Oxygen Isometry Yields Seasonality Estimates for a Shellfish Sample from CA-ORA-855

Henry C. Koerper and John S. Killingley

Abstract

This study documents the first Orange County application of oxygen isometry to estimate season of death in shellfish. The shellfish seasonality technique has been validated in tests against shellfish specimens with known month of death. $\delta^{18}O$ values for calcite samples from 14 *Mytilus californianus* specimens indicate that shellfish procurement was predominantly a summer to autumn activity at ORA-855, the historic site of Putuidem. Our data do not support the oft-held view that winter was a season of heightened shellfishing occasioned by diminished food stores in lean times. Experimental stable isotope measurements using two *Protothaca staminea* specimens suggest the possibility that these species might be employed to generate seasonal information.

Introduction

In some prehistoric cultures, shellfish constituted a hardship food (Rowley-Conwy 1980; Deith 1983). For the southern California coast, it is often thought that greater reliance on the ever available and easily exploited molluscs during the winter was necessitated by diminished food stores during this "lean" season (e.g., Landberg 1965:76; Hudson 1969:53, 1971:70; Drover 1974:229; Lyneis 1981:4). Winter has been viewed as the season of heightened shellfish procurement in several coastal Orange County settlement scenarios (Hudson 1969:53, 1971:70; Chace 1969:73, 1974; Anderson 1969:53; Lyneis 1981:4; see also Ross 1969) and in some local shellfish seasonality studies (e.g., Weide 1969; Drover 1974; see also Lyons 1978).

A salient component of local subsistence-settlement research design is "scheduling" (e.g., Koerper 1981; de Barros and Koerper 1990; Mason 1991), or the organization and timing of procurement activities when the ecosystem affords a choice of food resources (Flannery 1968). In Orange County archaeology, retrodiction of scheduling has involved visual observation of the sculpted surfaces of *Chione* clams in attempts to determine the season(s) when these largely bay/estuary dwelling invertebrates were exploited (Chace 1969; Weide 1969; Cooley 1971; Drover 1974; Lyons 1978; Howard 1977; Howard and Carter 1975). Visual examination of external shell growth for seasonal determination has also been employed in Los Angeles County (e.g., Carter 1978) and in Santa Barbara County (e.g., Macko 1983). The collective results of these efforts generally supported the notion that much shellfishing activity proceeded during cold months. However, the Drover (1974) and Lyons (1978) seasonality techniques were critiqued in Koerper (1980) and Koerper et al. (1984), respectively, and found problematic.

Live growth studies on *Chione* clams indicate that seasonality determinations are not possible for *Chiones* using external shell features (Cerreto 1988, 1992). Presently, seasonal patterns of procurement for bay/estuary molluscan species remain an enigma.

Weide's (1969) seasonality method applies to *Tivela stultorum* (Pismo clam), a sandy coastal beach species, but Weide did not test the technique against specimens with known seasons of death (Margaret Lyneis, personal communication 1994). Few Orange County shell middens yield Pismo clams in numbers required for meaningful seasonality study.

We have employed stable isotope geochemistry, specifically, oxygen isometry, to analyze calcite samples drilled from the surfaces of shells (see Killingley 1980, 1981). Here we report the results of our stable isotope ($^{18}O/^{16}O$ ratio) mass spectrometer assays to determine season of procurement of 14 *Mytilus californianus* (California mussel) and two *Protothaca staminea* (Littleneck clam) shells recovered from ORA-855, the historically recorded village of Putuidem (Koerper et al. 1988) in the San Juan Capistrano Valley (Fig. 1). Gatherers from Putuidem would have collected mussels from rocky shore locations and clams from sandy beach locations at the open coast after first having followed the San Juan Creek watercourse six kilometers to the Dana Cove region. These two species represent at least 90 percent of the molluscan protein consumed at Putuidem (see Koerper et al. 1988). The data of this study support the hypothesis that at ORA-855 shellfish collecting was probably a predominantly summer and autumn activity.

CA-ORA-855

ORA-855, or Putuidem (see O'Neil and Evans 1980; O'Neil 1988), dates to the latter half of the Late Prehistoric period, as determined by time sensitive artifacts (e.g., Sonoran projectile points-see Koerper and Drover 1983 and Koerper et al. 1996; and Tizon Brown pottery-see Koerper et al. 1978), radiocarbon dates (Koerper et al. 1988), and small hydration values (1.1-2.0 microns) for 18 specimens of Obsidian Butte volcanic glass (Koerper et al. 1986). Seventy-four of the 78 sourced obsidian specimens are from Obsidian Butte, but only four were traded from the Coso Range (Ericson et al. 1989).

Putuidem was occupied during a cold weather downturn known as the Little Ice Age (LIA). The LIA spanned roughly the A.D. 1400-1850 period (Calder 1975; Gribbin and Lamb 1978). A record-by-proxy of prehistoric ocean surface temperatures at Dana Point was secured by measuring the ^{18}O content of calcite from *Mytilus californianus* shells excavated from Putuidem. Surface water temperature was approximately 3.0°C colder than present temperature along the southern California coast, a fact consistent with LIA dating of ORA-855 (Koerper et al. 1985; Koerper et al. 1988). It is these same stable isotope data that are employed here to interpret seasonal pattern of shellfish procurement.

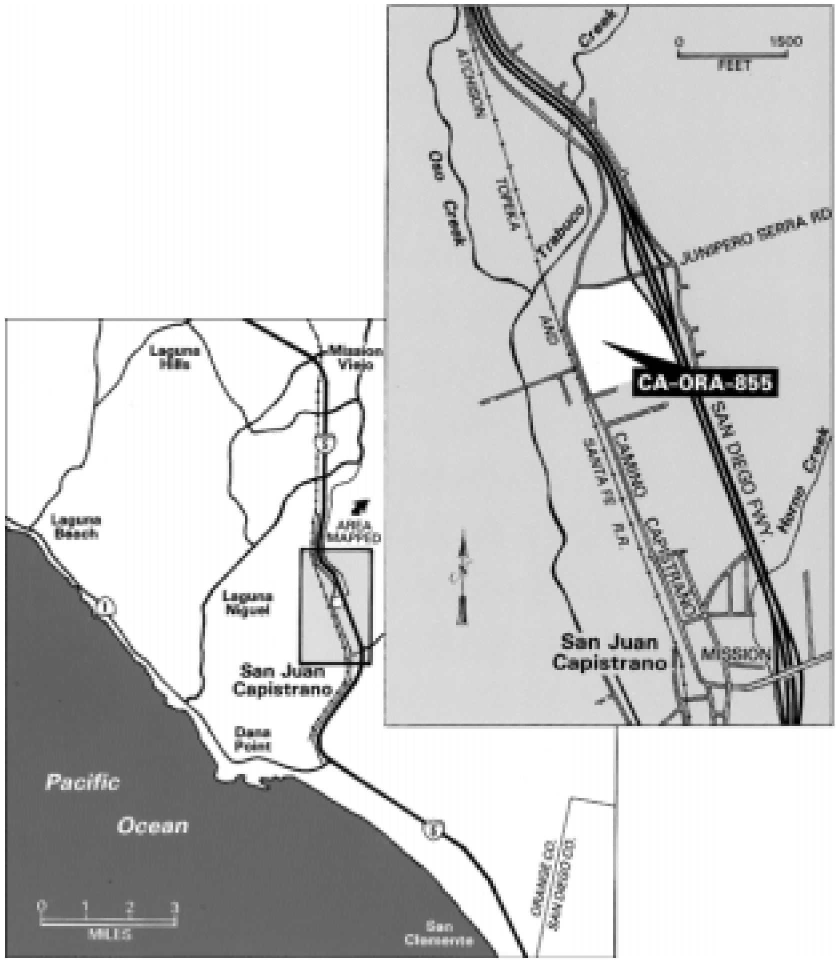

Fig. 1. Location of CA-Ora-855

The great variety of extraction and maintenance tools at Putuidem reflect a multitude of economic activities. A broad base of subsistence resources is reflected in the invertebrate and vertebrate faunal assemblages and in the many plant processing tools. The large numbers of sociotechnic artifacts (especially beads), the several ideotechnic items, seven burial features, and one possible cremation are additional data supporting the ethnohistoric evidence that ORA-855 was a village and not a camp (Koerper et al. 1988).

Background to the Technique

The archaeological purposes to which $^{18}O/^{16}O$ analysis of marine shell is applied (e.g., Shackleton 1969, 1973; Kennett and Voorhies 1996; Kennett et al. 1997) depend upon the isotopic composition of molluscan calcite being temperature dependent (Urey 1947), thus permitting, when certain criteria are met (Shackleton 1973), a record-by-proxy of ocean surface temperatures during the life of the animal (Epstein et al. 1951, 1953; Shackleton

1969). Soon after documentation that *Mytilus californianus* shells reflect changes in ambient water temperature (Killingley and Berger 1979), Killingley (1980) employed mass spectrometry to estimate time of death in prehistoric California mussel shells, later succinctly detailing the requisites necessary to support meaningful seasonality results (1981; see also Bailey et al. 1983 and Killingley 1983).

First, the animal ideally deposits $CaCO_3$ in thermodynamic equilibrium with the ambient water. However, if the carbonate precipitation occurs out of equilibrium but the degree of disequilibrium is constant, relative temperature changes can be generated.

Secondly, there should be no postdepositional changes in the isotopic composition (e.g., exchange of oxygen atoms with those of groundwater). If extraneous oxygen has contaminated the potential sample target, there are methods to remove those oxygen atoms. Contaminate avoidance of several types is discussed below.

Further, the shell must grow throughout the annual temperature range and should live in open water rather than in locally confined areas (e.g., rock pools) where temperature changes would be abnormal. *M. californianus* grows throughout the year in open water. Obviously, shellfish within Newport Bay are confined in varying degrees, and they are not regarded as useful to seasonality study through application of oxygen isometry. Also, reasonable estimates must be available of the oxygen isotopic composition of the ocean water from which the shell is precipitated.

Calcium carbonate is precipitated by molluscs from ions dissolved in sea water. As the reaction occurs, calcium carbonate is enriched in ^{18}O compared to the surrounding solution, with the isotopic fractionation being temperature dependent. In other words, the $^{18}O/^{16}O$ ratio in the water and the water temperature determine $^{18}O/^{16}O$ ratios in shell carbonates.

Increases in sea surface temperature (SST) shift thermodynamic equilibria, causing less of the heavier isotope to be part of the precipitated carbonate. As the shell grows through seasons of cold and warm, ratios of $^{18}O/^{16}O$ vary, being higher in cold months and lower in warm months, thereby providing a record-by-proxy of SSTs and a means to estimate seasonality of archaeologically recovered shells. It is crucial that $^{18}O/^{16}O$ ratios clearly differentiate between carbonates precipitated in summer months and those deposited in winter months. Further, the differential must be great enough that there be no confusion of seasonal fluctuations with short term variations in a shell’s development. With the various requisites addressed for mussels growing along the southern California coast, the object is to first remove calcite samples starting from a shell’s terminal margin.

Sample Selection

Shells selected for stable isotope analysis were characterized by sufficient growth manifested in easily visible contiguous growth increments leading to an intact terminal margin. “Sufficient growth” refers to a record of shell development from the ventral edge toward the umbo that appeared to cover at least one year in the life of the animal. None of the specimens selected gave any evidence of contaminants at the outer surface of the shell save for minor amounts of adhering midden. Of the fourteen *M. californianus* shells that underwent analysis, none was associated with any feature or had any special significance attached to it. They represent a variety of unit level proveniences, tending toward lower depths where shells had escaped damage from farm equipment.

Two *Protothaca staminae* shells were also selected for analysis. They were retrieved from a feature which contained fish remains and many whole *P. staminea* shells. Undoubtedly, the feature is a roasting pit, and the shells likely are from a single event. Thus, it was predicted that the two specimens would evidence seasonal procurement at the same time.

Sample Preparation

Several steps precede removal of calcite samples for analysis by mass spectrometer. Specimens must first be cleaned of debris and extraneous organic material adhering to their surfaces. When shells retain remnants of the periostracum, this contaminant along with debris generally yields to mild washing with water and scraping. For this study, an ultrasonic bath using deionized water proved efficacious. If, after washing, small amounts of organics should remain, and once the shell is thoroughly dry, the same drill used to take the calcite samples, when barely touched to resistant fragments of periostracum, usually causes these organics to tear cleanly away from the shell.

Diagenesis introduces another source of contamination, one that injects an isotopically lighter sample into shell surfaces. Shell surface carbonate is subject to dissolution and subsequent recrystallization (Shackleton 1973; Bailey, et al. 1983). That is, chemical exchange occurs with percolating groundwater. This alteration of a specimen’s isotopic signature is controlled by careful removal of any lighter appearing calcite on the shell surface, again using a dental bit.

Sequential growth increments were sampled beginning at a specimen’s ventral edge and proceeding over the growth surface toward the umbo. The goal was to secure as many samples deemed necessary to exceed at least one annual cycle of growth. A 0.5 mm dental drill reduced calcite samples to a fine powder. Target accuracy depends on locating growth lines using a 10X to 20X binocular microscope. Viewing sampling through the microscope prevented drilling too deeply and contaminating the sample with aragonite.

There are two forms of calcium carbonate ($CaCO_3$) in the crystal lattice of *M. californianus*. An easily distinguished underlying aragonite layer (the nacreous layer) differs from calcite in its orthorhombic crystallization, greater density, and less distinct cleavage; more importantly, aragonite has a different $\delta^{18}O$ enrichment factor than calcite.

Drilling turns calcite into a fine powder which is collected on glassine paper. We recommend that each calcite sample be placed in a gel cap, and each gel cap be put into a Ziploc bag with a white panel that can be labeled with specimen number, sample number, provenience, and any other relevant information.

Sample Measurement

A mass spectrometer is used to determine the proportions of ^{18}O and ^{16}O. Data are reduced by comparison to the isotopic signature of a Cretaceous belemnite from the Pee Dee formation in South Carolina. Belemnite refers to a fossil shell of an extinct cephalopod of the family Belemnitidae.

This international standard, then, provides an arbitrary reference point, or the zero line on the scale, any deviation from which is designated by the "δ" symbol. Deviations are measured in parts per thousand (per mil, ‰). Positive values indicate that a sample contains the heavier isotope, in this case ^{18}O, in excess of the standard, while negative values indicate a depletion of the heavier isotope with respect to the conventional standard.

Measured $\delta^{18}O$ values for a sample taken in sequence develop the profile of changing $^{18}O/^{16}O$ ratios through the growth of a shell. These ratios mirror temperature variation as the shell developed. The profile and especially the reading at the terminal margin of a shell offer the wherewithal to estimate season of death.

During measurement of stable oxygen isotopes, $\delta^{13}C$ values (measured with respect to the PDB) were also established with the mass spectrometer to enable certain corrections to be made to obtain accurate $\delta^{18}O$ values (and vice versa). Data are reduced by comparison to the carbon isotopic signature of the same belemnite standard. Variations in stable carbon isotopes can be due to a variety of causes, including metabolic effects and changes in the ambient $\delta^{13}C$ levels of dissolved carbon in the water from which shell is precipitated. In coastal environs, the dissolved carbon isotopes can be affected by input of terrestrial carbon with a light signal ($\delta^{13}C$ more negative) compared to ocean water (Killingley and Lutcavage 1983). Isotopically light carbon can also be produced during ocean upwelling periods when nutrient rich waters reach the surface (Killingley and Berger 1979). Consideration of the carbon isotopic values presented here, referenced to the temperature fluctuations indicated by the oxygen isotopic values, shows that in some shell specimens there appears to be a spring upwelling signal, but, in general, there does not seem to be a coherent, interpretable, trend in these values. This may imply that terrestrial input variations have "overprinted" the ocean $\delta^{13}C$ signal.

Results

Figures 2 through 5 plot the isotopic values of ^{18}O and ^{13}C for each *Mytilus* shell. These minus and plus values, which are recorded on the vertical axis of these figures, are expressed in the usual $\delta^{18}O$ and $\delta^{13}C$ notations with respect to the PDB standard (represented by the 0.0 value). The measurements are precise to about 0.1‰. The horizontal axis of the several figures represents distance (in mm) away from the terminal margin (death date) of the shellfish.

Plotting the values produces an approximation of a sine wave profile. Evaluations of the isotopic signals, especially those at a shell's terminal margin, take into consideration the fact that range of SST may vary from year to year causing amplitude variations in the plotted $\delta^{18}O$ signals. Further, wave length shortens, a reflection of the fact that less shell is added with increasing age of the mollusc. Wavelengths will vary between shells as a function of age differences between the animals.

Interpretation depends significantly on whether the $\delta^{18}O$ signal is on a trajectory of increase or decrease as the profile of seasonal growth nears the terminal margin, or death "month" of the shell. An increase in the $\delta^{18}O$ signal (profile trajectory descending in our figures) indicates decreasing SSTs, and a decrease in the $\delta^{18}O$ signal (profile trajectory ascending in our figures) indicates warmer SSTs.

Estimated season of procurement accompanies each shell profile figure. Table 1 and Figure 6 summarize the seasonal estimates. Any month designated as a time of shell death is best regarded as a center point of a three month range of possibilities (see Deith 1988). If the fourteen mussel shells are representative of the ORA-855 collection, then *Mytilus* collecting was predominantly a summer and autumn activity.

It appears, preliminarily, that *P. staminea* growth is absent or greatly truncated in the winter (Fig. 7). It may be that the major growth breaks always correspond to a winter break, but this suggestion would have to be substantiated with research on modern shells.

Useful seasonality information might be possible in species that grow only part of the year, providing that the annual "wavelength" is apparent. One concern is that if the range of isotopic variation is small, the "noise" from other effects may be a problem. Another issue is that if the "cool growth," or winter, increment is small, then the observer may miss it in drilling a sample.

The two *Protothaca* shells, specimens 15 and 16, seem to have grown only about 0.5 cm during their final year, making resolution a problem. Smaller, younger, specimens, then, would have been more useful. Tentatively, these limited clam data suggest a July and an August procurement. Given the error factor in the method, it is probable that the two shells were collected at the same time.

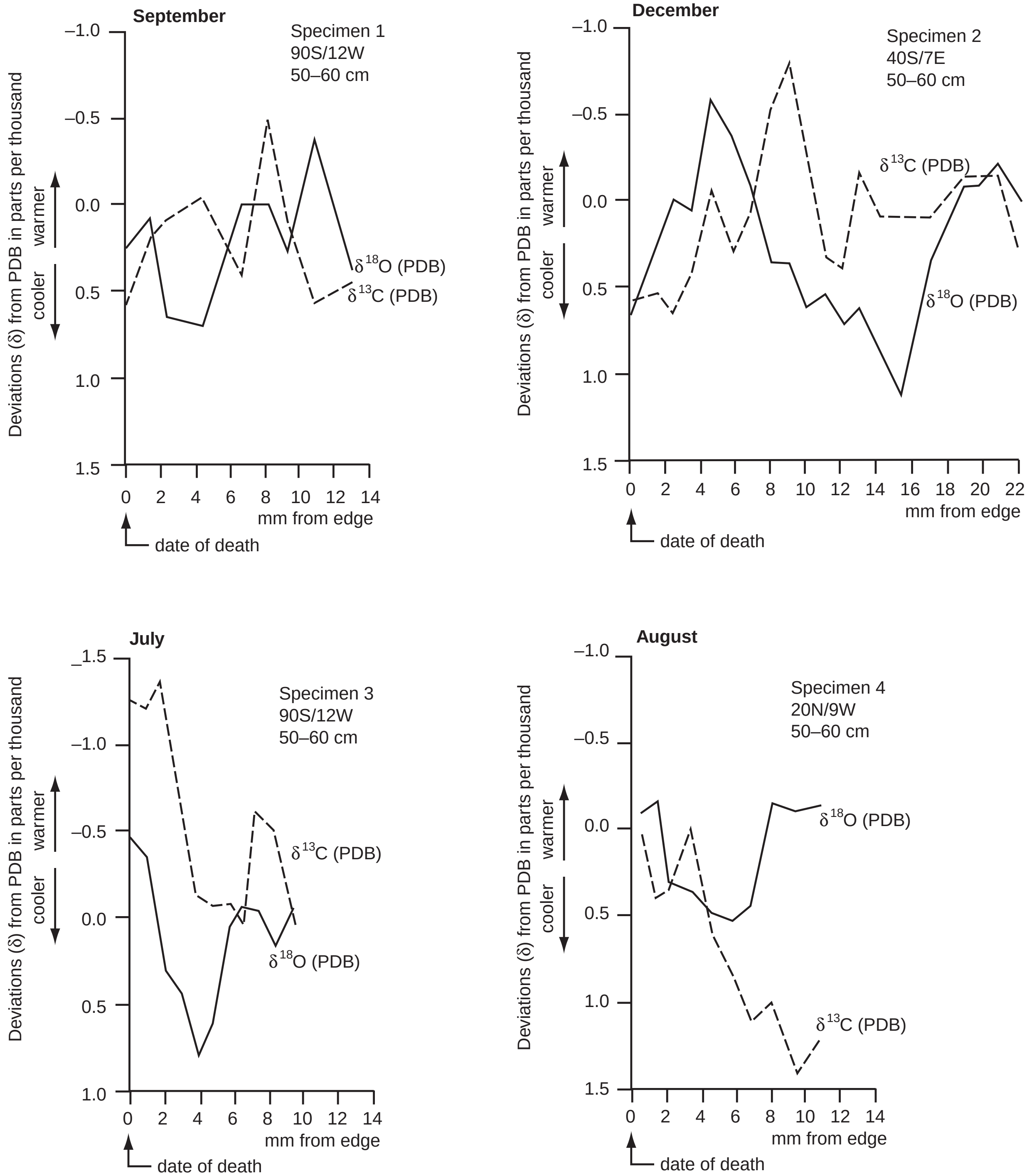

Fig. 2. Seasonality data from *Mytilus californianus*: Specimens 1-4. Per mil values (minus and plus) on the vertical axis are with reference to an international standard (represented by 0.0). The horizontal axis represents distance in mm away from the terminal margin (death date) of the shellfish.

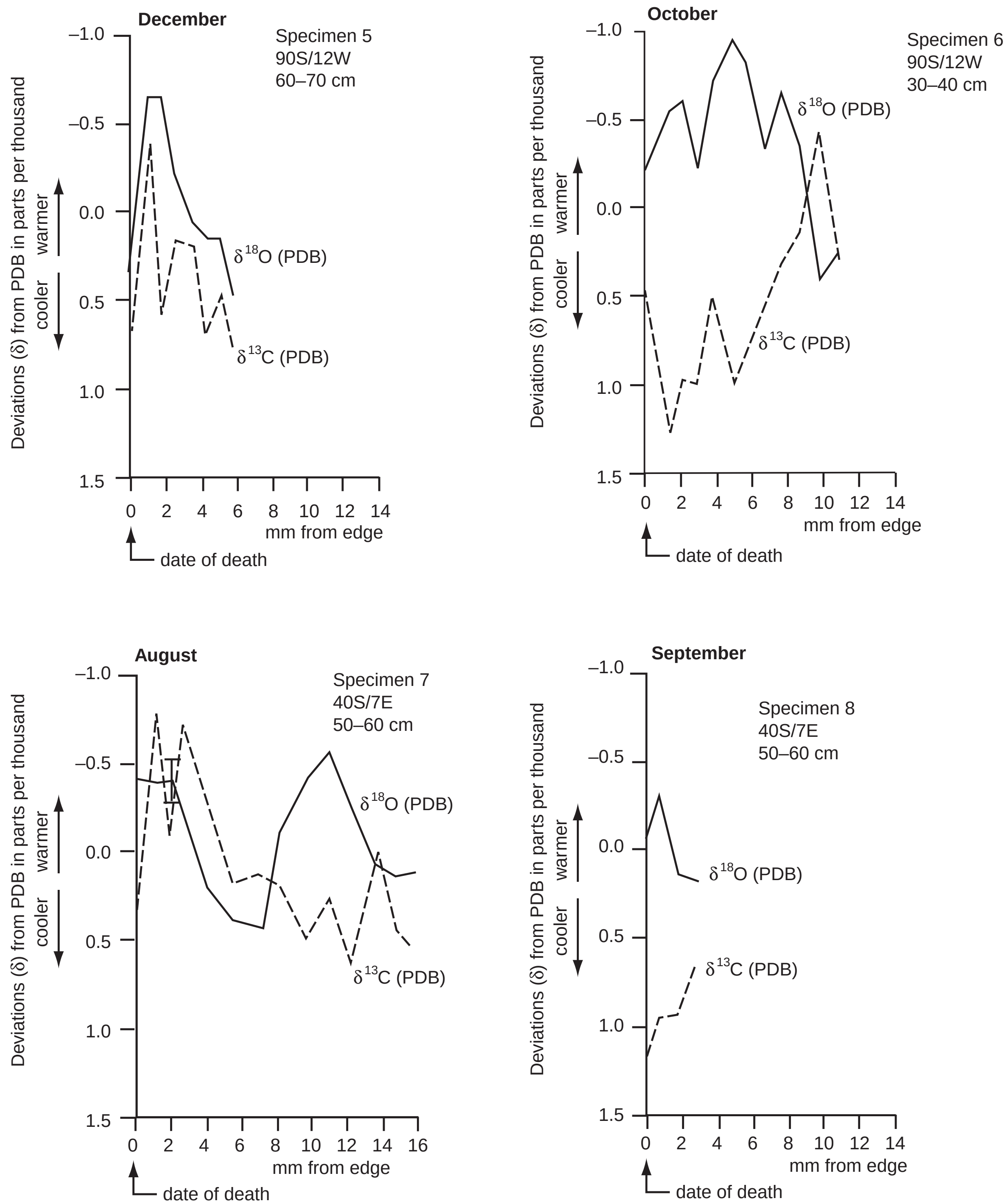

Fig. 3. Seasonality data from *Mytilus californianus*: Specimens 5-8. Per mil values (minus and plus) on the vertical axis are with reference to an international standard (represented by 0.0). The horizontal axis represents distance in mm away from the terminal margin (death date) of the shellfish.

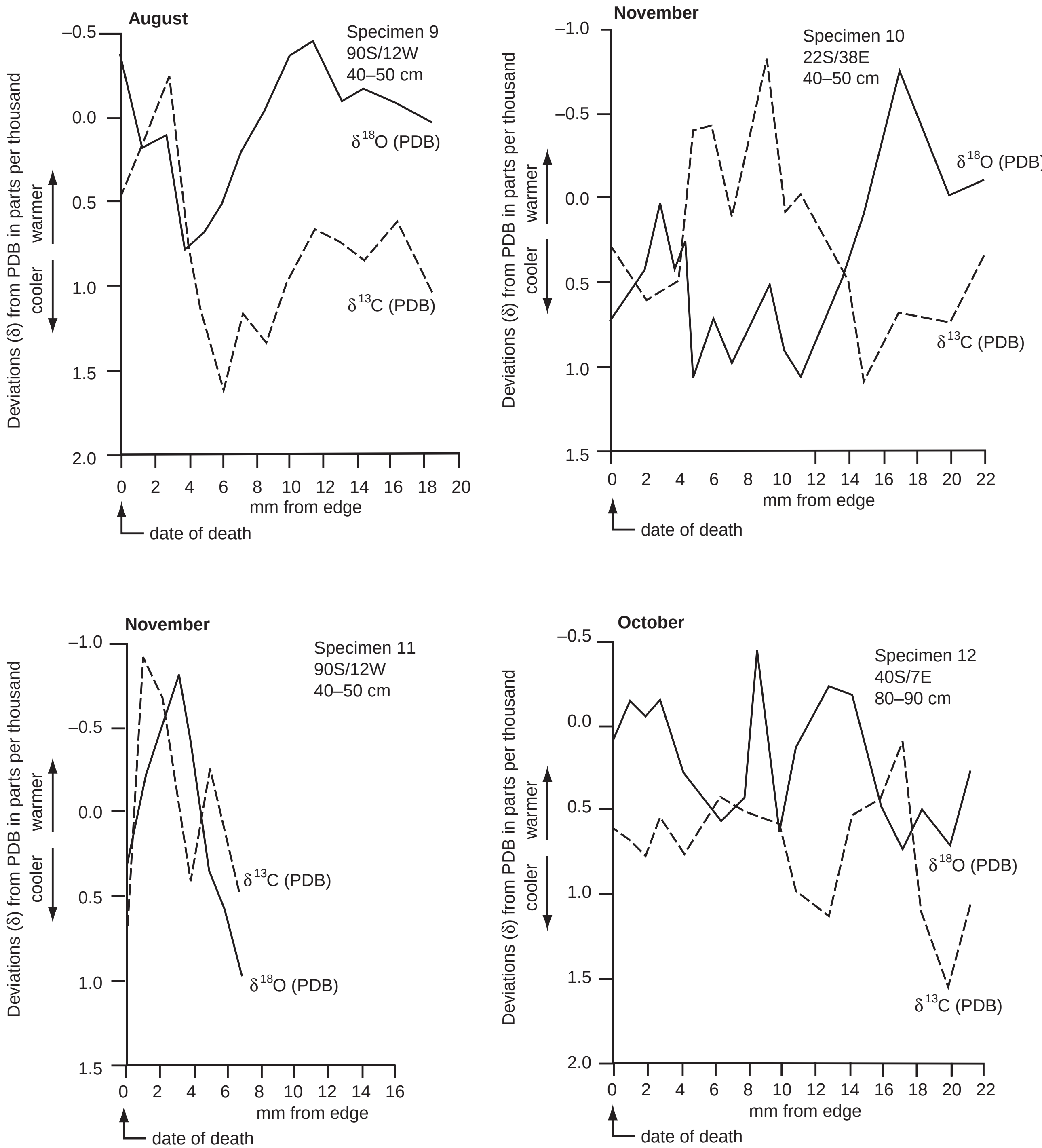

Fig. 4. Seasonality data from *Mytilus californianus*: Specimens 9-12. Per mil values (minus and plus) on the vertical axis are with reference to an international standard (represented by 0.0). The horizontal axis represents distance in mm away from the terminal margin (death date) of the shellfish.

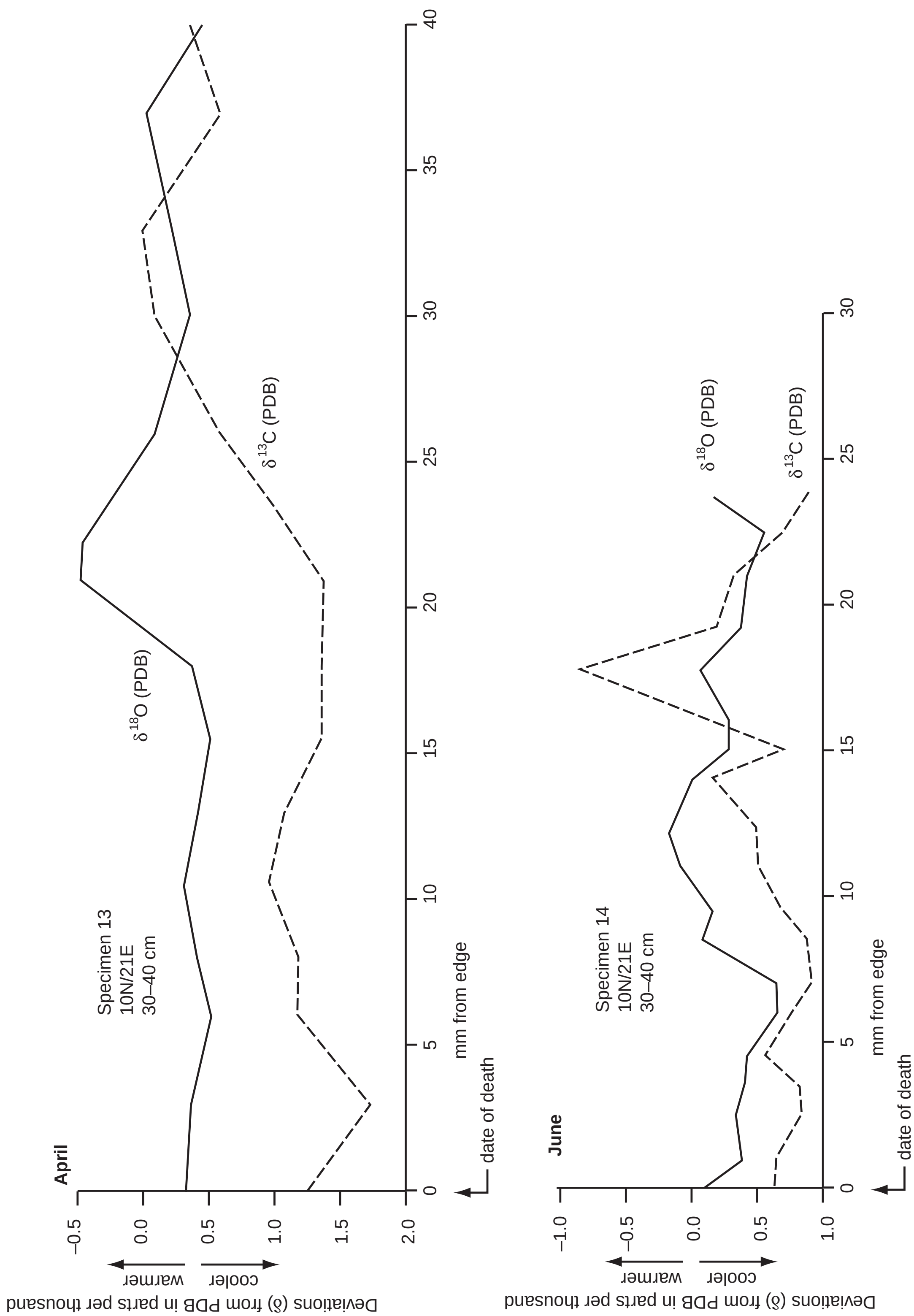

Fig. 5. Seasonality data from *Mytilus californianus*; Specimens 13 and 14. Per mil values (minus and plus) on the vertical axis are with reference to an international standard (0.0). The horizontal axis represents distance in mm away from the terminal margin (death date).

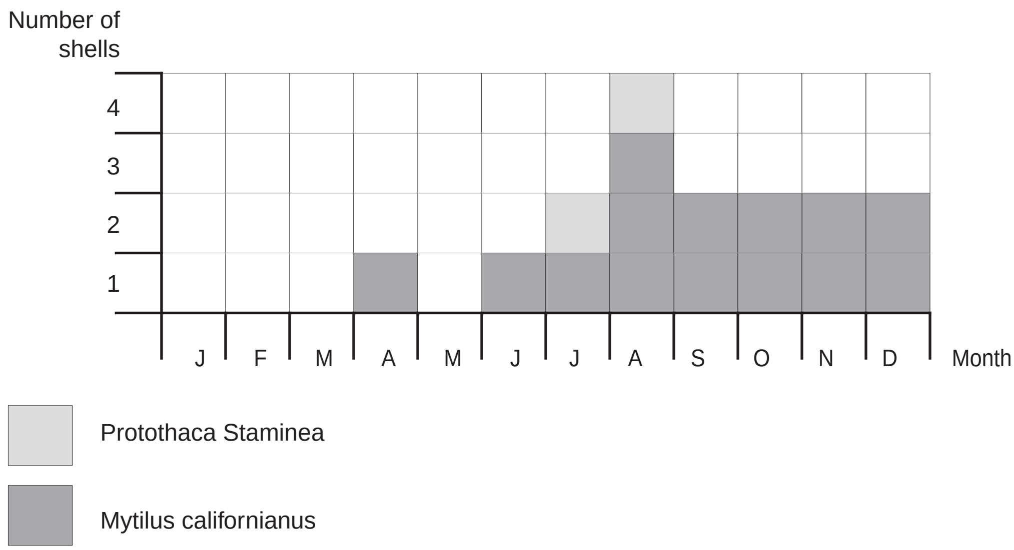

Fig. 6. Seasonality plots by month.

Table 1. CA-Ora-855 Seasonality Data.

Specimen Number	Material	Provenience, Unit	Provenience, Level	Seasonal Determination
1	Mytilus	90S/12W	50–60cm	September
2	Mytilus	40S/7E	50–60cm	December
3	Mytilus	90S/12W	50–60cm	July
4	Mytilus	20N/9W	50–60cm	August
5	Mytilus	90S/12W	60–70cm	December
6	Mytilus	90S/12W	30–40cm	October
7	Mytilus	40S/7E	50–60cm	August
8	Mytilus	40S/7E	50–60cm	September
9	Mytilus	90S/12W	40–50cm	August
10	Mytilus	22S/38E	40–50cm	November
11	Mytilus	90S/12W	40–50cm	November
12	Mytilus	40S/7E	80–90cm	October
13	Mytilus	10N/21E	30–40cm	April
14	Mytilus	10N/21E	30–40cm	June
15	Protothaca	40S/20W	60–70cm	July
16	Protothaca	40S/20W	60–70cm	August

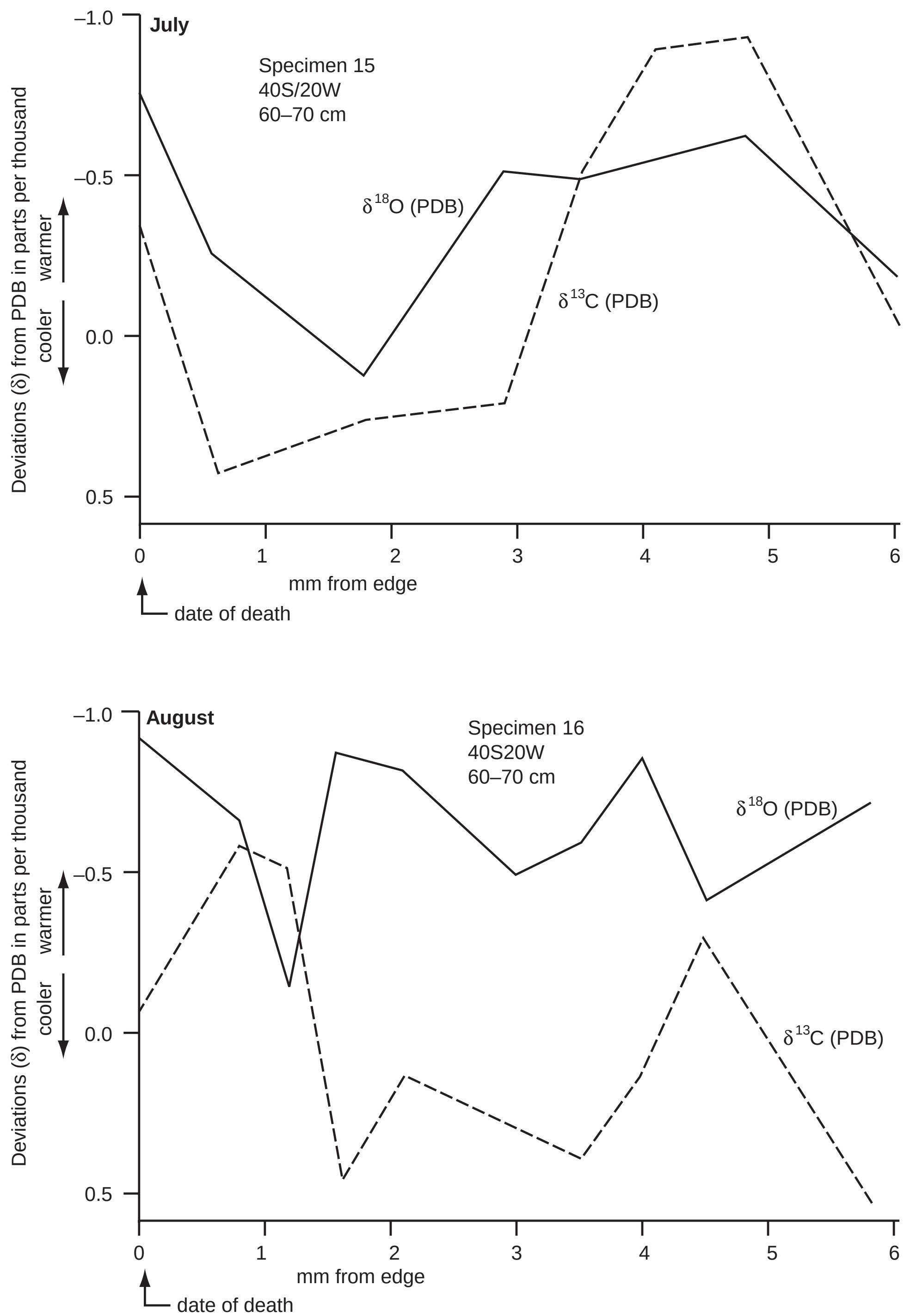

Fig. 7. Seasonality data from *Protothaca staminea*: Specimens 15 and 16. Per mil values (minus and plus) on the vertical axis are with reference to an international standard (represented by 0.0). The horizontal axis represents distance in mm away from the terminal margin (death date) of the shellfish.

Summary and Concluding Remarks

Of archaeologically recovered food evidence, saltwater molluscan remains, which preserve well, may provide the most reliable seasonality data. Deith (1985:119) points out that taphonomic processes are kinder to shell than to bone. Deith further notes the following: 1) shellfish are available throughout the year; 2) consumption generally occurs almost simultaneous to the time of their gathering and death, or, in other words, they are unlikely to have been stored for future use; 3) their relative immobility means that natural deaths occur within the intertidal zone; their presence at archaeology sites is almost certainly attributable to human activity since most other mammals have no interest in shellfish.

The only presently reliable seasonality method employing southern California molluscan species and tested against knowns is stable isotope analysis, and, so far, oxygen isometry does not support the old conventional view that winter was the season of heightened shellfish procurement in coastal Orange County or other locations along the southern California and Baja California coasts. At ORA-855, mussel collecting seems to have been predominantly a summer and autumn activity. Previously, for LC-219 (Punta Minitas) in Baja California, Killingley (1980:20) showed that mussel collecting "was most probable in mid-summer and least likely in fall and winter." A subsequent investigation of 29 *Mytilus* shells from ORA-660, -662, -667, and -674 indicate Late Summer/Early Fall and Late Spring/Early Summer shellfish procurement (Ericson 1993). Ericson's sample included remains from Millingstone and Late Prehistoric sites. The most recent Orange County efforts (Dunbar et al. 1998) utilized nine 4,000 year old mussel shells from ORA-1429, a Los Trancos Canyon fishing camp (see Chace 1995), eight middle Late Prehistoric specimens from ORA-1404 located at Muddy Canyon, and three early Millingstone period shells from ORA-64 at Newport Bay. Again, the data do not indicate a quickened pace for rocky shores shellfishing during the coldest months.

This kind of periodicity of procurement is perhaps linked to the possibility that shellfish gathering was an adjunct of fishing, which is less productive under winter conditions. If so, forays into the marine zone may have been less frequent during the winter.

Analysis of 25 fish otoliths from ORA-855 reveals all but one were from the summer season (mid-May to early October) (Huddleston 1988). Mid-October to early May is "winter" in the parlance of otolith studies. Other Orange County otolith data likewise correlate cold months with reduced fishing (Koerper 1981, 1995; Mason et al. 1997). The caveat here is that otoliths recovered from local sites are predominantly from near shore species, and it is not certain, say, that pelagic fishes were not being taken during winter.

Increased discomfort from cold may have made winter fishing and shellfishing less appealing to Little Ice Age inhabitants at Putuidem. Sea surface temperatures averaging 3°C cooler than today's temperatures characterized shellfish habitats when ORA-855 was occupied (Koerper et al. 1985).

Winter was unlikely to have been lean in terms of animal protein. Rabbits would have been abundant and easily taken with a variety of capture techniques, and deer would have been available (P. Langenwalter, personal communication 1995).

Parenthetically, the mussel-poison dinoflagellate, *Gonyaulax catenella* ("red tide"), may have had little or no effect on seasonal patterns of shellfishing. South of Point Concepcion, this particular "red tide" is extremely rare (Hinton 1969:37). "Red tide" conditions due to excessive phytoplankton production are more likely in the spring and early summer, thus winter drop-offs or absence of *Mytilus* collection can not be accounted for by "red tide" blooms (Killingley 1980:22).

The application of $^{18}O/^{16}O$ analysis using two *Protothaca staminea* specimens points up the possibility that similar stable isotope analysis might be used productively with this species as well as other kinds of clams. We hope that studies such as this one will encourage others in the archaeological community who have not already done so to pursue seasonality determinations by $^{18}O/^{16}O$ assay of calcite from mollusc shells.

Acknowledgments

We appreciate the efforts of several persons including Pat Lynch who rendered Figure 1 and Vicki Solheid and Chris Padon who designed Figures 2-7. We acknowledge the comments of Paul Chace and members of the PCAS editorial board. The assistance of Carole Magnusson, Pete J. Slota, R. E. Taylor, Christine Prior, and Louis A. Payen was invaluable. Our work was supported in part by the National Science Foundation (OCE 83-14984 [J. S. Killingley] and BNS 82-11804 [R. E. Taylor]) and funding from Saffell and McAdam, Inc., Irvine, California.

References Cited

Anderson, Catherine
1969 The North Bay #1 Site (ORA-193). *Pacific Coast Archaeological Society Quarterly* 5(2):1-63.

Bailey, Geoffrey N., Margaret R. Deith, and Nicholas J. Shackelton
1983 Limitations of Oxygen Isotope Analysis for Seasonality Determinations: A Comment on Killingley's Method. *American Antiquity* 48(2):390-398.

Calder, Nigel
1975 *The Weather Machine*. The Viking Press, New York.

Carter, Christina
1978 Seasonality Analysis of CA-LAn-702. *Pacific Coast Archaeological Society Quarterly* 14(2):52-56.

Cerreto, Richard

1988 A Test of Three Shellfish Seasonality Methods: Preliminary Results. *Journal of California and Great Basin Anthropology* 10(2):261-265.

1992 The Implications of Non-Periodic Growth of Bivalves for Three Seasonality Methods Used by Southern California Archaeologists. *Journal of California and Great Basin Anthropology* 14(2):216-233.

Chace, Paul G.

1969 Biological Archaeology of Some Coastal Middens, Orange County, California. *Pacific Coast Archaeological Society Quarterly* 5(2):65-75.

1974 Redating the Buck Gully Site, with Implications for Settlement Patterns, *Pacific Coast Archaeological Society Quarterly* 10(3 and 4):99-113.

1995 'Of the Old Summer Fishing Camp'—The Archaeological Heritage of ORA-1429, Los Trancos Canyon, Crystal Cove State Park; The Pacific Coast Highway - System 47 Site, Orange County, California. Report prepared for The County of Orange Environmental Management Agency Public Works, Construction Administration. Report on file at the South Central Coastal Archaeological Information Center, Institute of Archaeology, University of California, Los Angeles.

Cooley, Theodore G.

1971 Macro and Microscopic Analysis of *Chione undatella*: A Feasibility Study. Manuscript on file, Pacific Coast Archaeological Society Library.

de Barros, Philip and Henry C. Koerper

1990 Final Test Investigation Report and Request for Determination of Eligibility for 23 Sites Along the San Joaquin Hills Transportation Corridor, Vol. I. Report on file, Transportation Corridor Agencies, Costa Mesa, California.

Deith, Margaret R.

1983 Seasonality of Shell Collecting Determined by Oxygen Isotope Analysis of Marine Shells from Asturian Sites in Cantabria. In *Animals and Archaeology 2. Shell Middens, Fishes and Birds*, edited by C. Grigson and J. Clutton-Brock, pp. 67-76. BAR International Series S183. Oxford.

1985 Seasonality from Shells: An Evaluation of Two Techniques for Seasonal Dating of Marine Molluscs. In, *Paleobiological Investigations Research Design, Methods and Data Analysis*, edited by N. R. J. Fieller, D. D. Gilbertson, and N. G. A. Ralph, pp. 119-130. BAR International Series 266. Oxford.

1988 Shell Seasonality: An Appraisal of the Oxygen Isotope Technique. In, *Environmental Analysis in Old and New World Archaeology*, edited by R. E. Webb,pp. 37-49. BAR International Series 416. Oxford.

Drover, Christopher E.
1974 Seasonal Exploitation of *Chione* Clams on the Southern California Coast. *The Journal of California Anthropology* 1(2):224-232.

Dunbar, Robert, Henry C. Koerper, David Mucciarone, and Michael Macko
1998 $^{18}O/^{16}O$ Study of *Mytilus californianus* Shells Exhumed at the Irvine Site (CA-ORA-64) and CA-ORA-1429. Paper presented at the 63rd Annual Meeting of the Society for American Archaeology, Seattle.

Epstein, S., R. Buchsbaum, H. A. Lowenstam, and H. C. Urey
1951 Carbonate-water Isotopic Temperature Scale. *Bulletin of the Geological Society of America* 62:417-426.
1953 Revised Carbonate-water Isotopic Temperature Scale. *Bulletin of the Geological Society of America* 64:1315-1326.

Ericson, Jonathan E.
1993 Appendix C. Seasonality of Marine Shellfish Death for Sites on the Newport Coast Archaeological Project Determined by Oxygen Isometry. In, Newport Coast Archaeological Project, Newport Coast Settlement Systems: Summary and Discussion, Vol. II: Technical Appendices, edited by Roger D. Mason and Mark L. Peterson. Report on file, University of California Irvine Library Special Collections.

Ericson, Jonathan E., Henry C. Koerper, Christopher E. Drover, and Paul E. Langenwalter II
1989 Advances in Obsidian Hydration Dating and Obsidian Exchange in Prehistoric Orange County. *Pacific Coast Archaeological Society Quarterly* 25(2):45-60.

Flannery, Kent V.
1968 Archaeological System Theory and Early Mesoamerica. In, *Anthropological Archaeology in the Americas*, edited by B. J. Meggars, pp. 67-87. Anthropological Society of Washington. Washington, D.C.

Gribbin, John and Hubert H. Lamb
1978 Climatic Change in Historical Times. In, *Climatic Change*, edited by J. Gribbin, pp. 68-82. Cambridge University Press, London.

Hinton, Sam
1969 *Seashore Life of Southern California, California Natural History Guides, No. 26*. University of California Press, Los Angeles.

Howard, Jerry
1977 Seasonality and Settlement Patterns in the Orange County Coastal Foothills. *Pacific Coast Archaeological Society Quarterly* 13(2):11-21.

Howard, Jerry and Christine Carter
1975 Excavations of the Spyglass Hill Sites, CA-ORA-202 and CA-ORA-203, in Orange County, California. Manuscript on file, Pacific Coast Archaeological Society Library.

Huddleston, Richard
1988 Appendix J. Seasonality Analysis of Fish Otoliths. In, The Putuidem Project: Archaeological Investigations at CA-ORA-855, Vol. III, by H. C. Koerper, P. E. Langenwalter and A. Schroth. Report on file, City of San Juan Capistrano, California.

Hudson, Dee T.
1969 The Archaeological Investigations During 1935 and 1937 at ORA-237, ORA-238, and ORA-239, Santiago Canyon, Orange County, California. *Pacific Coast Archaeological Society Quarterly* 5(1).
1971 Proto-Gabrielino Patterns of Territorial Organization in South Coastal California. *Pacific Coast Archaeological Society Quarterly* 7(2):49-76.

Kennett, Douglas J. and Barbara Voorhies
1996 Oxygen Isotopic Analysis of Archaeological Shells to Detect Seasonal Use of Wetlands on the Southern Pacific Coast of Mexico. *Journal of Archaeological Science* 23:689-704.

Kennett, Douglas J., B. Lynn Ingram, Jon M. Erlandson, and Phillip Walker
1997 Evidence for Temporal Fluctuations in Marine Radiocarbon Reservoir Ages in the Santa Barbara Channel, Southern California. *Journal of Archaeological Science* 24:1051-1059.

Killingley, John S.
1980 Seasonality of Mollusk Collecting at Hubb's Midden Site 1959: VI: 28A. *Pacific Coast Archaeological Society Quarterly* 16(4):19-23.
1981 Seasonality of Mollusk Collecting Determined from O-18 Profiles of Midden Shells. *American Antiquity* 46(1):152-158.
1983 Seasonality Determination by Oxygen Isotopic Profile: A Reply to Bailey et al. *American Antiquity* 48(2):399-403.

Killingley, John S. and Wolfgang H. Berger
1979 Stable Isotopes in a Mollusk Shell: Detection of Upwelling Events. *Science* 205(4402):186-188.

Killingley, John S. and Molly Lutcavage
1983 Loggerhead Turtle Movements Reconstructed from ^{18}O and ^{13}C Profiles from Commensal Barnacle Shells. *Marine Estuarine, Coastal and Shelf Science* 16:345-349.

Koerper, Henry C.
1980 Comment on Drover's Proposed Seasonality Method. *Journal of California and Great Basin Anthropology* 2(1):137-140.
1981 Prehistoric Subsistence and Settlement in the Newport Bay Area and Environs, Orange County, California. Ph.D. dissertation, University of California, Riverside.
1995 The Christ College Project: Archaeological Investigations at CA-ORA-378, Turtle Rock, Irvine, California. Report Prepared for Fieldstone Communities, Inc., Newport Beach. Report on file at the South Coastal Archaeological Information Center, Institute of Archaeology, University of California, Los Angeles.

Koerper, Henry C., Richard Cerreto, and Karl Reitz
1984 Cautionary Notes on the Use of a Statistical Method of Seasonality Determination from *Chione undatella* Shells. *Pacific Coast Archaeological Society Quarterly* 20(3):67-75.

Koerper, Henry C. and Christopher E. Drover
1983 Chronology Building for Coastal Orange County: The Case from CA-ORA-119-A. *Pacific Coast Archaeological Society Quarterly* 19(2):1-34.

Koerper, Henry C., Christopher E. Drover, Arthur E. Flint and Gary Hurd
1978 Gabrielino Tizon Brown Pottery. *Pacific Coast Archaeological Society Quarterly* 14(3):43-58.

Koerper, Henry C., Jon E. Ericson, Christopher E. Drover, and Paul E. Langenwalter II
1986 Obsidian Exchange in Prehistoric Orange County. *Pacific Coast Archaeological Society Quarterly* 22(1):33-69.

Koerper, Henry C., John S. Killingley, and R. E. Taylor
1985 The Little Ice Age and Coastal Southern California Human Economy. *Journal of California and Great Basin Anthropology* 7(1):99-103.

Koerper, Henry C., Paul E. Langenwalter II, and Adella Schroth
1988 The Putuidem Project: Archaeological Investigations at CA-ORA-855. 3 Vols. Report on file, City of San Juan Capistrano, California.

Koerper, Henry C., Adella B. Schroth, Roger D. Mason, and Mark L. Peterson
1996 Arrow Projectile Point Types as Temporal Types: Evidence from Orange County, California. *Journal of California and Great Basin Anthropology* 18(2):258-283.

Landberg, Leif C. W.
1965 The Chumash Indians of Southern California. *Southwest Museum Papers* 19. Los Angeles.

Lyneis [Weide], Margaret M.
1981 Excavations at ORA-193, Newport Bay, California. *Pacific Coast Archaeological Society Quarterly* 17(2 and 3):1-80.

Lyons, Edward E.
1978 A Statistical Method of Seasonality Determination from *Chione undatella* (Sowerby), *Pacific Coast Archaeological Society Quarterly* 14(4):33-41.

Macko, Michael E.
1983 Beads, Bones, Baptisms, and Sweat Lodges: Analysis of Collections From "Elijman" (CA-SBa-485), A Late Period Ynezeño Chumash Village in the Central Santa Ynez Valley, California. Master's thesis, University of California, Santa Barbara.

Mason, Roger D.
1991 Newport Coast Archaeological Project. Project Background and Research Design. The Keith Companies, Costa Mesa. Report on file, Office of Historical and Cultural Programs, Orange County Environmental Management Agency, Santa Ana.

Mason, Roger D., Henry C. Koerper, and Paul E. Langenwalter II
1997 Middle Holocene Adaptations on the Newport Coast of Orange County. In, Archaeology of the California Coast During the Middle Holocene, edited by J. M. Erlandson and M. A. Glassow, pp. 35-60. *Perspectives in California Archaeology, Vol. 4*, Institute of Archaeology, U.C.L.A.

O'Neil, Stephen
1988 Their Mark Upon the Land: Native American Place Names in Orange County and Adjacent Areas. In, *The Natural and Social Sciences of Orange County*, edited by Henry C. Koerper, pp.106-122. Memoirs of the Natural History Foundation of Orange County, Vol. 2. Newport Beach, California.

O'Neil, Stephen and Nancy H. Evans
1980 Notes on Historical Juaneño Villages and Geographical Features. *Journal of California and Great Basin Anthropology* 2(2):226-232.

Ross, Lester A.
1969 The Irvine Complex: A Late Prehistoric Horizon Archaeological Complex for the Newport Bay Area, California. Master's thesis, Washington State University, Pullman.

Rowley-Conwy, P. A.
1980 Continuity and Change in the Prehistoric Economies of Denmark 3700 BC-2300 BC. Ph.D. dissertation, University of Cambridge.

Shackelton, Nicholas J.
1969 Marine Molluscs in Archaeology. In, *Science in Archaeology*, edited by D. Brothwell and E. S. Higgs, pp. 407-414. Praeger Publishers, New York.
1973 Oxygen Isotope Analysis as a Means of Determining Season of Occupation of Prehistoric Midden Sites. *Archaeometry* 15:133-141. Oxford University, Oxford.

Urey, Harold C.
1947 The Thermodynamic Properties of Isotopic Substances. *Journal of the Chemical Society* pp. 562-581. London.

Weide, Margaret L.
1969 Seasonality of Pismo Clam Collecting at ORA-82. *University of California, Los Angeles, Archaeological Survey, Annual Report No. 11*, pp. 127-141.