Seasonal Shellfish Foraging Strategies from Bodega Bay, California

Michael A. Kennedy, Ann D. Russell and Tom P. Guilderson

Recently there has been increased focus on the emergence of intensified maritime adaptations among hunter-gatherers along the California coast; however, little is known about these strategies along the northern California coast. How intensively did hunter-gatherers utilize marine resources throughout the year in northern California? We measured $\delta^{18}O$ and $\delta^{13}C$ from the terminal margins of Mytilus californianus shells from three ^{14}C-dated archaeological components in the Bodega Bay region. We determined the harvest season by comparing these end values to the annual range of values of contemporaneous shells. Our preliminary results from Duncan's Point Cave (CA-SON-348) and the Bodega Lagoon site (CA-SON-322) indicate that exploitation of M. californianus was predominately seasonal (fall) at ~8500 cal B.P., ~3100 cal B.P. and ~200 cal B.P.

In recent years, there has been increased focus on the emergence of intensified huntergatherer maritime adaptations along the shorelines of California, and the role of climate change as a selective force in shaping cultural responses (e.g., Erlandson and Colten 1991; Erlandson and Glassow 1997; Jones *et al*. 1999). Archaeological and paleoceanographic evidence from southern and central California indicates that major cultural changes (such as the use of marginal resources, and economic and sociopolitical complexity) may have developed from resource stress related to changes in sea surface temperature (SST) and marine productivity (e.g., Arnold 1992; Arnold 2002; Glassow *et al*. 1994; Glassow *et al*. 1988; Jones and Kennett 1999; Kennett and Kennett 2000; Raab and Larson 1997). Whereas abundant data exist from these regions, our understanding of the conditions that led to an intense maritime focus in northern California is limited (see Jones 1991; Lightfoot 1993).

How intensively did hunter-gatherer's utilize marginal marine resources, such as shellfish, throughout the year? And, what role did marine climate (SST, seasonal upwelling and nutrient content) play in the development of intensified marine foraging strategies? We are presently exploring these questions using the shell $\delta^{18}O$ and $\delta^{13}C$ of *Mytilus californianus* (the California sea mussel) from 14C-dated archaeological components near Bodega Bay, California (38^{0}19'N, 123^{0}03'W) (Figure 1). Here we present preliminary data from the harvest season portion of our research and discuss the stable isotope results of: 1) a modern calibration study for the Bodega Bay region; and 2) an archaeological study from three components to determine harvest seasons.

Marine resource intensification on the north coast of California involved a broadening of the diet and should be reflected in the annual intensity with which foragers utilized low-ranked (low caloric return and high handling cost) marine resources, such as shellfish. In particular, hunter-gatherers might be inclined to exploit these resources year-round rather than limit procurement to a single season.

Background

Marine Resource Intensification in Northern California

Foraging theory proposes that decreases in resource productivity and/or increased harvest pressure can lead to reductions in the abundance of high-ranked resources (high caloric return and low handling cost), such as marine mammals. As resource stress ensues, foragers adapt by adjusting their subsistence strategies. One possible adaptive strategy is resource intensification. Intensification is a strategy in which additional labor costs are incurred to increase the yield of selected resources, such that reduced net returns result in decreased levels of foraging efficiency (Beaton 1991; Boserup 1965; Broughton 1994). This strategy involves an expansion of the diet to include

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more lowranked resources (Bettinger 1991; Broughton 1994), like shellfish (see Raab 1992). This also often entails reduced mobility, a reduced foraging radius and increased sedentism (e.g., Baumhoff and Bettinger 1982).

Early Holocene (~8500 cal B.P.) faunal evidence in coastal northern California is limited to the lower levels at Duncan's Point Cave (CA-SON-348/H) (Schwaderer 1992). The small faunal assemblage suggests limited use of marine resources at this time. Middle Holocene (~7000-3000 cal B.P.) faunal data in northern California reveal use of high-ranked marine resources (e.g., northern fur seal and California sea lion); however, use of lower-ranked resources also increases (e.g., shellfish, fish, birds and marine mammals like harbor seals and sea otters) (see Jones and Hildebrandt 1995; Kennedy *et al.* 2001; Schwaderer 1992; Wake and Simons 2000). It appears that these developments occurred during a period of relatively low population density (Hildebrandt and Levulett 1997).

Late Holocene archaeological evidence points to decreasing return rates with concomitant reductions in mobility; especially after 2000-1500 cal B.P. The use of high-ranked marine mammals declined, as more elusive harbor seals and sea otters were hunted (Hildebrandt and Jones 1992; Jones and Hildebrandt 1995). By ~2000 cal B.P. shellfish use increased significantly, and by ~500 cal B.P. coastal hunter-gatherers expanded their diet further to include low-ranked red abalone (Kennedy 2001). Explanations for the intensified use of marine resources has focused on settlement pattern changes due to mounting population pressure in inland regions and the evolution of complex maritime technologies (Hildebrandt and Jones 1992; Hildebrandt and Levulett 2002). Along the shores of northwestern California large sedentary villages emerged and their permanent inhabitants subsisted year round on marine resources (Gould 1975; Hildebrandt and Levulett 2002). These complex societies did not emerge south of Cape Mendocino (Hildebrandt and Levulett 2002; Levulett 1985), although permanent and established seasonal settlements may have existed (Layton 1990; Lightfoot 1992; Lightfoot *et al.* 1991; White 1989).

Sea Mussels and Stable Isotopes

The $\delta^{18}O$ of mollusk shell carbonate depends on SST and the $\delta^{18}O$ of seawater ($\delta^{18}O_w$; related to salinity), and is an established paleothermometer for near-shore SST with seasonal resolution[1] (Craig and Gordon 1965; Epstein *et al.* 1951; Epstein *et al.* 1953).

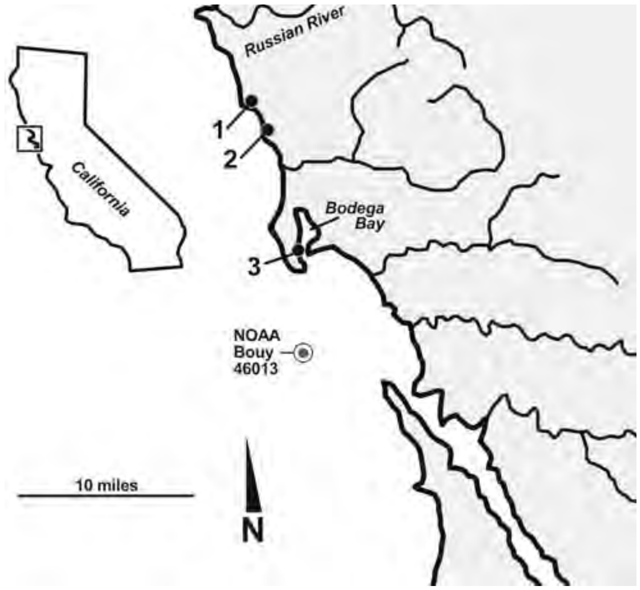


Figure 1: Location map. (1) Duncan's Landing (CA-SON-348/H); (2) Portugese/Schoolhouse Beaches; (3) Bodega Lagoon Site (CA-SON-322).

The $\delta^{18}O$ of archaeological mollusk shells has been used extensively to determine the season of specimen harvest and reconstruct seasonal consumption patterns (e.g. Deith and Shackleton 1988; Jones *et al.* 2002; Kennett and Voorhies 1996; Killingley 1981; Koerper and Killingley 1998; Mannino *et al.* 2003; Shackleton 1973). In general, if $\delta^{18}O_w$ (salinity) remains constant, the terminal margin (or growing edge) of shells harvested in cooler seasons show higher $\delta^{18}O$ (low SST), and margins of shells harvested in warmer seasons exhibit lower $\delta^{18}O$ (high SST).

The $\delta^{13}C$ of *M. californianus* calcite is a potential recorder of dissolved inorganic carbon ($\delta^{13}C_{DIC}$), a geochemical tracer of upwelling[2] (Killingley and Berger 1979). Upwelled waters are relatively cold, and are characterized by depleted $\delta^{13}C_{DIC}$ from the addition of respiratory ^{12}C at depth and high phosphate concentrations due to the remineralization of (light ^{13}C) organic matter. If disequilibrium effects (for example, due to the incorporation of metabolic carbon) are small or can be accounted for, shell $\delta^{13}C$ can be used in combination with $\delta^{18}O$ to trace changes in marine environmental conditions (e.g., Ortiz *et al.* 1996). Shell intervals characterized by relatively high $\delta^{18}O$ (low SST) and low $\delta^{13}C$ suggest periods of upwelling with increased nutrient content and inferred higher marine productivity. Therefore, the $\delta^{18}O$ and $\delta^{13}C$ in *M. californianus* calcite form a high resolution seasonal record of SST, nutrient content and intensity of upwelling over at least one to two years.

METHODS

Modern Calibration/Verification

To test our approach, we first confirmed that shell $\delta^{18}O$ and ^{13}C from *M. californianus* reliably records SST and $\delta^{13}C_{DIC}$ on an annual basis. We measured one to two years of $\delta^{18}O$ and $\delta^{13}C$ measurements in three modern specimens collected live on January 11, 2000 (n=2) and May 10, 2002 (n=1) from Portuguese Beach and School House Beach (PB/SHB) (see Figure 1) to compare with: 1) the modern annual range of SST measured at NOAA Buoy 460133 (Figures 1 and 2) estimates of $\delta^{13}C_{DIC}$ from regional phosphate data[4].

We then confirmed that samples collected from the terminal margin of modern shells with a known collection date record conditions at the time of collection and allow accurate reconstruction of the season of harvest. *M. californianus* specimens were harvested monthly and seawater was collected biweekly for SST, salinity, $\delta^{18}Ow$ (a component of the equation used to calculate temperatures from shell $\delta^{18}O$) and $\delta^{13}C_{DIC}$ at PB/SHB during 2002-2003. Estimated SST and $\delta^{13}C$ from the margin shells was compared with measured SST and $\delta^{13}C_{DIC}$ of seawater from the harvest location. Season of harvest was evaluated by comparing the $\delta^{18}O$ and $\delta^{13}C$ values from terminal margin samples with the values from the modern annual range. Data from one day sampled during the upwelling season (May 10, 2002) are presented here. The rest of the monthly shells are currently being analyzed.

Archaeological Sea Mussel Shells

To establish the annual range of isotopic values typical for each component we measured one to two years of isotope samples (n=57-66) from three *M. californianus* shells from each of three archaeological components located near Bodega Bay (Figure 1). Our hypotheses regarding the annual intensity of shellfish harvest was tested by comparing the annual range of $\delta^{18}O$ and $\delta^{13}C$ values from the three components with the margin samples (n=19-20) from the same component. We make the assumption that the general pattern of upwelling, as measured by the seasonal progression of coincident changes in $\delta^{18}O$ and $\delta^{13}C$ in sea mussel calcite (see below), has remained the same over the last 8500 years despite range variability and changes in their mean values. This permits us to assess season of collection using margin samples for which the annual ranges and means are known.

M. californianus specimens from Duncan's Landing (38⁰23'42"N, 123⁰5'40") were collected from the archived column sample matrix excavated from the Duncan's Point Cave locus by the California Department of Parks and Recreation in 1989. Shells were chosen from levels within Duncan's Point Cave, components 2 (190-260 cm) and 5 (60-100 cm) (Schwaderer 1992). Our mean calibrated charcoal 14C (AMS) ages from each component are 8544±107 cal B.P. (1σ) and 3129±228 cal B.P. (1σ), respectively (Kennedy *et al.* 2004). In addition, *M. californianus* shells were also chosen from soil samples and midden matrix excavated from test units at the Bodega Lagoon site, CASON-322 (38⁰18'58"N, 123⁰3'30"W), by the University of California (UC) Davis, Archaeological Field School in 1998. The Bodega Lagoon site has a calibrated mean charcoal age of 197±109 cal B.P. (1σ) (Kennedy *et al.* 2004).

All shells with annual profiles were radiocarbon dated using accelerator mass spectrometry (AMS). In addition, a random sample of two to seven margin shells, and three to seven charcoal samples from each component were also ^{14}C dated to assess component integrity (see Kennedy *et al.* 2004). Mean calibrated dates for each component were calculated using the intercept (or mean intercepts) of each charcoal ^{14}C age with the atmospheric calibration curve as determined by CALIB version 4.3 (Stuiver and Reimer 1993; Stuiver *et al.* 1998a; Stuiver *et al.* 1998b).

Procedures

Shell valves were sectioned lengthwise and mounted on glass slides to expose a crosssection of the crystalline structure. Calcite samples were removed in 2-mm increments with a 0.5 mm drill bit along the growth axis of annual range shells to establish cyclical patterns of isotopic variation throughout the life of the specimen. Margin samples were removed from the growing edge in the same manner with the assistance of a scalpel. Powdered calcite samples were analyzed for $\delta^{18}O$ and $\delta^{13}C$ using the Fisons isotope mass spectrometer at Dr. Howard Spero's Stable Isotope Laboratory at the UC Davis, Department of Geology.

PRELIMINARY RESULTS

Seasonal Variability in the Modern Ocean: SST and $\delta^{13}C_{DIC}$

The $\delta^{18}O$ and $\delta^{13}C$ in the three modern shells co-vary as expected for a system characterized by seasonal upwelling, with heavier $\delta^{18}O$ (cooler temperatures) associated with lower $\delta^{13}C$ values (Figure 2). In addition, SST estimates[3] based on $\delta^{18}O$ for these specimens agree well with measured SST at NOAA

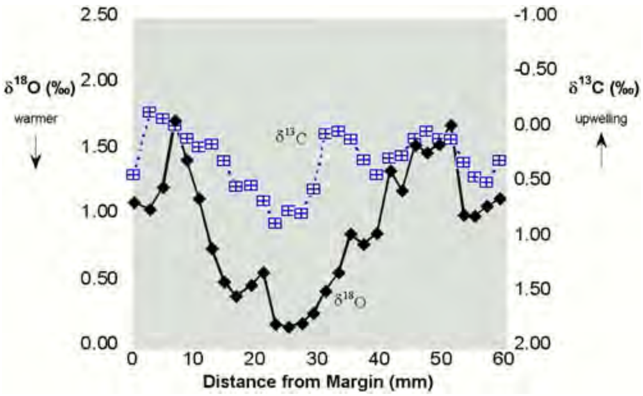
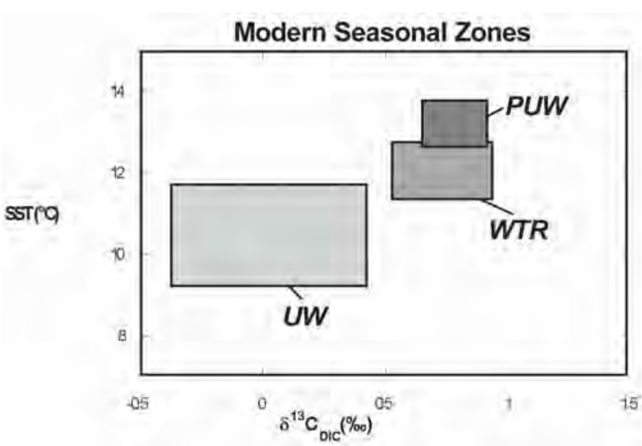


Figure 2: $\delta^{18}O$ and $\delta^{13}C$ profiles from M. californianus *specimen 17-2 collected live on January 11, 2000 from Portugese Beach.*

Buoy 46013 (Kennedy *et al.* 2001). The shell $\delta^{13}C$ values range from -0.42 percent to 0.86 percent, in excellent agreement with the seasonal range (-0.36‰ to 0.90‰) of estimated seawater $\delta^{13}C_{DIC}$ from 1991-1996. Persistent seasonal upwelling is evident in the average SST (NOAA Buoy 46013) and estimated $\delta^{13}C_{DIC}$ for the five-year period from 1991-19965. This seasonal variability results in characteristic seasonal ranges in SST and $\delta^{13}C_{DIC}$ (Figure 3). The upwelling season (May to August) is characterized by minima in both SST and $\delta^{13}C_{DIC}$. In the fall (September to December), upwelling ceases and the water column becomes stratified, resulting in maximum SST and relatively high $\delta^{13}C_{DIC}$. The winter season (January through March) is characterized by intermediate SST and a $\delta^{13}C_{DIC}$ range similar to the fall. As the year progresses, we expect SST and $\delta^{13}C_{DIC}$ values to move clockwise through these zones. Such strong seasonal contrasts in upwelling signals should be recorded in the stable isotope geochemistry of *M. californianus* shells, whose growing margins should register coeval seawater conditions.

Figure 3: Seasonal SST-$\delta^{13}C_{DIC}$ zones in the modern ocean. UW=spring upwelling; PUW=fall post-upwelling; WTR=winter.



Terminal Margin Isotope Values as Season of Death Estimates

We determined the isotopic composition of margin samples from 20 modern shells harvested during the upwelling season (May 10, 2002). The SST estimated6 from mean shell $\delta^{18}O$ was 9.0±.3^{0}C, compared to a measured SST of 9.3^{0}C at the time of collection. The mean shell $\delta^{13}C$ for these samples was .02±.23‰, compared to a measured value of –.17 percent in a seawater sample collected at the same time, both of these values being consistent with upwelling conditions (see Figures 2 and 3). Finally, as predicted, the terminal margin $\delta^{18}O$ and $\delta^{13}C$ values of these twenty samples are significantly lower than the mean annual values (n=80) representing the annual range pooled from three modern shells ($\delta^{18}O$: t=12.3; df=96; p <.0001; $\delta^{13}C$: t=-3.86; df=31; p<.001). These values accurately place the season of harvest in the modern upwelling season SST-$\delta^{13}C_{DIC}$ zone defined from modern seawater parameters (Figure 4).

Ancient Seasonality of Harvest

The $\delta^{18}O$ and $\delta^{13}C$ margin values (n=20) from *M. californianus* shells for the ~8500 cal B.P. component at Duncan's Point Cave are significantly different than the means of the annual samples (n=66) ($\varkappa^2$=7.71; df=1; p<.01). This suggests that the majority of the shells were harvested during the higher-SST/high $\delta^{13}C$ region typical of the warm stratified post-upwelling period along the coast of northern California today (Figure 5). This corresponds to the period from September to December in modern records and suggests a fall harvest. Likewise, the terminal margin values (n=19) from component 5 at Duncan's Point Cave indicate shellfish were harvested during the fall at ~3100 cal B.P., as suggested by the clustering of margin values in the region typical of the warm post-upwelling period along the modern day coast ($\varkappa^2$=15.92; df=1; p<.001) (Figure 6). This is also the case with the margin values (n=19) from the ~200 cal B.P. component at the Bodega Lagoon site ($\varkappa^2$=10.66; df=1; p<.01) (Figure 7). Margin values of several shells from the three components indicate that some specimens (~33%) were collected during the upwelling (May-August) and winter seasons (January-April).

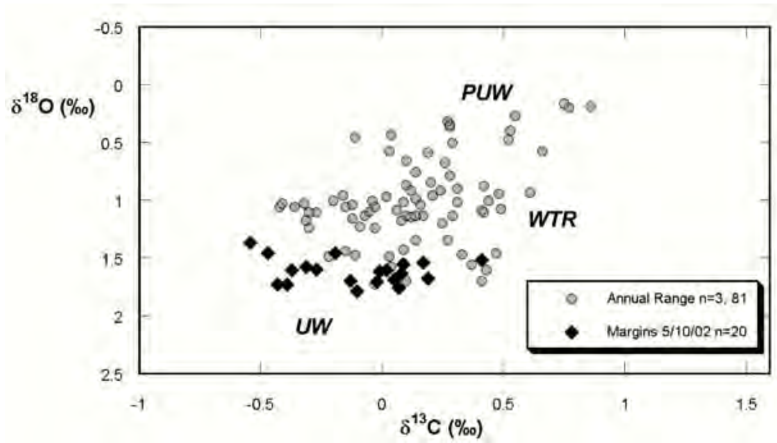


Figure 4: δ^{18}O and δ^{13}C values of M. californianus *specimens collected live on May 10, 2002 from Portugese Beach.*

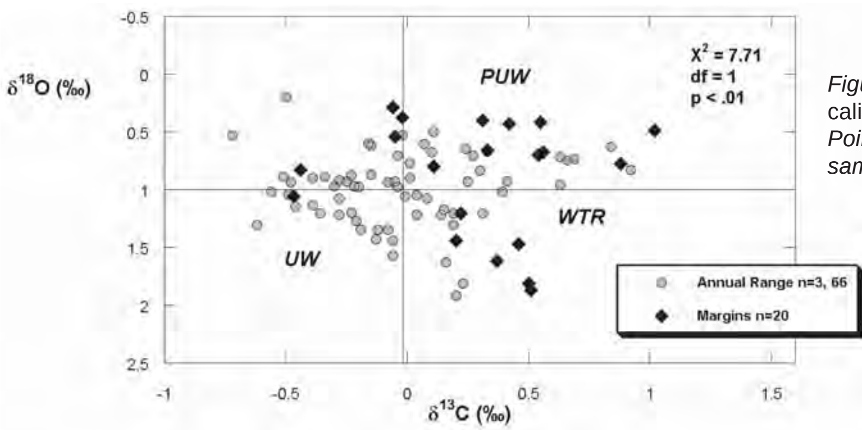


Figure 5: δ^{18}O and δ^{13}C values of M. californianus *specimens from Duncan's Point Cave (CA-SON-348/H), column sample, 190-260 cm, 8544±cal B.P. (1σ).*

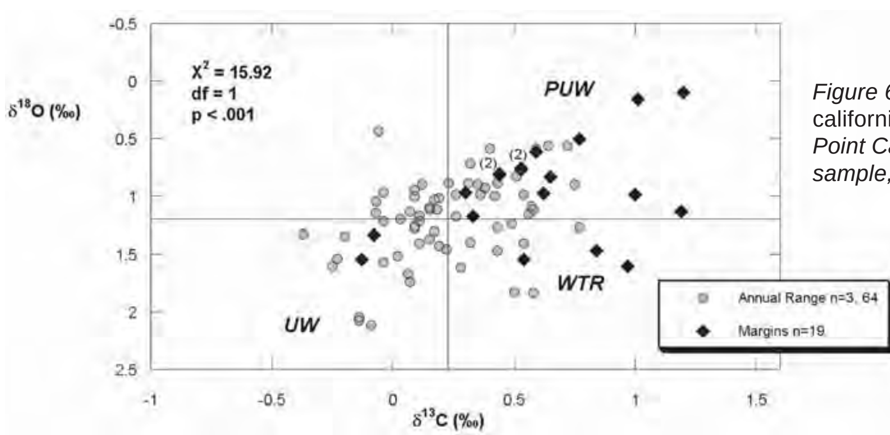


Figure 6: δ^{18}O and δ^{13}C values of M. californianus *specimens from Duncan's Point Cave (CA-SON-348/H), column sample, 60-100 cm, 3129±cal B.P. (1σ).*

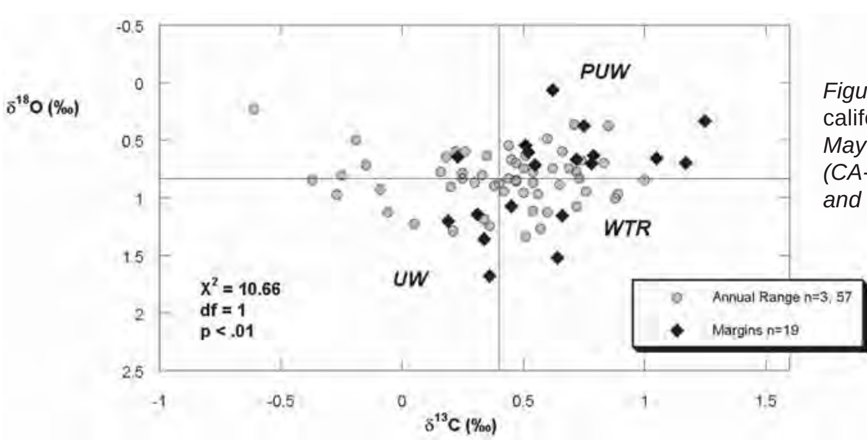


Figure 7: δ^{18}O and δ^{13}C values of M. californianus *specimens collected live on May 10, 2002 from Bodega Lagoon site (CA-SON-322), units B and D (111-115 cm), and unit F (141-150 cm), 197±cal B.P. (1σ).*

DISCUSSION

Modern Sea Mussel Shell $\delta^{18}O$ and $\delta^{13}C$

Our experiments with modern shells indicate that the record of $\delta^{18}O$ and $\delta^{13}C$ in *M. californianus* calcite reliably records ocean conditions (SST and $\delta^{13}C_{DIC}$) at the time of harvest and accurately indicated the season of harvest to be in the upwelling season. This is true because seawater off Bodega Bay is characterized by a strong seasonal signal in both SST and the carbon isotopic composition of $\delta^{13}C_{DIC}$. The interpretation of $\delta^{13}C$ values should be used with caution because seasonal signals may also be influenced by such other factors, such as shellfish metabolism (e.g., Andreasson *et al.* 1999) and phytoplankton blooms (e.g., Kirby *et al.* 1998). Nevertheless, the consistency of the shell and seawater values suggest that the disequilibrium effects on shell $\delta^{13}C$ are minor compared to the contribution of $\delta^{13}C_{DIC}$ during the upwelling season.

Shellfish Harvest Seasons and Marine Resource Intensification

The seasonal nature of shellfish exploitation suggested by our isotope study and the small faunal assemblage from Duncan's Point Cave at ~8500 cal B.P suggest limited use of marine resources by mobile hunter-gatherers. Supporting archaeological evidence from the same component includes the presence of faunal remains from taxa not present near the site today (ducks, coot, geese, clams and oyster) (Schwaderer 1992; Wake and Simons 2000), and a high frequency of exotic lithic materials (Fenenga 1991).

Likewise, data from Duncan's Point Cave component 3 at ~3100 cal B.P indicate shellfish were also only collected seasonally. These two Duncan's Point Cave components were occupied during periods of relatively low population density (see Hildebrandt and Levulett 1997; Jones 1992; Kennedy *et al.* 2001; Lightfoot *et al.* 1991). Certainly, population would have provided little incentive to exploit low-ranked marine resources, such as shellfish, on more than a seasonal basis at ~8500 and ~3100 cal B.P. At the same time, middle Holocene maritime adaptations do appear to be more diverse than previously believed. Recent excavations in the Bodega Dunes for example, have revealed four single component seafood processing loci ^{14}C dated between ~5300-4100 cal B.P. (1σ). Initial stable isotope results from Duncan's Point Cave suggest possible multi-season shellfish use during the same period.

Late Holocene shellfish evidence points to decreasing return rates. Exponential increases in the number of ^{14}C-dated components after ~2000 cal B.P. suggests settlement and population pressure were contributing factors here (see Hildebrandt and Levulett 1997; Hildebrandt and Levulett 2002; Jones 1992; Kennedy *et al.* 2001; Lightfoot *et al.* 1991). Surprisingly, our initial isotopic data do not demonstrate an increase in the number of seasons of harvest at ~200 cal B.P. as would be expected under conditions of marine resource intensification. However, the Bodega Lagoon samples are from a food processing locus associated with the nearby ethnographic and prehistoric settlement *Tokau* (CA-SON-321), thus may represent a season-specific processing location associated with the more permanent settlement. Additional stable isotope sampling of remains from other late Holocene components will help resolve this issue.

PRELIMINARY CONCLUSIONS

Our preliminary modern data indicate that the record of $\delta^{18}O$ and $\delta^{13}C$ in shell calcite of *M. californianus* provides unique and valuable information on the seasonality of shellfish harvest in the Bodega Bay region. In contrast to our archaeological prediction, our initial results suggest that shellfish foraging remained seasonal with harvest occurring predominantly in the fall at ~8500 cal B.P., ~3100 cal B.P. and ~200 cal B.P. This result conflicts with the expected pattern of more year-round use given greater population pressure coupled with decreased foraging return rates. However, our 200 cal B.P. component may be a single-season processing locus associated with a more permanent settlement, and may suggest the seasonal employment of foraging task groups from centralized locations. At this point it is unclear whether this seasonal pattern persists over time, or whether this harvesting strategy involved patterns of movement within regional coastal zones (e.g. between rocky and protected shorelines) or between coastal and inland areas. These issues will be explored when additional *M. californianus* remains from other components in the Bodega Bay region are analyzed for their isotopic composition.

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Endnotes

1. Oxygen isotope compositions are denoted as a per mil (‰) difference relative to a standard; SMOW (Standard Mean Ocean Water) for water and VPDB (Vienna Pee Dee for solid carbonate (shell).

$$\delta^{18}O_{sample} = \left(\frac{[^{18}O/^{16}O]_{sample}}{[^{18}O/^{16}O]_{reference}} - 1 \right) \times 1000$$

2. Carbon isotope compositions for both dissolved inorganic carbon (DIC) and shell are denoted as a per mil (‰) difference relative to VPDB (Vienna Pee Dee Formation).

$$\delta^{13}C_{sample} = \left(\frac{[^{13}C/^{12}C]_{sample}}{[^{13}C/^{12}C]_{reference}} - 1 \right) \times 1000$$

3. SST for the shells was estimated from $d^{18}O$ using Epstein and colleague's (1951, 1953) paleotemperature equation assuming constant salinity (33.5).

4. $d^{13}C_{DIC}$ was estimated from PO4 data (A. van Geen, hppt:/www.ldeo.Columbia.edu/datarep/html) using the relationship reported by Ortiz *et al.* (2000) for 0-200 m in the northeast Pacific: $d^{13}C_{DIC}$=1.6-0.96*PO4; r^2=0.80.

5. This was a comparison between the daily average (1991-1996) of hourly SST (±1s) at NOAA Buoy 46013 (38.2^0N, 123.3^0W), and the average $d^{13}C_{DIC}$ estimated from PO4 measured at Pillar Point (37.5^0N, 122.5^0W) 1991-1996 (see note 4).

6. SST for the *M. californianus* specimens collected on May 10, 2002 was estimated from the mean $d^{18}O$ of the shell margins and salinity at the time of harvest (34.7 PSU) using Epstein and colleague's (1951, 1953) paleotemperature equation.

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