^{18}O$ and $\delta^{13}C$ values of surface and relatively shallow shelf bottom waters (~100m) influenced by the Alaska Coastal Current (Carpenter and Barnhart, 2000; Carpenter, unpublished data).

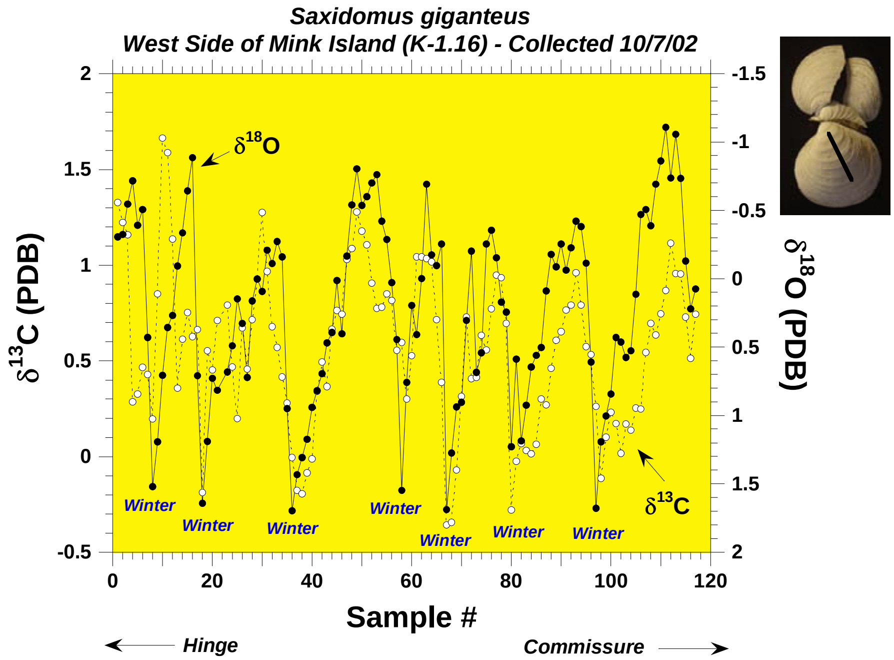

Figure 4. Carbon and oxygen isotope data collected from a micro-sampling transect perpendicular to shell growth increments of *Saxidomus giganteus*. Modern conditions have relatively brief intervals where $\delta^{18}O$ values are at maximum and minimum values. Late summer-early fall has the lowest $\delta^{18}O$ values. $\delta^{13}C$ and and $\delta^{18}O$ values exhibit a strong negative correlation.

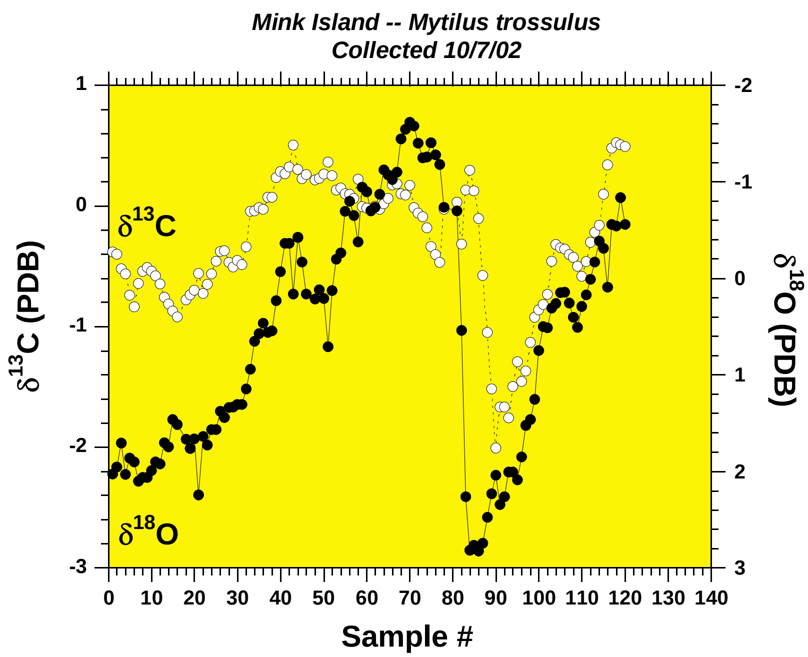

Figure 5. Carbon and oxygen isotope data collected from a micro-sampling transect perpendicular to shell growth increments of *Mytilus trossulus*. Modern conditions have relatively brief summer and winter intervals with late summer-early fall having the lowest $\delta^{18}O$ values. The spring meltwater flux of low $\delta^{18}O$ values can be seen in samples 30-50.

Carbon isotope ratios of surface water dissolved inorganic carbon (DIC or ΣCO_2, predominantly HCO_3^- at seawater pH) is controlled by changes in primary productivity (phytoplankton). Such productivity is controlled by insolation and nutrient supply. Temperature decreases in the fall-winter and diminished sunlight yield dramatic decreases in productivity and subsequent oxidation of plant organic matter. As plant organic matter preferentially sequesters ^{12}C ($\delta^{13}C$ values below -20 ‰), productivity tends to increase ambient surface water DIC $\delta^{13}C$ values. Oxidation of this organic matter returns this ^{12}C to surface waters as $CO_2 \rightarrow HCO_3^-$. Shell $\delta^{13}C$ values respond to these changes as mollusks use a large proportion of ambient HCO_3^- for shell carbonate precipitation. In general, winters are marked by precipitous decreases in shell $\delta^{13}C$ values and spring and summer are marked by elevated shell $\delta^{13}C$ values.

Comparison of *Saxidomus* results

The three samples taken from these middens were selected on the basis of their associated radiocarbon ages that correspond with important climate episodes (5750 ±40 years BP – end of the Hypsithermal or Mid-Holocene Thermal Optimum; 850 ±50 years BP – Medieval Warm Period; 540 ±60 years BP– Little Ice Age). Each of these shell specimens has yielded distinctly different patterns in $\delta^{18}O$ and $\delta^{13}C$ values.

Mid-Holocene Climatic Optimum (Hypsithermal)

This specimen (Figure 6) exhibits no low $\delta^{18}O$ value inflections in the seasonal sinusoid – indicating relatively warm and dry conditions. Spring meltwaters and late summer rains are markedly reduced relative to modern conditions. Higher wintertime $\delta^{18}O$ values suggest colder winter temperatures (perhaps due to overall lower relative humidity). Summertime $\delta^{13}C$ values indicate a marked increase in surface water productivity – perhaps due to dry conditions and skies (allowing greater insolation) during the spring and summer.

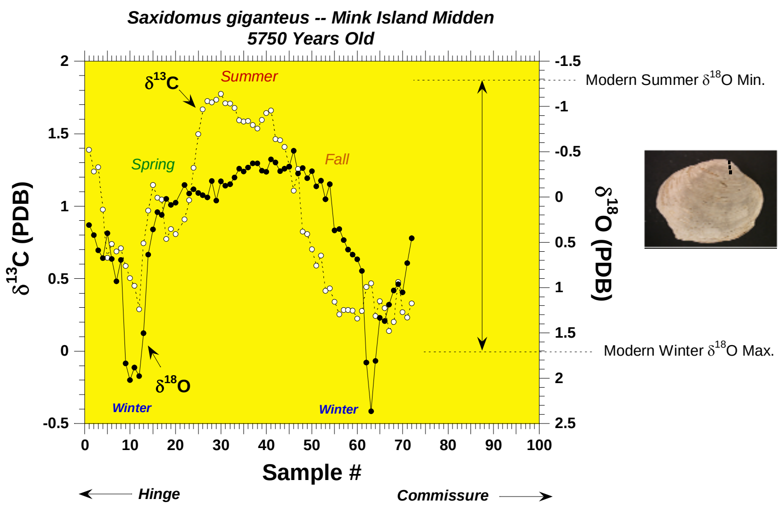

Figure 6. Carbon and oxygen isotope data collected from a micro-sampling transect perpendicular to shell growth increments of a 5750-year-old *Saxidomus giganteus* shell.

Little Ice Age

This specimen (Figure 7) exhibits the typical two peak $\delta^{18}O$ value sinusoid – indicating relatively high moisture levels. Higher summer and winter $\delta^{18}O$ values suggest cooler conditions. Significantly lower $\delta^{13}C$ values (relative to modern) indicate significantly lower surface water productivity. Lower productivity may result from a greater number of cloudy days relative to today.

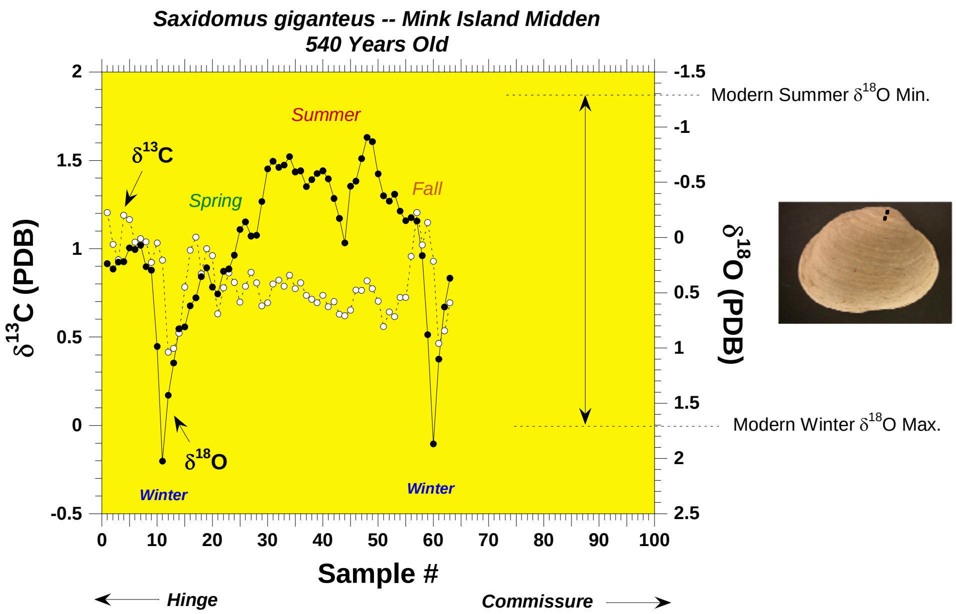

Figure 7. Carbon and oxygen isotope data collected from a micro-sampling transect perpendicular to shell growth increments of a 540-year-old *Saxidomus giganteus* shell.

Medieval Warm Period

Values are presented for both *Saxidomus* and *Mytilus* shells (Figures 8 and 9). Winter $\delta^{18}O$ values for both species are approximately equal to modern values. However, summer $\delta^{18}O$ values are high relative to modern values. Unlike other *Saxidomus* specimens, for this aged one there is no wintertime decrease in $\delta^{13}C$ values (and productivity). However, the *Mytilus* shell shows a wintertime drop in productivity ($\delta^{13}C$ values). In addition, $\delta^{13}C$ values peak in the spring and fall and actually decrease during the summer. These patterns are stronger in the *Saxidomus* shell. This suggests that productivity is not high during the summer – presumably due to cloudy, wet conditions?

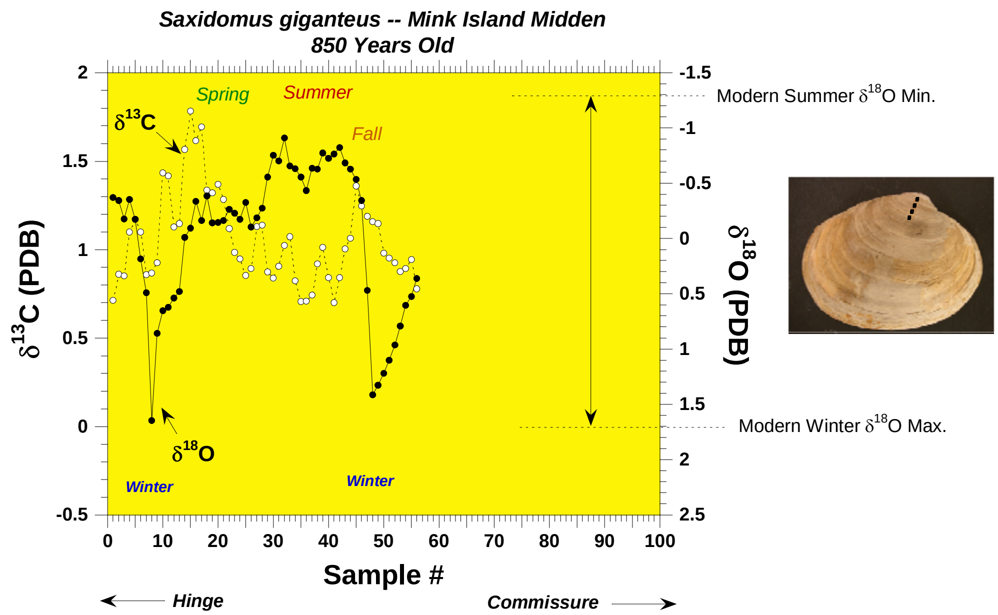

Figure 8. Carbon and oxygen isotope data collected from a micro-sampling transect perpendicular to shell growth increments of an 850-year-old *Saxidomus giganteus* shell.

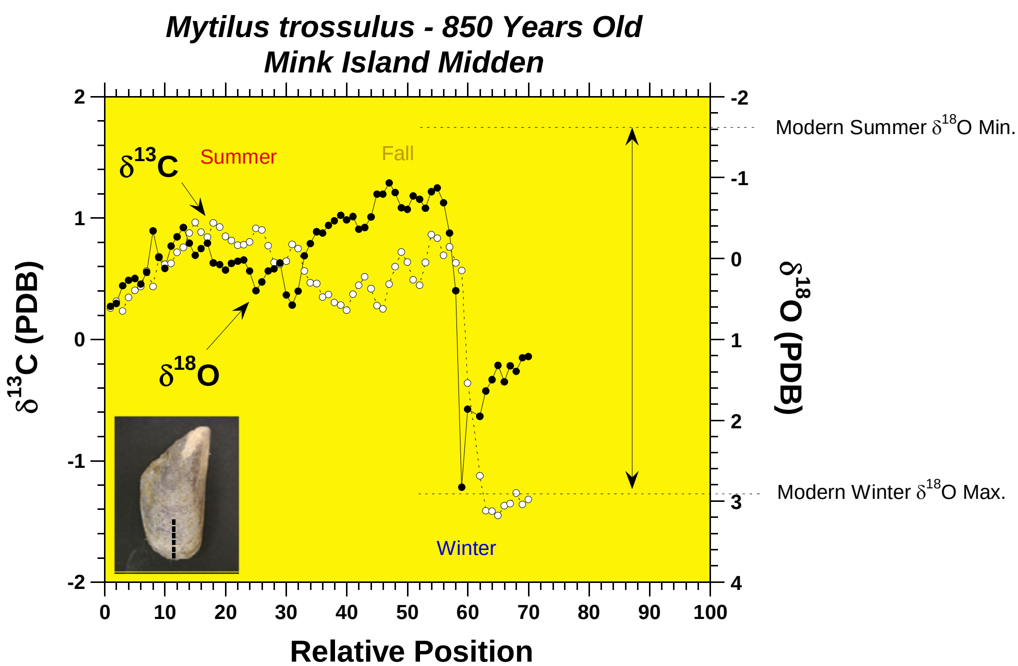

Figure 9. Carbon and oxygen isotope data collected from a micro-sampling transect perpendicular to shell growth increments of an 850-year-old *Mytilus trossulus* shell.

Comparison of Saxidomus and Mytilus Patterns

The only periods for which we currently can compare *Saxidomus* and *Mytilus* isotopic data are for modern and 850-year-old shells (Figures 4, 5, 8, and 9), the latter from the Medieval Warm Period. The most marked difference in the patterns of isotopic values is the much larger range of $\delta^{18}O$ values found for *Mytilus*, especially for the modern shell. This $\delta^{18}O$ difference in maximum and minimum values is approximately 4.6‰, compared to a range of 2.8‰ for modern *Saxidomus*. This difference may be due to the emergent (epibenthic) habit of the *Mytilus* compared to the primarily infaunal habit of *Saxidomus*. For *Mytilus*, the range of differences in $\delta^{18}O$ values between the 850-year-old shell and the modern shell is great (0.7‰), while there is much less difference in comparable temporal $\delta^{18}O$ values for *Saxidomus* (approximately 0.2‰).

The situation is reversed when comparisons of $\delta^{13}C$ values, reflecting productivity, are made. In this case, although the $\delta^{13}C$ values shift in *Mytilus*, the range of variation is similar (approx. 2.5 or 2.6‰). For *Saxidomus*, the $\delta^{13}C$ values are quite variable, not just for the 850-year-old and modern shell comparison (range approx. 2.05‰ versus approx. 1.1‰). Perhaps the most striking difference in the 850-year-old *Mytilus* and *Saxidomus* shells is the lack of a drop in winter productivity indicated by *Saxidomus*, versus the drop indicated by the isotopic values in the *Mytilus* shell. Additional sampling of these shells may indicate the consistency of these patterns; however, note that the pattern of no winter drop in productivity in *Saxidomus* held over two winter's sampling.

Discussion

As Mann et al. (1998) stated in their review of Holocene geologic and climatic history along the Gulf of Alaska, "Although poorly understood at present, climate fluctuations at all time scales observed in the prehistoric record were intimately connected with oceanographic changes in the North Pacific Ocean." We have used a combination of oxygen and carbon stable isotopic analyses ($\delta^{13}C$, $\delta^{18}O$) of bivalve shells from the Mink Island midden to examine long-term changes in nearshore primary productivity and ocean conditions/climate at one location in the Gulf of Alaska. Carbon is transferred relatively conservatively in food webs and stable isotopic analysis of $\delta^{13}C$ gives excellent information on sources and magnitudes of productivity. Recent studies of the relationships between stable carbon isotope ratios in phytoplankton and the growth of diatoms (Laws et al., 1995) and for haptophytes inhabiting differing ocean productivity regimes (Bidigare el al., 1997) indicate a close relationship between $\delta^{13}C$ and algal growth rates (Schell, 1998, 2000). These findings provide a mechanism for linking $\delta^{13}C$ values and the magnitude of primary production, which can then be expressed in higher order consumers.

Recent analyses of stable isotope ratios of baleen of bowhead whales suggest declining productivity in the Bering Sea (Schell, 1998, 2000). In this case, analysis of carbon isotope ratios provided a means of indirectly assessing relative primary production. The bowhead whales feed on zooplankton that they filter with their baleen, and are thus one step removed from the phytoplankton primary producers. Bivalve mollusks, the dominant constituents of the middens at the Mink Island site, are also filter feeders, but feed more commonly on phytoplankton, thus responding more directly to patterns in primary productivity. Additionally, shell formation is interactive with the isotopic composition of the seawater milieu in which the bivalve resides. Thus bivalve shells provide a close link to both water and plankton isotopic constituencies.

Our emphasis is to examine correlations between the patterns in shell isotopic values and major climate periods experienced in the Gulf of Alaska (Figure 3). Our hypothesis, that patterns of change in primary productivity, as evidenced by isotopic analyses, are correlated with changes in climate, appears to be substantiated by the isotopic analyses. These analyses revealed major differences in ocean temperature/salinity and productivity at different climatic periods. The consideration of both $\delta^{13}C$ and $\delta^{18}O$ analyses provided especially compelling information on variation in ocean conditions and climate over millennial time scales, while providing high resolution information on annual and interannual patterns.

These results, while reinforcing some currently held views of Holocene climate bordering the Gulf of Alaska (Mann et al., 1998), also provide some contrast (e.g. colder winters for the near-coastal ocean during the Hypsithermal). Does this suggest that ocean circulation patterns were different during this time? If most of the glaciers had melted back by this later Hypsithermal time (5,750 years BP), and summers were drier (Mann et al., 1998; our results) then the Alaska Coastal Current, which is driven by wind and freshwater input (Royer, 1982; Weingartner et al., 2003), might have been altered. The lack of a spring melt-water peak and relatively flat $\delta^{18}O$ values over the spring/summer/fall for the Hypsithermal *Saxidomus* support a drier climate at this time. The sustained high productivity also expressed in this shell gives us an idea of how changes in precipitation or in the Alaska Coastal Current might be expressed biologically.

The strongest contrast to the Hypsithermal pattern is provided by the isotopic patterns from the Little Ice Age *Saxidomus*. Here there are isotopic indications of wetter conditions in the summer, cool winter conditions, and depressed summer productivity. Surprisingly, although there is a drop in winter productivity it is not nearly as steep a decline as for modern *Saxidomus*. Another of the interesting findings is the lack of a drop in winter productivity during the Medieval Warm Period for *Saxidomus*. These findings suggest that the responsiveness of productivity to shifting climate patterns. Further dissection of the specific climate and ocean factors that influence these productivity patterns may provide insight into how changing climate in modern times may affect species populations and community dynamics in marine systems.

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