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The Implications of Non-Periodic Growth in Bivalves for Three Seasonality Methods Used by Southern California Archaeologists

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ARISTOTLE was perhaps the first person in recorded history to comment about the growth layers seen in fossilized marine shells, suggesting that these inorganic structures grew within the soils surrounding them and were influenced by the planets and stars. However, it is Leonardo Da Vinci who is credited with the first realistic attempt to explain the existence of growth layers in invertebrate exoskeletons by suggesting a relationship between these growth lines and lunar, monthly, and annual cycles based on the analogy that such growth occurred in vertebrates and plants (Barker 1970:2-3). It is also noted that some 19th century naturalists employed growth layer counts to guess at the ages of invertebrate organisms, guesses based upon an assumption that a relationship exists between one type of growth layer and an annular periodicity in the growth history of the organism. Thus, there is a lengthy history to the assumption that the existence of a particular growth layer indicates the completion of a full year of growth for an organism, and therefore represents their age in years when counted.

Growth line research on the skeletal parts of fishes, echinoids, and gastropods increased through the latter portion of the 19th century (Barker 1970:3). After the turn of this century, researchers began looking more closely at the growth line patterns of living bivalve clams (Pelecypods) for growth rate studies (e.g., Richards 1928; Coe and Fox 1942; Coe and Fitch 1950; Swan 1952; Seed 1968, 1973; Berry and Barker 1977) of fossil bivalves in relation to synodic month lengths, and of both fossil and recent bivalves for paleoenvironmental reconstructions (see Davenport 1939; Craig and Hallam 1963; Pilkey and Goodell 1964; Malone and Dodd 1967; Berry and Barker 1968; Pannella and MacClintock 1968a; Pannella et al. 1968; Rhoads and Pannella 1970; Andrews 1972; Pannella 1972, 1975, 1976; Jones 1980).

More specific studies concentrated on defining shell structures and constituents useful in such work, in particular, the formation of annular, fortnightly, and daily growth layers, lines, grooves, or bands on the external surface of the bivalve shell;[1] the annual, seasonal, daily, and bi-daily growth lines evident within the internal microstructure of the shell;[2] and isotopic profiles of certain elements (e.g., carbon and oxygen) incorporated chemically into the shell during growth.[3]

Methods developed from these three research areas have been applied to archaeological questions concerning subsistence scheduling and paleoenvironmental reconstructions (see Nelson 1967; Weide 1969; Coutts 1970, 1974, 1975; Anderson 1973; Koike 1973, 1979; Perlman 1973; Shackleton 1973; Coutts and Jones 1974; Drover 1974; Berta 1976; Clark 1977, 1979; Lyons 1978; Killingley and Berger 1979; Killingley 1980, 1981; Ursula 1981; Macko 1983; Claassen 1986; Rollins 1986).

EXTERNAL GROWTH LINE STUDIES

Employing the information supplied by Barker and others (see Note 1), researchers have projected the possibility of deriving the season of death for shellfish recovered at coastal archaeological sites using fortnightly and/or annual external periodic landmarks (Weide 1969; Coutts 1970, 1974, 1975; Coutts and Higham 1971; Farrow 1971; Perlman 1973; Drover 1974; Ham and Irvine 1975; Berta 1976; Clark 1977, 1979; Lyons 1978; Koike 1979; Macko 1983).

The study results presented in this paper are concerned only with external shell growth. In particular, this research centers on highly defined ridges and grooves on the external shell surface. These pronounced external features, or external periodic landmarks, are presumed to represent fortnightly and annual periodicities in shell growth. The presumed fortnightly ridges of *Chione* clams are evident as raised concentric sculptures on the shell surface, and are each supposed to represent a two-week period of shell growth. The presumed annual bands or grooves, which more often appear as checks in the shell surface, are visible on most molluscan skeletons, and are believed to record the winter cessation of growth. Biologists counting these checks achieve the chronological age of the organism. From the archaeological perspective, it has been proposed that the season of death can be inferred from the number of fortnightly ridges per year, and from the position of the last annual band in relation to preceding annuli or to the shell margin itself (Fig. 1). This paper reports the final results of a test for three seasonality methods (Cerreto 1988).

As this paper is meant only to report the results of testing the external methods of deriving seasonality of resource procurement along the coast of southern California, only a discussion of external methods proposed for this region is presented below, and only the results of testing the external methods for *Chione* are presented.

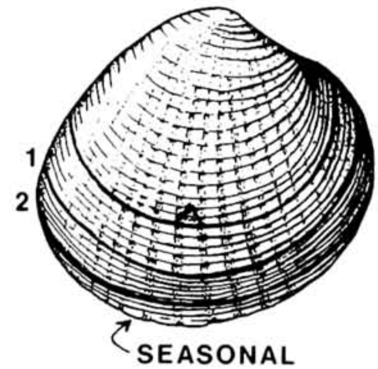

Fig. 1. The relation of seasonal growth to annular growth bands is illustrated. The numbers (1, 2) show annular growth bands.

SOUTHERN CALIFORNIA STUDIES

Four methods of deriving seasonal information have been suggested for the southern California coast (Weide 1969; Drover 1974; Lyons 1978; Macko 1983). Weide's (1969) method of determining seasonality using the Pismo clam (*Tivela stultorum*) is not considered here for two reasons. First, their occurrence at most archaeological sites in southern California is rare. Second, *Tivela* is a sandy open coast habitat species, and requires a completely different experimental approach than *Chione,* a mostly sandy enclosed bay and estuary habitat species. That is, because *Tivela* reside in areas of heavy wave action and appear to be more mobile than *Chione*, they are less likely to be as easily contained as species residing in areas of lighter wave action. The three remaining methods of seasonal determination each use a *Chione* clam. These three methods are discussed in some detail below.

Drover's Method of Seasonality

In 1974, Drover suggested using the external annular rings on *Chione fluctifraga* and

C. undatella as seasonal markers for archaeological sites and for their use in understanding prehistoric settlement adaptations for the coast of southern California. The method was adapted from the results of Barker's (1970) work with *C. undatella* at Cholla Bay, Mexico.

For *C. undatella*, Drover used Barker's average of fortnightly ridges per year from the specimens collected by Barker at Cholla Bay, Mexico. "In wavy Chione, Barker (1970:178) found that in the first year of growth an average of 16.9 fortnightly growth ridges were added. Thereafter, the number of such ridges decreased to 8.8 in the second year, 4.5 in the third year, and only 4.0 in the fourth year of life" (Drover 1974:227). Drover's analysis of *C. fluctifraga* clams from site CA-Ora-119 involved measuring the growth of the shell between each of the annual growth bands and from the last annuli to the shell margin.

> All measurements and observations were made on the exterior of the shells (valves) without prior preparation other than washing. Weight, height, and age measurements were taken of each valve. Height (or growth) increment measurements were taken for each year and for the total height of the shell. These measurements were made with a calipers at the widest extent of each growth ring [Drover 1974:227].

Using this information, Drover suggested a method for deriving seasonality from *C. undatella* and *C. fluctifraga* which relied upon equal division of the average growth for the three growth period seasons, fall, summer, and spring. For *C. undatella,* this could be easily accomplished "By dividing each of these values by three, the resulting number should be an adequate approximation of growth during a single season, such as summer" (Drover 1974:227). For *C. fluctifraga,* Drover contended that

> The analysis of smooth *Chione* is more difficult because the sharp concentric fortnightly ridges characteristic of wavy *Chione* are absent and therefore could not be counted. The mean annual growth was determined by height measurements taken with a sliding calipers. The annual growth measurement was then divided by three, resulting in an approximation of growth for a given season [Drover 1974:227, 229].

Drover cautioned that such an approximation implied a linear growth throughout the year and postulated that this was not the case because increasing age would affect seasonal growth. That is, with age the winter growth cessation becomes longer and more growth may occur in summer than in spring or fall.

Problems with Drover's technique were discussed in Koerper (1980) and reviewed briefly by Cerreto (1988). Mainly, Koerper (1980) and Koerper et al. (1984) argued that the life history of *Chione* clams was not known well enough to substantiate the use of Drover's technique. However, concerning this issue Koer-per came to the same conclusion as Drover: modern growth studies on *Chione* clams were needed to test the validity of the method.

Lyons' Method of Seasonality

Four years after Drover, Lyons (1978) developed a method of seasonality based upon the annular and fortnightly growth bands found by Barker (1968) on *C. undatella*. Citing the logarithmic growth of *Chione* clams, and using Barker's fortnightly ridge count averages per year, Lyons created a growth function formula (see Lyons 1978:34, equation 2). Using this equation, Lyons computed a table of seasonality (Lyons 1978:Table A, 36). Like Drover, Lyons divided his growing seasons into three units. Unlike Drover, these divisions included four months, each apparently based upon a May 1st beginning for shell growth. Lyons explained that

> Each growth ridge count of the sample was placed in the appropriate subdivision A, B, C of Table A. For example, a valve displaying 50 growth ridges would be placed in the "C" subdivision of the year since it was harvested within the months of January through April of its fourteenth year of life. Choosing May 1st as the optimum time for shell growth to begin, the year was divided as follows:

A=clams harvested during the months May, June, July, August
B=clams harvested during the months Sept., Oct., Nov., Dec.
C=clams harvested during the months Jan., Feb., March, April [Lyons 1978:37-38].

To apply Lyons' method, the total number of growth ridges are counted from umbo to margin. Although Lyons (1978) did not explain how to do so in his methods section, the fractional growth past the last ridge is recorded in tenths. However, Lyons explained to the author (personal communication 1987) that by using the distance between ridges, the amount of growth is estimated as any tenth of that length accordingly. Unfortunately, this means that Lyons had failed in one of his primary purposes, that is, to offer a metric technique to determine season of death (Lyons 1978:33). Ridge counts from archaeological samples are matched to the values in Table A (Lyons 1978:36) to determine the season or seasons of death.

Problems with Lyons' technique were discussed by Koerper (1980), Koerper et al. (1984) and Lyons (1984), and reviewed briefly by Cerreto (1988). Again, the major argument was biological, centering upon the validity of the annual and fortnightly external periodic landmarks and shell growth rates. Here, Lyons was contradictory, citing alternatively that modern growth rates are and are not equivalent to archaeological growth rates (Lyons 1984:76-78). If modern growth rates do reflect archaeological growth rates, then a modern growth study presents an excellent test of the reliability of any seasonal technique. If modern growth rates do not reflect archaeological growth rates, then arguing the usefulness of Lyons' or any method of deriving seasonality from shellfish is a moot point.

Macko's Method of Seasonality

Macko's method of determining seasonality was based upon information from both Barker's (1970) and Coutts and Higham's (1971) shell growth studies (Macko 1983:114). As with Drover and Lyons, Macko cited Barker's average fortnightly ridge counts per year. From Coutts and Higham's study, Macko surmised that "Their study shows that approximately 35% of a shell's annual growth occurs in spring, 50% in summer, 15% in fall, and no measurable growth occurs during the winter" (Coutts and Higham 1971:269-270 and Fig. 7). Macko (1983:117-118) stated that

> The season of collection is inferred from the percentage of growth occurring after the last winter ring for each age group. For example, a shell exhibiting 35% of its second year of growth (i.e., one winter groove plus three fortnightly rings) is considered to have passed through spring, and is estimated to have been collected in early summer. Because annual growth is measured in relation to winter rings, inferring season of collection must be based on an arbitrary starting point for winter. For the purposes of the present study, winter, spring, summer, and fall are considered to begin at the middle of December, March, June, and September, respectively.

Macko (1983:119) described the procedure for determining seasonality as follows.

> The first stage of analysis involved counting the number of fortnightly rings between annual winter grooves beginning at the first evident winter ring, or with the second year of growth. Counting involved beginning at the first winter groove (all 34 valves were at least one-year old) and included the winter groove representing the end of annual growth for a particular age group (i.e., two-year olds, three-year olds).

To this end, for the archaeological sample used, Macko computed two sets of means for the second and third year growths. For the shells from Structure 2, the second year mean was 9.22 and the third year mean was 5.13. For the shells from Structure 3, the second year mean was 8.0 and the third year mean was 5.6. For shells exhibiting four years of growth, Macko used Barker's mean of 4.0 from the Cholla Bay sample. Macko also attempted to solve inaccuracies in the earlier technique proposed by Drover (1974) and used by others (e.g., Carter 1978) by correcting for differential seasonal growth.

> The technique utilized in this [Macko's] study differs from that used by Carter (1978) and Drover (1974). To interpret their data, each investigator divided the mean number of fortnightly rings within each full year of growth (assuming a nine month growth period each year) by three. They assume that the derived quotient represents the mean number of rings produced each season of the growth period (i.e., spring, summer, and fall). By dividing the growing season into even thirds, they assume that growth is evenly distributed throughout spring, summer, and fall. But, as Coutts and Higham (1971) have pointed out, growth is not evenly distributed throughout the year [Macko 1983:119, 121].

However, Macko misinterpreted the data presented by Coutts and Higham as neither their Figure 7 nor Table 1 (Coutts and Higham 1971: 270, 271) reveal data that indicate percentages of seasonal growth. In fact, all that is shown is a time series of growth characteristics used to illustrate similarities between four- and seven-year old specimens, and a comparison of growth ratios projecting season of death for several archaeological samples. The only information pertaining to growth rates given by Coutts and Higham (1971) is from pages 269 and 270 as noted by Macko (1983:117).

> From the analysis of the monthly samples, it became apparent that the growth rate was greatest during the summer, and decreased markedly with the onset of colder autumnal conditions. No perceptible growth was recorded during the months of winter; the results of the marked shell experiment indicated that there was no measurable growth in April-May [Coutts and Higham 1971:269-270].

Only general statements were presented concerning seasonal growth rate comparisons. Still, it is possible to achieve some approximation of the growth rates that may have occurred monthly as described by Coutts and Higham. In this case, a simple algebraic equation can be constructed to estimate the percentages of growth throughout the year. Only one month's growth occurs in the spring (1x), and that growth in the summer is greatest (3x), whereas growth in the fall decreases greatly (1x). There is no growth occurring during the winter (0x). Setting one month's growth equal to x%, the equation is constructed by adding the seasonal growth for fall (x%), for spring (x%), and for summer (3x%). The equation then is $3x + x + x = 100\%$, $5x = 100\%$, or $x = 20\%$. Therefore, it is possible that, for the population Coutts and Higham studied, fall and spring each may exhibit 20% (1x) of the yearly growth, whereas summer may exhibit 60% (3x) of the yearly growth.

Using these percentages for Coutts and Higham's growth rates, it can be seen that Macko's estimated growth for his seasonal categories may have an error margin as much as 5% for fall (20%-15%), 10% for summer (60%-50%), and 15% for spring (35%-20%). Because this may have an effect upon the accuracy of the technique, these percentages are also considered in the subsequent analysis.

DISCUSSION

There are numerous problems with using external periodic landmarks on the shell surface that affect the reliability of such methods. For example, many researchers state that it is impossible to distinguish the annual winter bands easily seen on the exterior of the shell (see Orton 1926; Moore 1934; Coe and Fox 1942; Dehnel 1956; Craig and Hallam 1963; Seed 1968; Stanley 1969; Rhoads and Pannella 1970; Evans 1975; Lutz 1976; Kennish 1980). Preliminary results from a modern live growth study (Cerreto 1988) have already cast suspicion on the reliability of using such external landmarks as annual indicators.

In order for any seasonality method to be reliable, it must be consistent and it must perform the task it is developed to perform. That is, using the proposed external techniques, shells collected in any particular season must be placed into the appropriate seasonal category with a high degree of accuracy. The methods described above have supposedly accomplished this task as they have placed shellfish from archaeological sites into seasonal categories.

However, the major problem with these three external methods is that the researchers used an archaeological sample to test the problem of seasonality when the primary issue was not seasonality of shellfish collecting but whether or not seasonality can be determined for shellfish using external periodic growth landmarks. In other words, the problem is not anthropological but biological in nature.

If external fortnightly and annual features exist as reliable periodic growth landmarks then their use as seasonal indicators is invaluable. However, if the external periodic landmarks are not reliable (i.e., not fortnightly or annual), then any of the methods proposed to derive seasonality information for southern California are invalid.

To test the reliability and validity of using external periodic landmarks for *Chione* and *Protothaca*, a simple growth experiment was performed. The two species of bivalves were allowed to grow undisturbed for two years and were killed in a particular season. Since we have a collection that has grown for two years, the reliability of the external annual landmarks can be tested. Because we have a collection of clams with a known season of death, we should be able to show the validity of each of the proposed methods of seasonality for southern California.

METHODS

Containment pens were constructed to hold the specimens in one location and so increase the frequency of recovery, but not to restrict movement in an unnatural manner. This was accomplished through a literature review of past studies which utilized containment pens, and of population studies within the bay (Seapy 1981).

Containment Pens

The pens were constructed of 1/2-in. aviary netting cut into 3.048 m. by 25.4 cm. lengths, and four 3.048 m. lengths of 25.4 cm. diameter polyethylvinylchloride (PVC) pipe. The netting formed the walls of the pen, while the PVC pipe formed the tops of these four walls. The PVC pipe was attached to the netting by steel wire, and the walls of the pen were connected by folding over both sides of the twisted strands of the netting edges of the cut lengths. The completed pen was a rectangle measuring 3.048 x 3.048 m. x 25.4 cm., open on both the top and bottom. Pen size and construction was determined by previous studies on the population dynamics of *Chione* and *Protothaca* in Newport Bay, California (Seapy 1981), and by the success or failure of containment pens used in previous works (cf. Orton 1926; Newcombe 1935; Coe and Fox 1942; Coe 1945; Swan 1952; Stevenson and Dickie 1954; Butler 1965; Merrill et al. 1965; Harger 1970; Ropes and Merrill 1970; Koike 1973; Seed 1973; Coutts 1974; Crabtree 1975; Lutz 1976; Crabtree et al. 1979).

The pens were installed with their uppermost edges at the 0.2438 meter tide line. Each pen was installed as four separate wall sections and in three consecutive steps. First, each section of wall and pipe was laid out in position and trenches were dug to receive each of the four walls. To stay ahead of the incoming tide, the trench for the lowest wall was dug first, and the wall positioned within the trench. This trench, except for either corner, was filled in on the wall. Second, the trenches for the two ascending sides of the pen were dug, and each wall was positioned in their respective trenches simultaneously. The lower corners of the pen were connected by folding the protruding ends of the net edge of one wall over the opposing edge of another wall, and the trenches, except for the upper two corners, were filled in on both walls and both lower corners. Finally, the uppermost trench was dug, the wall positioned, the upper corners connected, and the trench filled completely. Two such containment pens were installed in the summer of 1985. All clams discovered while digging the trenches were placed in buckets of seawater prepared beforehand to receive the collected specimens for processing and replanting.

Specimen Preparation

The *Chione* clams utilized for this study were found along a narrow peninsula in the lower half of Newport Bay in fairly muddy sand in 1984. In the summer of 1985, 148 *Chione* clams of all three species were collected at this locale. The specimens were found at the beach strand surface, half-buried in the substratum, and required little or no effort for their retrieval.

The specimens were brought by bucket to a temporary field lab located along the peninsula less than a mile from the study area to receive identification numbers. The sharp relief of the external structures of the shell of two *Chione* clams prohibited a simple identification method using written arabic numbers. Instead, a coding system employing colors representing the numbers from zero to nine was utilized. That is, black for zero, purple for one, dark green for two, etc. Identical code colors were applied to both shell valves of each clam. When dry, the identification numbers were coated with clear nail polish as a sealant.

The specimens were weighed using an Ohaus triple beam balance 700 series, with a capacity of 2,610 grams at an accuracy of 0.1 grams, and the total wet weight for each specimen was recorded. The length, width, and height of each of the specimens was taken using a sliding metric vernier calipers at an accuracy of 0.1 mm. Length is defined as the distance measured from the shell umbo to the shell margin and bisecting the shell equally. Width is defined as the distance from the shell margin as measured perpendicular to the length measurement. Height is defined as the distance between the highest points of both valves. Figure 2 illustrates the orientation of the three linear measurements as recorded.

After the specimens were numbered, weighed, and measured, they received a zeroing notch on the edge of the shell margin directly opposite the hinge. This was done to provide a zero point from which all future growth during the length of the experiment could be measured. The notching was accomplished by running a triangular metal file across the shell margin until a "V"-shaped notch was created (see Fig. 3).

Once numbered, measured, weighed, and notched, the clams were released into the pens. The specimens were redistributed along the surface throughout the 100 ft.^{2} area of the pens as the tide came in, and left to burrow themselves into place. The incoming tide provided shelter from predatory birds while the clams repositioned themselves in the substrate. The clams were recovered after a two year period of undisturbed growth. That is, to the best of the author's knowledge no unnatural disturbances occurred at the site.

Within three days of their recovery, the recaptured clams were killed by freezing, their date of death recorded, and stored unshucked in this frozen state. After a time, the specimens were retrieved and identified. The identification numbers were checked twice before the clams were boiled open to remove the organism. The fleshy parts were placed in plastic bags marked with the appropriate identification number and refrozen for storage. The shells were remeasured, reweighed, the fortnightly growth ridges and annual grooves counted, and the annual band distances measured. In all, 19 *C. undatella* species clams were recollected from the containment pens in June of 1987.

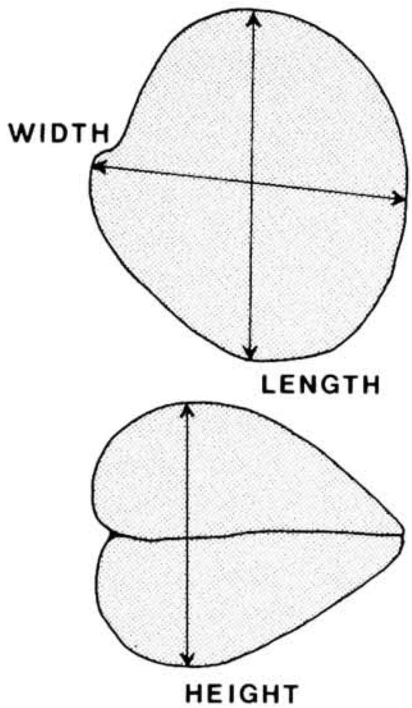

Fig. 2. The orientation of three linear measurements recorded for all specimens.

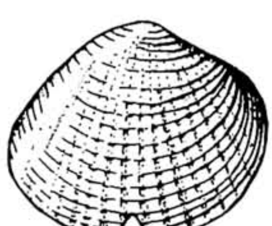

Fig. 3. The V-shaped notch at the shell margin used for zeroing growth.

Table 1
ANNULI LENGTHS, TOTAL LENGTHS, AND GROWTH LENGTH AVERAGES (in *C. undatella*) FOR THE NEWPORT BAY MODERN GROWTH SAMPLE

	Annuli Lengths (mm.)					
Specimen Number	1	2	3	4	a	b
206	4.5	14.8	--	--	8.3	37.6
356	3.0	17.4	6.9	--	3.1	30.4
382	5.3	14.5	7.0	--	4.8	31.6
388	19.5	--	--	--	9.0	28.5
390	7.3	13.4	6.7	--	1.5	28.9
406	10.8	14.2	--	--	5.1	30.1
407	9.1	7.4	2.5	--	7.5	26.5
413	7.1	20.6	0.4	--	1.2	29.3
417	8.5	12.3	8.2	--	0.0	29.0
418	16.6	9.1	--	--	7.7	33.4
419	9.0	10.4	8.2	--	6.7	34.3
431	9.1	12.9	2.6	1.6	1.4	27.6
449	9.3	19.8	1.3	--	0.9	31.3
459	5.0	21.1	3.7	--	1.0	30.8
463	6.7	15.2	6.8	--	1.8	30.5
465	10.9	10.7	5.4	--	1.5	28.5
466	9.2	11.5	4.3	--	6.2	31.2
474	4.8	11.6	5.2	6.1	4.8	32.5
479	5.4	15.9	8.0	--	1.1	29.4
Means	8.48	14.0	5.15	3.9	3.87	30.6

[a] Amount of seasonal growth after last annuli in millimeters.
[b] Total lengths of the shell from umbo to margin.

RESULTS

Under the assumption that each band on the shells is an annular band, the growth between each of the bands present on all of the shells from umbo to margin was measured and the mean growth rates calculated for each specimen. Under the same assumption, all annular bands counted suggest that the clams used for the study were already one or two years old. Table 1 shows the results of the growth study at Newport Bay for the *Chione* clams retrieved in

Table 2
RIDGE COUNTS FOR ANNULI, TOTAL RIDGE COUNTS, AND RIDGE COUNT MEANS (in *C. undatella*) FOR THE NEWPORT BAY MODERN GROWTH SAMPLE

Specimen Number	Annuli Lengths (mm.) 1	2	3	4	a	b
206	16	13	--	--	13	42
356	15	15	7	--	3	40
382	18	14	8	--	5	45
388	30	--	--	--	12	41
390	19	16	3	--	3	42
406	21	12	--	--	4	37
407	8	8	10	--	5	31
413	17	20	2	--	1	40
417	15	11	10	--	0	36
418	22	8	--	--	12	42
419	15	10	7	--	11	43
431	14	10	4	2	2	32
449	15	19	2	--	1	37
459	17	20	5	--	1	43
463	16	15	10	--	4	45
465	19	9	6	--	3	37
466	16	12	6	--	9	43
474	12	9	6	9	9	45
479	15	15	7	--	3	40
Means	16.8	13.1	6.2	5.5	5.3	36.9

[a] Number of growth ridges after last annuli.
[b] Total number of growth ridges from umbo to margin.

June 1987. The mean growth rates are 8.48 mm. in the first year, 14.0 mm. in the second year, 5.15 mm. in the third year, and 3.90 mm. in the fourth year.

Table 2 shows the results of the ridge counts for the growth study *Chione* clams retrieved in June 1987. The mean number of fortnightly ridges are 16.8 for the first year, 13.1 for the second, 6.2 for the third, and 5.5 for the fourth. These means differ from Barker's means of 16.9, 8.8, 4.5, and 4.0, suggesting differential growth between populations of species.

Table 3
PROJECTED SEASON OF DEATH FROM KNOWN SEASON OF DEATH (in *C. undatella*) USING DROVER'S METHOD OF SEASONALITY

Specimen Number	Annuli Lengths (mm.) 1	2	3	4	a	b	c	d
206	16	13	--	--	13	F	F	Su
356	15	15	7	--	3	Su	Sp	Su
382	18	14	8	--	5	F	Su	Su
388	30	--	--	--	12	Su	Su	Su
390	19	16	3	--	3	Su	Sp	Su
406	21	12	--	--	4	Sp	Sp	Su
407	8	8	10	--	5	F	Su	Su
413	17	20	2	--	1	Sp	Sp	Su
417	15	11	10	--	0	W	W	Su
418	22	8	--	--	12	F	F	Su
419	15	10	7	--	11	F	F	Su
431	14	10	4	2	2	Su	Sp	Su
449	15	19	2	--	1	Sp	Sp	Su
459	17	20	5	--	1	Sp	Sp	Su
463	16	15	10	--	4	F	Su	Su
465	19	9	6	--	3	Su	Sp	Su
466	16	12	6	--	9	F	F	Su
474	12	9	6	9	9	F	F	Su
479	15	15	7	--	3	Su	Sp	Su
Means	16.8	13.1	6.2	5.5	5.3			

[a] Number of growth ridges after last annuli.
[b] Drover's projected season of death for the modern sample using Barker means.
[c] Drover's projected season of death for the modern sample using Cerreto means.
[d] The actual season of death of the modern sample.

Table 3 shows the results of applying Drover's method of determining season of death for *C. undatella* using both Barker's and Cerreto's mean values for each sample (Table 3, columns b and c respectively). Using Barker's mean values, only six specimens (31.6%) were placed in the appropriate seasonal category. Using Cerreto's mean values, only four specimens (21.1%) were so placed.

Table 4
PROJECTED SEASON OF DEATH (in *C. undatella*) FOR KNOWN SEASON OF DEATH SAMPLE USING LYON'S SEASONALITY METHOD

Specimen Number	Ridge line counts	Lyon's season of death	Actual season of death[a]
206	42.9	B	A
356	40.3	C	A
382	45.0	C	A
388	41.3	B	A
390	42.1	C	A
406	37.5	B	A
407	31.5	A	A
413	40.0	B	A
417	36.0	C	A
418	42.0	C	A
419	43.0	B	A
431	32.0	B	A
449	37.0	A	A
459	43.3	C	A
463	45.0	C	A
465	37.0	A	A
466	43.9	A	A
474	45.0	C	A
479	40.2	C	A

[a] Of the 19 specimens killed in the summer season (June), only 4 (21.05%) were placed into the correct season of death.

Table 4 shows the results of applying Lyons' method of seasonal determination. Only four of the specimens (21.1%) were placed in the appropriate seasonal category.

Table 5 shows the results of applying Macko's method for deriving the season of collection. Using Barker's sample means, only 6 specimens (31.6%) were placed in the appropriate seasonal category. Using Macko's sample means from structures 2 and 3, only two (10.5%) and four (21.1%) of the specimens respectively were placed into the appropriate seasonal category. Using the possible correction for Macko's samples, only six and seven specimens (31.6% and 36.8%) for structures 2 and 3 respectively were placed into the appropriate seasonal category. Using Cerreto's sample means and Macko's projected percentages, only five (26.3%) of the specimens were placed into the appropriate seasonal category. Correcting for the possible seasonal growth percentages, only four (21.1%) specimens were placed into the appropriate seasonal category.

Using the data presented in each of the tables, the author also attempted to develop a technique for deriving seasonality by using the growth and ridge means and ranges with and without standard deviations. All attempts to develop a reliable technique for determining season of death utilizing external growth features failed.

CONCLUSIONS

The results of this live growth experiment in relation to archaeological applications is quite clear. Using a known season of death sample, it has been shown that none of the three proposed techniques are capable of accurately determining the season of death. In fact, not one of the proposed methods nor any of the possible corrections were accurate above 36.8%. It can therefore be concluded that the three seasonality techniques utilizing *Chione* clams and proposed for use along the southern California coast are invalid. Any inferences about subsistence scheduling of shellfish resources using these three methods of data analysis must be considered erroneous.

However, the possibility of developing means of determining season of death using different species, and testing of these species in different coastal regions, still exists and should be pursued. It is suggested that growth studies employing external landmarks as means of determining season of death be performed in other coastal regions and on other shell species in order to ascertain their usefulness. An

Table 5
SEASON OF DEATH (in *C. undatella*) FROM KNOWN SEASON OF DEATH USING MACKO'S METHOD OF SEASONALITY

	Annuli Lengths (mm.)												
Specimen Number	1	2	3	4	a	b	c	d	e	f	g	h	i
206	16	13	--	--	13	F	F	F	F	F	F	F	Su
356	15	15	7	--	3	Su	Sp	Sp	Su	Su	Sp	Sp	Su
382	18	14	8	--	5	F	F	Su	F	F	Su	Su	Su
388	30	--	--	--	12	Su	Su	Su	Su	Su	Su	Su	Su
390	19	16	3	--	3	Su	Sp	Sp	Su	Su	Sp	Sp	Su
406	21	12	--	--	4	Sp	Sp	Sp	Sp	Sp	Sp	Sp	Su
407	8	8	10	--	5	F	F	Su	F	Su	Su	Su	Su
413	17	20	2	--	1	F	Sp	Sp	Sp	Sp	Sp	Sp	Su
417	15	11	10	--	0	W	W	W	W	W	W	W	Su
418	22	8	--	--	12	F	F	F	F	F	Su	F	Su
419	15	10	7	--	11	F	F	F	F	F	F	F	Su
431	14	10	4	2	2	Sp	Sp	Sp	Sp	Sp	Sp	Sp	Su
449	15	19	2	--	1	Sp	Sp	Sp	Sp	Sp	Sp	Sp	Su
459	17	20	5	--	1	Sp	Sp	Sp	Sp	Sp	Su	Su	Su
463	16	15	10	--	4	Su	Su	Su	Su	Su	Sp	Sp	Su
465	19	9	6	--	3	Su	Sp	Sp	Su	Su	Sp	Sp	Su
466	16	12	6	--	9	F	F	F	F	F	F	F	Su
474	12	9	6	9	9	F	F	F	F	F	F	F	Su
479	15	15	7	--	3	Su	Sp	Sp	Su	Su	Sp	Sp	Su
Means	16.8	13.1	6.2	5.5	5.3								
Number of Correct Placements						6	2	4	6	7	5	4	

a Number of growth ridges after the last annuli.
b Macko's projected season of death for the modern sample using Barker sample means.
c Macko's projected season of death using the means from Structure 2.
d Macko's projected season of death using the means from Structure 3.
e Macko's projected season of death using the means from Structure 2 with possible corrected growth rates.
f Macko's projected season of death using the means from Structure 3 with possible corrected growth rates.
g Macko's projected season of death using Cerreto sample means.
h Macko's projected season of death using Cerreto sample means with corrected growth rates.
i The actual season of death of the sample.

example of another possible species that can be tested for the southern California region is the Littleneck clam (*Protothaca staminea*). The results of live growth research on *P. staminea* are currently under analysis by the author.

NOTES

1. Orton 1926; Fraser and Smith 1928; Weymouth 1921; Weymouth and Thompson 1931; Moore 1934; Newcombe 1935; Newcombe 1936a, 1936b; Coe and Fox 1942; Coe and Fitch 1950;

Haskin 1954; Stevenson and Dickie 1954; Dehnel 1956; Mason 1957; Craig and Hallam 1963; Merrill et al. 1965; Seed 1968; Schmidt and Warme 1969; Stanley 1969; Barker 1970; Rhoads and Pannella 1970; Farrow 1971, 1972; Andrews 1972; Koike 1973; Coutts 1974; Feder and Paul 1974; Evans 1975; Whyte 1975; Berta 1976; Lutz 1976; Paul et al. 1976; Clark 1977; Jones et al. 1978; Dillon and Clark 1980; MacDonald and Thomas 1980; Zolotarev 1980, Rhoads et al. 1981; Jones 1983, Rollins et al. 1986.

2. Shuster 1957; Barker 1964; Dodd 1964; Clark 1968; House and Farrow 1968; Pannella and MacClintock 1968b; Kobayashi 1969; Barker 1970; Farrow 1971, 1972; Evans 1972; Rosenberg 1972; Clark 1974; Hall et al. 1974; Clark 1975; Crabtree 1975; Evans 1975; Kennish and Olsson 1975; Thompson 1975; Berta 1976; Lutz 1976; Clark 1977; Gordon and Carriker 1978; Jones et al. 1978; Clark 1980a, 1980b; Crabtree et al. 1980; Jones 1980; Kennish 1980; Lutz and Rhoads 1980; MacDonald and Thomas 1980; Thompson et al. 1980; Jones 1981a, 1981b; Shaul and Goodwin 1982; Jones 1983; Rollins et al. 1986.

3. Epstein et al. 1951; Urey et al. 1951; Epstein and Lowenstam 1953; Lowenstam 1954; Clayton 1961; Keith et al. 1964; Pilkey and Goodell 1964; Weber and Raup 1966; Hudson 1967; Malone and Dodd 1967; Nelson 1967; Mook and Vogel 1968; Anderson 1973; Shakelton 1973; Fairbanks and Dodge 1979; Killingley and Berger 1979; Killingley 1980; Wefer and Killingley 1980; Killingley 1981; Williams et al. 1982.

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