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Reliability Assessment of Season-of-Capture Determination from Archaeological Otoliths

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Abstract.—A technique involving microscopic examination of otolith growth zones has been commonly used by archaeologists along the coast of California to estimate season-of-capture of prehistoric fishes and to infer the season of site use. A test of otolith edge analysis techniques was performed on modern otoliths by estimating season-of-capture for otoliths with known dates of capture. Successful identification of season-of-capture was low, even in a best case scenario with the age-validated spotted sand bass (*Paralabrax maculatofasciatus*), emphasizing the subjectivity of this kind of analysis and inherent variability of growth zone formation in otoliths. Alteration of the otolith matrix from environmental factors further complicates the determination for archaeological otoliths, but surfperches (family Embiotocidae) hold promise for future studies. This study has called into question the validity of protocols that have not utilized age validated otolith collections and begs caution when estimating season-of-capture from otoliths.

Evaluations of site seasonality are an important component of archaeological research in North America (Monks 1981; Bettinger 1991; Kelly 1995). For areas such as California that were inhabited by hunter-gatherers, estimates of archaeological site seasonality provide critical insights into the relative mobility of foraging communities. Estimates of the seasonality of occupation have been developed from a variety of indices in California including the remains of migrating shorebirds and marine mammals (Howard 1929; Hildebrandt 1993), visual analysis of growth increments in shellfish remains (Cerreto 1992; Lyons 1978), analysis of oxygen isotopes in molluscan remains (Killingley 1981; Kennett 2003), and investigation of annual growth zones in deer teeth (O'Brien 2001; Moffitt 2002). Casteel (1976) suggested that fish otoliths might be useful in this context because of their extensive use in fishery biology and, in particular, age estimation in fishes (Huyghebaert and Nolf 1979; Nolf 1985). Periodic deposition of growth zones in otoliths has been attributed to temperature, feeding, spawning, seasonal changes and other causes (Beckman and Wilson 1995). In general, favorable growing conditions lead to the formation of an opaque growth zone and a period of poor conditions leads to a translucent growth zone (Pannella 1980), but this trend has not been firmly established for all species of marine fishes. Smith (1983) used the huge otoliths of black drum (*Pogonius cromis*) from an archaeological site in Texas to determine the season-of-capture, and in the most elaborate use of otoliths for seasonality determination to date, Higham and Horn (2000) demonstrated seasonal capture of red cod (*Pseudophycis bachus*) in New Zealand.

For numerous archaeological sites along the coast of California, a technique developed and applied by Huddleston (1981) has been used to determine season of site occupation by estimating the season-of-capture from recovered otoliths (Langenwalter et al. 1989; Salls et al. 1989; Langenwalter and Huddleston 1991; Jones et al. 1994, 1996). The basis of the technique used to determine season-of-capture, and consequently the season of occupation, involves microscopic examination of growth zones in whole otoliths when thin enough for transmitted light, or sectioned otoliths when too thick for transmitted light. In some cases, heating of the otolith was used to enhance growth zone visibility; this technique is commonly known as break-and-burn (Christensen 1964). It is hypothesized in these studies that the growth ring type (opaque or translucent) at the otolith margin can be used as an indicator of season-of-capture (Huddleston 1981, Erlandson 1994).

Although age determination of fishes using otoliths has long been an established practice in fisheries research (Chilton and Beamish 1982), it has not been established that season-of-capture determination from otolith margin observations is accurate for some studies (Gobalet 2001). Examination of the otolith margin is typically associated with a subjective form of age estimate validation, where the formation of the successive growth zones is documented over a period of time that elucidates the annual formation of growth zones (Campana 2001). Because the formation of a growth zone can be associated with a season it is possible that season-of-capture can be determined (Gobalet 1989). Determining season-of-capture for fishes using this approach, however, is subjective and can be very problematic. For freshwater fishes, seasonal changes in growth may be better defined in the otolith than for marine fishes because ocean seasons can be offset by several months (Niiler 1977) or growth may be complicated by events like upwelling or El Niño. Freshwater fishes, however, can have a broad period of growth zone formation that could confound season-of-capture determination (Thompson and Beckman 1995). In general, the timing of growth zone formation in otoliths has substantial variability at the individual, population, and species levels (Williams and Bedford 1974; Thompson and Beckman 1995).

Season-of-capture determination for archaeological otoliths is further complicated by the difficulty of species identification. While keys are available to assist with species determination from otolith shape (e.g. Smale et al. 1995; Harvey et al. 2000), some otoliths can only be identified to genus or family at best. Therefore, the application of otolith edge analyses leads to an assumption that age and growth information for one or some family members is applicable to all members. Most temperate fishes (23° to 45° north latitude) form an opaque zone during spring and summer with a peak at April to May (Beckman and Wilson 1995). There are marked exceptions, however, like the California grunion (*Leuresthes* *tenuis*) which does not grow during its spring to summer spawning period, making the timing of opaque and translucent growth zone formation completely out of phase from what is expected (Spratt 1971; Fritzsche et al. 1985). The best case scenario for determining season-of-capture from an otolith section would be for a fish known to species, for which age and growth has been described and validated.

In this study, an attempt was made to determine season-of-capture for modern and archaeological otoliths from transverse sections. The modern specimens, with known date of capture, were used to evaluate the reliability of this technique. To further describe the subjectivity of season-of-capture estimation, modern otoliths from spotted sand bass (family Serranidae, *Paralabrax maculatofasciatus*), age validated using otolith edge analysis (Allen et al. 1995; Andrews, unpublished data), were also used to qualitatively assess the difficulty of season-of-capture determination in a best case scenario. It was anticipated that the technique would prove reliable enough that estimates of season-of-capture could then be made for the archaeological specimens to provide a season of occupation estimate for the two prehistoric sites from which the specimens were collected. It was hypothesized, however, that season-of-capture estimation for archaoelogical otoliths might be complicated by problems with species identification and environmental effects on the otolith margin.

Methods and Materials

Ninteen modern otoliths from marine fishes of coastal California, identified to species with known dates of capture, were selected by Ken Gobalet from the skeletal collection in the Department of Biology, California State University, Bakersfield. Twelve archaeological otoliths collected from two prehistoric sites near San Simeon in San Luis Obispo, County, California (CA-SLO-179 and CA-SLO-267) were also used in this analysis. Excavations at these sites were directed by Terry Jones (Jones and Ferneau 2002). Otolith specimens from both the museum collection and the archaeological sites were identified by Ken Gobalet, and the otoliths, including the taxonomic designations of the museum specimens (but not the dates of death) were provided to Allen Andrews for season-of-capture estimation and evaluation of the archeological otoliths. The fisheries standard of Robins et al. (1991) was used for the taxonomic and common nomenclature.

The otoliths were mounted in casting resin and transversely sectioned using a Buehler Isomet® saw with diamond wafering blades separated by acetate spacers (0.6 mm). Sections were mounted to glass slides with Cytoseal® mounting medium. Further grinding on a Buehler® lapidary wheel (800 grit carbide wet/dry paper) was necessary for most sections to enhance the definition of growth zones.

Finished otolith sections were viewed through an Olympus® dissecting microscope using transmitted light at magnifications best suited for each section (10–25 ×). Otoliths were aged based on the assumption that growth zones were formed annually (one per year). Margin type, defined as either translucent or opaque to transmitted light, was determined for each section when possible. Reflected light was also used to attempt to clarify unclear sections. Translucent margins, typically three seasons of growth (fall through spring), were categorized in three different stages based on the thickness of the translucent zone relative to the previous translucent zone (previous years growth). When the translucent zone was thin, it was labeled "early," thicker than one half the previous years growth was labeled "late," and in between was labeled "middle." Opaque margins, typically one season of growth (summer), were usually thinner and were not broken into categories. Season-of-capture was subjectively estimated based on the margin observation described above and an appropriate literature source for age and growth information (Tables 1 and 2). In some cases, age and growth information was lacking for the species and extrapolation from other species of the same family was required.

Because the initial set of modern otoliths included a wide range of species, a larger group of specimens representing a single species was used for a second test of the reliability of season-of-capture estimation. A total of 40 spotted sand bass otoliths collected in the Gulf of California, Mexico, with known dates of capture, was available to the senior author. These otoliths were previously mounted and sectioned in the same manner stated above. Ten spotted sand bass otolith sections from each collection season (Winter = January, Spring = April, Summer = July, Fall = October) were randomly selected and the season-of-capture was estimated. Because age and growth was validated using an otolith edge analysis covering collections made during the four seasons (Andrews, unpublished data), season-of-capture was estimated for these 40 otolith sections using the same guidelines stated above.

Results and Discussion

A thorough literature search for age and growth information on each fish species, genus and family was performed to assist with proper season-of-capture estimation for the modern and archaeological otoliths. An attempt was made to obtain species level information first, followed by genus and family with similar geographical or latitudinal distribution when specific information was unavailable.

The modern otoliths represented 16 species from 8 families and edge or margin analyses could be found for only 6 species, of which 2 studies used scales (Table 1). Age was estimated for otolith sections that had clear, quantifiable growth zones. Age could not be determined for three otoliths. Margin type was determined for the remaining specimens when the thickness of the growth zones at the otolith margin permitted: six margins were opaque and nine were translucent. Two had growth zones that were too thin to determine margin type and two were estimated based on the thickness of the previous years growth. Stage was assigned for eight of the translucent margined sections. Season-of-capture was estimated for 14 of the sections, of which month to month designations were assigned when the information was available from references, and generic season (e.g. spring) was assigned when larger assumptions were necessary. Many age and growth references were researched for pertinent marginal growth zone information, but only a few had useful data for edge type relative to season (Table 1). In some cases, the season-of-capture was estimated based on very general information.

Once season of capture estimates were made, the senior author obtained actual capture dates for the specimens from Dr. Gobalet. Comparison showed that the estimated season-of-capture for the modern otoliths was within the seasonal limits for only six otoliths, well outside for eight, and five were not useful (Table 1). Of the six within the known season-of-capture, *Paralichthys californicus* was only marginally useful because of the broad estimated range, spring to summer. The

Table 1. Results from season-of-capture estimations for modern otoliths.*

Species	Margin type	Estimated age (yr)	Stage	Estimated season-of-capture	Actual death date	Estimate accurate?	Helpful reference
Merluccius productus (Pacific hake)	translucent	12	early	Sept–Nov	6/80	no	Dark (1975)
Atherinopsis californiensis (jack-smelt)	translucent	1	late	early spring?	9/15/80	no	Beckman and Wilson (1995)
Sebastes flavidus (yellowtail rock-fish)	translucent	14	mid–late	Jan–Mar	11/19/78	no	Kimura et al. (1979)
S. melanops (black rockfish)	?	12–16	n.a.	n.a.	6/15/97	n.a.	Six and Horton (1977)
S. nebulosus (china rockfish)	?	16	n.a.	n.a.	9/1/80	n.a	
S. rufus (bank rockfish)	translucent	11	?	Dec–Jan	1/11/85	yes	Watters (1993)
S. rufus (bank rockfish)	n.a.	not ageable	n.a.	n.a.	1/11/85	n.a.	
Hexagrammos decagrammus (kelp greenling)	opaque	2	—	Jul–Sept	9/2/80	yes	Ye (1993)
H. decagrammus (kelp greenling)	opaque	2	—	Jul–Sept	11/80	no	
Ophiodon elongatus (lingcod)	opaque	3		Jul–Sept	11/80	no	Cass and Beamish (1983)
Atractoscion nobilis (white seabass)	n.a.	not ageable	n.a.	n.a.	1/8/86	n.a.	
Seriphus politis (queenfish)	translucent	6	late	late summer–early winter	4/4/85	no	Goldberg (1976)
Embiotoca lateralis (striped surf perch)	translucent?	8	late	Jan–Mar	3/20/94	yes	Gnose (1967)
Rhacochilus vacca (pile perch)	translucent	8	late	Jan–Mar	3/20/94	yes	Ware (1971)
Chromis punctipinnis (blacksmith)	n.a.	not ageable	n.a.	n.a.	7/3/86	n.a.	
Paralichthys californicus (California halibut)	opaque	5	—	spring–summer?	7/27/90	yes	Beckman and Wilson (1995)
Eopsetta jordani (petrale sole)	opaque	9		April–Oct.	3/20/94	no	Gregory and Jow (1976)
Eopsetta jordani (petrale sole)	translucent	5	late	Jan–Mar	6/16/79	no	
Psettichthys melanostictus (sand sole)	translucent	2	early	fall?	10/26/94	yes	Beckman and Wilson (1995)

* n.a. not applicable.

Table 2. Season of capture estimations for archaeological otoliths recovered from SLO-179 and SLO 267

Location and taxon	Estimated age (yr)	Margin type	Stage	Estimated season-of capture
SLO-179				
Osmeridae (smelt family)	2	translucent	middle?	winter?
Osmeridae (smelt family)	< 1?	translucent	early?	fall?
Osmeridae (smelt family)	< 1	translucent	early?	fall?
Spirinchus starksi (night smelt)	6?	translucent	middle to late?	winter to early spring?
Spirinchus starksi (night smelt)	< 1	?	n.a.	n.a.
Sebastes sp. (rockfish)	not ageable	n.a.	n.a.	n.a.
Hexagrammidae (greenling family)	2?	translucent	?	n.a.
Cymatogaster aggregata (shiner perch)	not ageable	opaque	n.a.	n.a
Embiotoca sp. (surfperch)	12	opaque?	n.a.	midsummer to winter?
SLO-267				
Sebastes sp. (rockfish)	8 to 28	?	n.a.	n.a.
Sebastes sp. (rockfish)	20	?	n.a.	n.a.
Embiotoca sp. (surfperch)	5?	n.a.	n.a.	midsummer to winter?

n.a. -not applicable.

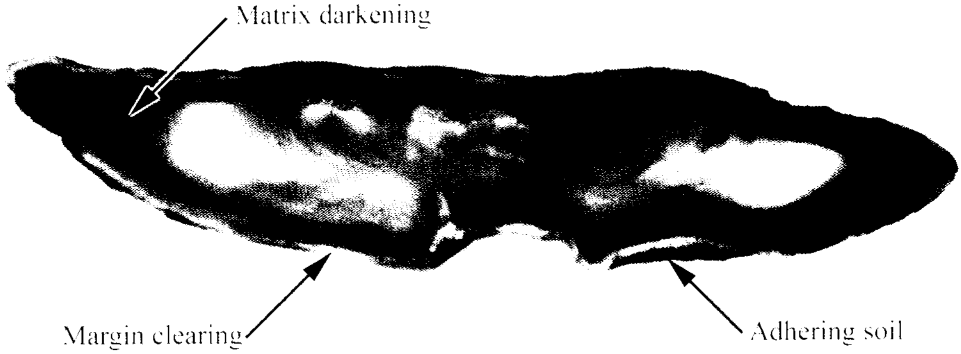

Fig. 1. A transverse cross section of an archaeological otolith, identified as a rockfish (*Sebastes* sp.), viewed with transmitted light and exhibiting the typical forms of otolith matrix alterations that can occur from environmental factors. Matrix or margin darkening and clearing, and adhering soil, can lead to a misinterpretation of the margin type for season-of-capture estimation. The symmetrical depth of the margin clearing is inconsistent with the asymmetrical growth known to occur in rockfish otoliths.

actual date of death was July 7, 1980. Consequently, the season-of-capture was accurately determined for only 32% of the specimens and 43% of those attempted.

The archaeological otoliths consisted of three specimens identified to two species, five otoliths identified to two genera, and four otoliths identified to two families from two archaeological sites (Table 2). Age was estimated for 10 otolith sections and was tenuous at best for some samples. Two were not ageable because the growth zones were poorly defined. Edge type was determined for eight sections and stage was assigned to four sections with translucent zones. Season-of-capture was tentatively estimated based on the margin type and the assumption that the available age and growth information was applicable. The appearance of some of the otolith margins, however, made the margin type subject to additional scrutiny.

Because no age and growth information could be found for the family Osmeridae (including *Spirinchus starksi*), assumptions were made based on the general seasonal growth pattern observed in otoliths (Beckman and Wilson 1995). For four of the five samples, the season-of-capture could have been from fall to early spring (Table 2), however, if the growth of osmerids are similar to California grunion (*Leuresthes tenuis*), another inshore epipelagic fish, the season-of-capture could be 6 months out of phase from the estimate (Spratt 1971; Fritzsche et al. 1985). These otolith sections exhibited what appeared to be a clearing (increased transluscence to transmitted light) of the otolith matrix at the edge.

The three otoliths identified as members of the rockfish family (family Scorpaenidae: *Sebastes* sp.) provided the least amount of marginal growth zone information (Table 2). One sample from archaeological site CA-SLO-179 did not produce a readable section, but had a strong symmetrical translucent margin (Figure 1). Because the translucent margin was symmetrical and the growth of rockfish otoliths is usually asymmetrical (Beamish 1979), it was concluded that this margin was from a clearing of the otolith matrix. Use of reflected light did not aleviate the problem and season-of-capture could not be determined. The two sections from archaeological site CA-SLO-267 produced readable sections, but this was complicated by a different kind of interference. One sample was aged at both eight years (based on grouping of fine growth increments) and twenty-eight years (based on a count of all the fine growth increments). Because the species of rockfish was unknown and many rockfish can be quite old, either estimate would have been possible (Cailliet et al. 2001). The margin type, however, could not be determined because of what appeared to be a denaturing of the otolith matrix, which made the edges appear black in transmitted light (Figure 1). The other sample was aged at about 20 years, but season-of-capture determination was not possible because the growth zones were too thin near the margin and appeared to have suffered the same denaturing problem. Use of reflected light did not alleviate the problem.

The one sample identified as a member of Hexagrammidae was tentatively aged at two years and had a translucent margin. This otolith, however, appeared to have suffered from the same otolith clearing observed in other species. While the growth zones were not well defined, as is often the case with young fish, the presence of a symmetrical translucent margin made season-of-capture estimation suspect.

Two of the three otoliths from the archaeological sites identified as members of the surfperch family (Embiotocidae) seem to have provided the most reliable season-of-capture information. The *Cymatogaster aggregata* sample was very dark to transmitted light and did not provide a readable section. The two samples identified as members of *Embiotoca* sp. produced readable sections, but determination of margin type was hindered by a darkening of the margin to transmitted light. One sample was aged at about 5 years and the margin type forming at the time of capture may have been opaque. If this is correct, the season-of-capture may have been mid-summer to winter (Gnose 1967). The other sample had an estimated age of 12 years (15 years using reflected light). This sample also had a darkened margin which interfered with season-of-capture estimation. This age estimate was greater than the maximum age of seven years reported for each *Embiotoca* species (*E. jacksoni* and *E. lateralis*; Baltz 1984). This discrepancy could be explained by a change or variation in longevity (Boehlert and Kappenman 1980; Craig 1985), misidentification of the otolith, or the existence of older individuals at the time of capture because of lower fishing pressure (Craig 1985). The margin type appears to be opaque using reflected light; therefore, the season-of-capture may be mid-summer to winter. It must be noted, however, that this determination was inferred from an age and growth study that used scales, not otoliths (Gnose 1967).

Because of the problems observed in this study with determining margin type, it is likely that some archaeological season-of-capture estimates from otolith margin type have been erroneous. Clearing or darkening of the otolith matrix can be explained by processes that occurred when the fish was utilized and during the long period of burial at the archaeological site. Altered otoliths are typically eliminated from consideration, but no study has ever documented this problem. If altered otoliths are missed and considered further, a cleared otolith margin could lead to the determination that the otolith has a translucent margin and was captured in the respective season for that species or family. Hence, loss of growth zone information from a change in the otolith matrix over time may preclude an accurate season-of-capture determination.

To help define the difficulty of determining season-of-capture, transverse otolith sections from spotted sand bass taken seasonally from the Gulf of California were studied for edge type. Note that this was an opportunistic addition to this study and that the geographical location of this species was not an issue. The motive was to demostrate the difficulty of season-of-capture determination in a best case scenario. Based on the otolith edge analysis, the opaque growth zone was narrow and formed during the summer months (Andrews, unpublished data). The translucent growth zone was broad and formed during the remainder of the year (Fall to Spring). These results were consistent with results for spotted sand bass from southern California waters (Allen et al. 1995).

Spotted sand bass otoliths were easily aged and estimated age ranged from 1 to 6 years, most being 2 to 3 years. Summer growth was easiest to identify because of the thin opaque margin. The season-of-capture was correctly identified in 9 out of 10 summer fish sections. Determining season-of-capture for fish with a translucent margin was much more difficult. Fall fish were correctly identified in only 2 out of 10 otolith sections, and the remainder were not correct (60% Winter and 20% Spring). No winter fish were identified correctly (30% Spring, 20% Summer and 50% Fall). Spring fish were second most identifiable because the translucent margin was thick relative to previous years growth (40% identified correctly). Two out of 10 were identified as summer fish because the margin type was opaque. This can be explained by the results given by Allen et al. (1995) for spotted sand bass of southern California where April was the beginning of the period for some fish to start forming an opaque margin. In addition, the specimens from the Gulf of California always had some fish forming an opaque margin in all seasons (Andrews, unpublished data). Overall, 15% were placed in a season 6 months from the actual season of capture and 37.5% (15 out of 40) were identified correctly. Hence, season-of-capture can often be inaccurate even in a best case scenario where seasonal growth patterns are known.

Based on the findings of this study it seems that season-of-capture determination from otolith sections can be problematic under any circumstances. For archaeological otoliths the determination of species can be critical, especially with marine fishes where seasonal growth patterns can be offset by a full 6 months. Even when an otolith can be identified to species, evaluation of its season of capture is further complicated by the inherent variability in otolith growth zone formation. In many cases an opaque growth zone can form at any time, but is more or less probable during certain times of the year. An examination of any otolith edge study reveals that there is always some percentage of individuals that deviate from the margin type expected; annual growth zone formation is a trend based on a majority.

To further complicate matters, environmental factors can change the otolith matrix of archaeological otoliths (Figures 1). The clearing or darkening of the otolith matrix observed here make season-of-capture determination very subjective, if not impossible, because the growth zone information was altered or lost. These changes to the otolith margin could lead to a false determination of margin type and, as a consequence, an incorrect season-of-capture determination.

Conclusions

Based on findings in this study, season-of-capture determination from otoliths of both modern and archaeological otoliths requires an adherence to specific protocol that utilizes a validated set of otoliths from the species, or perhaps family, in question. Ten genera have been recovered from middens of central California, of which, embiotocids are common nearshore species commonly found in middens (Gobalet and Jones 1995). In our study, the modern embiotocid otoliths were correctly identified to season. The combination of availability of embiotocids in the archaeological record, abundance nearshore, and the potential accuracy of season-of-capture determination makes them a strong candidate for future seasonality work; however, the high degree of subjectivity in all determinations of season-of-capture from otolith margin analyses because of the inherent variability of growth zone formation and alteration of the otolith matrix begs caution when interpreting the results. This study has called into question the validity of protocols that do not utilize age validated otolith collections.

The need to validate any age determination procedures has been stressed by numerous authors (Lagler 1969; Chilton and Beamish 1982; Beamish and McFarlane 1983; Baltz 1990; Busacker et al. 1990). Validation is having comparative sectioned otoliths from the species in question from the same locality with known dates of death for comparison. Chilton and Beamish (1982) stipulate that validation procedures should be applied to all age classes in a population of a species and to different populations of the same species. The procedures used for young members of a species may not apply to old members of the same species and each species must be independently validated. Seasonality determinations using otoliths should be no different.

Higham and Horn (2000) published the most thorough seasonality study based on otoliths recovered from an archaeological site to date. Their validation samples consisted of over 500 sectioned otoliths of red cod from the waters near the midden in New Zealand. The date of fish death of each individual fish was known for all comparative otoliths. The same rigor needs to be applied to other studies of seasonality based on growth in skeletal parts. This is daunting considering the number of possible species that may be commonly encountered and the number of locations where archaeological investigations are undertaken. In coastal central California the number of species recovered from middens exceeds 80 (Gobalet and Jones 1995). In addition, there needs to be further consideration to possible changes in the fish assemblage, fishing techniques, and fishing pressure during site occupation. Developing comparative otolith collections for particularly common species would be a starting point and the results for embiotocids in this study provide some grounds for optimism in future studies of archaeological sites in coastal California.

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