GROWTH COLORATION: A METHOD FOR DETERMINING THE SEASON OF COLLECTION OF ARCHAEOLOGICAL SHELLFISH.

by

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ABSTRACT

Marine bivalves are often studied as indicators of the season of occupation of coastal archaeological sites. Literature review shows that most studies are based upon faulty assumptions about shell growth. The potential of a recently introduced technique for determining the season of death of marine bivalves is examined and tested. The technique records seasonal patterns in the growth coloration of the ventral margin of modern shells. The margin will appear either opaque or translucent when viewed in thin section. Ratios of opaque and translucent shells are recorded for each month of the year. An estimate of the season of death of prehistoric shells can be made through comparison with modern ratios.

Literature reviews of the mechanisms of shell growth, of types of archaeological analysis based upon shellfish remains, and of previous archaeological studies of the season of death of marine bivalves are provided. Appropriate methods for collecting, sectioning, and analyzing modern comparative shells, as well as the time required for these activities, and the reliability of the results are discussed.

It can be concluded that the bivalve *Protothaca staminea*, common in archaeological sites in British Columbia, is the most useful species for archaeological season of death studies. This species displays the most distinctive seasonal changes in growth coloration, and is the easiest to analyze in terms of time expenditure. Future researchers should concentrate on this species.

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CHAPTER ONE: OBJECTIVES OF RESEARCH

Bivalve season of death estimates have been a part of coastal archaeology for the last twenty years. Despite the number of studies done on this subject, very few researchers have presented convincing results. This is usually due to a combination of erroneous assumptions about shell growth, and techniques of analysis based upon these assumptions.

Recently, these problems have been acknowledged. On the Atlantic coast of North America, new methods of analysis have been implemented. These new methods use modern comparative collections of shellfish to discern growth patterns within a population. It is recognized that shell growth is highly variable, and it is through the study of variability that a seasonal growth pattern can be determined. Analyzing small numbers of individuals will not reveal the variability within the population from which they are drawn.

This thesis undertakes a study of seasonal growth variation in bivalves common to the Gulf of Georgia area of the British Columbia Coast. The technique of comparing the proportions of different growth coloration within populations of shellfish is tested to determine its utility for application on the Pacific coast. The goal of the study is to document a seasonal growth sequence which can be used for comparison with archaeological shell.

The study examines the mechanisms of shell growth, and attempts to determine the importance of environmental factors. A

review of previous archaeological determinations of the season of death of bivalves is presented. The techniques used in earlier studies of season of death are brought into question based upon the recognition that a wide variety of environmental forces can produce analogous patterns of shell growth.

The technique of comparing proportions of specimens dying during stages of Translucent and Opaque growth to determine the season of death is then tested. Its validity is demonstrated through the analysis of modern materials collected at known dates. Both the precision and the reliability of the technique are tested. Possible confounding variables are suggested, and their effect on patterns of shell growth coloration are analyzed. Seasonal growth curves are constructed for each species, and all species combined.

Six different species of bivalves are examined in the study. Each is discussed in terms of how well its growth coloration reflects seasonal changes in the environment. The efficiency of the technique is also tested. The amount of time needed to prepare and analyze specimens is considered, along with sources of hinderance, such as breakage.

Finally, the utility of the growth coloration technique to archaeological analysis is examined. The efficiency of the technique is compared to the precision of the results, and recommendations for additional research are made.

CHAPTER TWO: SHELL GROWTH

Figure 1 illustrates the important aspects of bivalve shell morphology, using a generalised valve. Illustrated are the ventral and dorsal margins, the umbo, and growth lines, both external and internal. The bivalve is composed of a left and a right valve. These are connected at their dorsal margin by a ligament. This ligament is often called the hinge. Not illustrated in figure 1 is the chondrophore, which is found on the species *Mya arenaria*. This is a small protrusion of shell which emanates from the umbo, and curves toward the ventral margin on the internal side of the shell. The ligament attaches to the umbo, assisting in shell closure. Quayle (1960:13) provides an excellent illustration of bivalve shell morphology.

Shell is produced by the deposition of calcium carbonate crystals ($CaCO_3$) onto an organic matrix known as conchiolin (Wilbur 1964:244). Conchiolin is primarily proteinacious. The portion of the animal responsible for this deposition is the mantle, which covers the inner growing surface. The chemical substances (calcium and carbon dioxide) needed for shell growth are taken in by the organism from the external environment. They are moved into the mantle, where calcium and carbon dioxide are combined to form calcium carbonate ($CaCO_3$). Beyond the mantle is the extrapallial fluid, where the organic matrix and the crystalline components of the shell are formed. The organic matrix (conchiolin) is deposited as a layer on the inner surface of the shell. The crystalline substance is then deposited onto

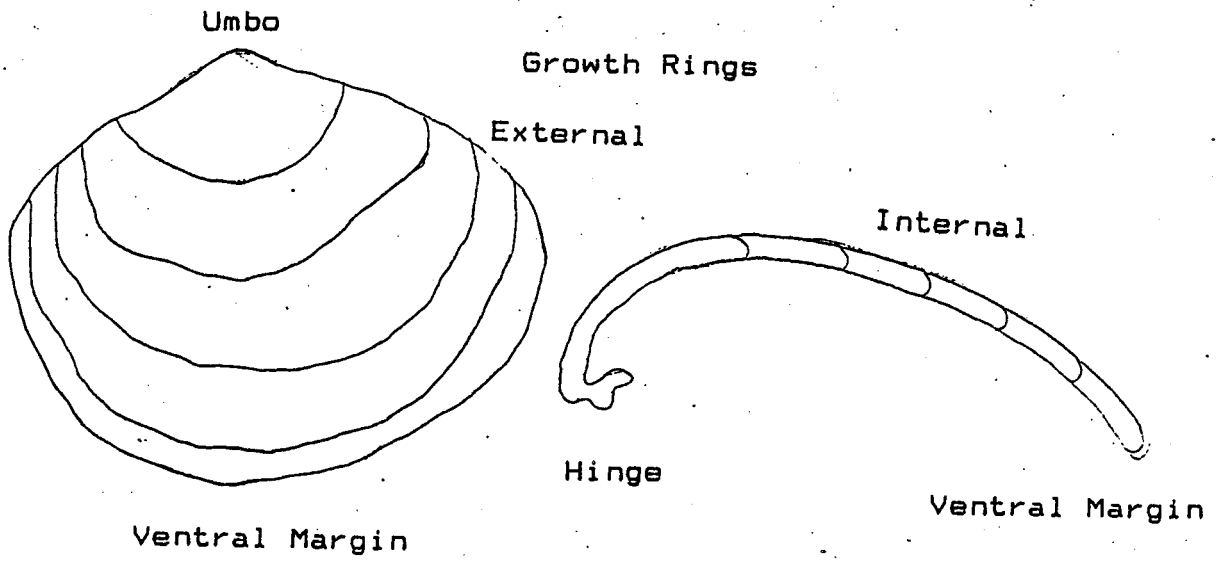

Figure 1.

Bivalve Shell Morphology

the organic matrix, and the two may or may not mix, depending on the species in question (see Crenshaw 1980). Barnes (1987:404-405) suggests that shell formation occurs first at the points of muscle attachment (mantle to shell). Crenshaw (1980) points out that shell formation is not unidirectional, and involves dissolution (decalcification).

Recently, Lutz and Rhoads (1977) proposed an hypothesis of shell growth which utilizes calcification and decalcification as its basis. These authors suggest that calcium carbonate is deposited during aerobic metabolism (when the shell is open to the external medium -- gaping), as is organic material. This results in shell construction. At this time, which is associated with high tide, the water is high in oxygen content.

> As the concentration of dissolved oxygen falls, such as in the internal microenvironment created by the organism during periods of shell closure, anaerobic respiratory pathways are employed, and the level of succinic acid ... within the extrapallial fluid rises. The acid produced is gradually neutralized by the dissolution of shell calcium carbonate, leading to increased levels of Ca^{2+} and succinate... within the extrapallial and mantle fluids.... As a result of this decalcification, the ratio of relatively acid-insoluble organic material to calcium carbonate increases at the interface between the mantle and shell (Lutz and Rhoads 1980:211).

This leaves a concentration of organic material without calcium carbonate to support it. Lutz and Rhoads (1980) suggest that the weakened structure tends to collapse inward, to decrease the distance between the mantle and the shell. With the shell opening again, and aerobic metabolism returning, calcium carbonate and organic material are once again deposited. This deposition goes

onto an area where there is already a relative abundance of organic material, resulting in a localized variation in compound ratio. "The end product of this process, from a strictly structural viewpoint, is one growth increment" (Lutz and Rhoads 1980:211). In other words, calcium carbonate and organic material are deposited, followed by the dissolution of one of these compounds, calcium carbonate, and another deposition of both compounds, resulting in a location with more of the organic compound than the calcium carbonate. For a more detailed discussion of this phenomenon, see Lutz and Rhoads (1977; 1980).

Day (1984:2503) suggests a slight variation on this theme, in which both calcium carbonate and conchiolin are deposited throughout the year, but with calcium carbonate deposition being reduced or halted during times of stress. This explains variations in growth increment width throughout the year.

The following discussion mentions many types of growth lines, rings, or increments. External growth lines are ridges which can be seen on the external surface of a valve. They are usually slightly raised, relative to the surface of the valve. The so-called winter check ring is an example of an external growth line. Internal growth lines can only be seen if the valve is sectioned. Larger lines, such as annual, storm-induced, or spawning lines may be seen with the naked eye. Smaller lines, such as tidal and daily lines can only be seen with high power magnification. Different types of lines are assigned names on the basis of the phenomena which is thought to be responsible for

their formation. For example, a name suggestive of a time interval, such as "tidal lines", is assigned when the number of lines observed corresponds with the number of times an event is known to have happened. Thus, if ten lines are observed between marking and sectioning, and there have been ten tides in this interval, the lines are refered to as tidal lines.

Smaller growth lines, which can only be seen under magnification, apparently form continuously. Larger lines, such as spawning lines, storm-induced lines, or winter check-rings, are only formed at irregular intervals. They are distinguished from other types of lines on the basis of their size and their sudden appearance.

FACTORS AFFECTING SHELL GROWTH

Growth is most apparent in shells in the form of external growth rings. The formation of these rings has interested a number of researchers in a variety of disciplines. Archaeologists have studied these growth lines to determine the season of death of the organism in question, which in turn yields information about the gathering practices of the people under study. The nature of growth rings in shells (and a number of other organisms including fish and corals) is still not entirely understood, and needs further study before it can be fully utilized. It has become apparent that a number of things can influence the growth patterning of shell. A number of

physiological and environmental events are recorded in shell growth. These are: Circadian (daily, i.e.: light and darkness) rhythms, spawning, temperature, season, tides, and storms. These will be discussed briefly.

LIGHT

A number of authors have considered light to be an important influence on shell growth. Clark II (1975) reports the results of a number of experiments with shortened light cycles (i.e.:8 hours light, 8 hours darkness). He found that the number of growth increments encountered tends to correspond to the number of light-dark cycles to which the animal was exposed, which suggests that the lines are formed in response to exposure to light or darkness. Clark II (1975) feels that this is a biological rhythm. His work suggests that the organism will follow the light cycle so long as it does not deviate from the normal solar cycle by more than six to eight hours.

Other authors who have studied the effects of light on bivalve growth have noted that its effect seems to work in combination with tidal cycles. Thompson (1975) suggests that shell growth occurs in darkness, and with a high tide (when gaping occurs). Hence, the growth increments seen in shell are a combination of light and tidal exposure lines, with growth ceasing during daylight, and at low tide when it occurs at night. Thus, a group of lines will contain a pattern of single lines, representing one opening per 24-hour period (when low tide occurs during the day) and complex lines, representing two openings per

24-hour period (low tide occurs at night). These will repeat every fortnight. Richardson et al. (1979) have dismissed light as a factor in the formation of growth lines, citing an experiment which demonstrates that "...there is no significant difference in the number of bands in either layer between those animals exposed to submarine daylight and those kept in the dark box" (Richardson et al. 1979:281-283).

SPAWNING

The effects of spawning on line formation have received relatively little study. Thompson, et al. (1980), suggest that there is a correlation between spawning and check-line formation in the ocean quahog (*Arctica islandica*). Samples of this species were taken every 2-4 weeks for a period of two years. A line appears to form during the fall season, between September and December, which coincides with the season of spawning. Thompson, et al., note that spawning occurred only once per year in each individual studied. "These data are completely consistent with the hypothesis that line deposition occurs only once a year at the time of spawning, making the bands annual" (Thompson et al. 1980:29). These authors also report that a coincidence of spawning and line formation are also present in two species of surf clam (*Spisula solidissima* and *S. sachalinensis*). Thus spawning could play an important role in the deposition of growth rings.

TEMPERATURE

Many authors cite the presence of a winter "check-ring" or cessation mark (i.e.:Fairbanks 1963; House and Farrow 1968; Orton 1926; Pannella and MacClintock 1968; Fritz and Lutz 1986). The prevailing view is that this is a mark of growth cessation, which occurs annually and is caused by a decrease in temperature. Pannella and MacClintock (1968) observed that there was a break in the deposition of increments in the specimens of their study, and that it seems to correspond to the first major freezing spell encountered. However,there was no stoppage in growth, as thin layers were put down daily, although at an angle to the previous growth plane. House and Farrow (1968:1384) also note that "there is little evidence for complete cessation of growth". Both authors suggest that there is a definite decrease in the size of the growth increment if it is deposited in winter. Inherent in this argument is the idea that growth increments should be largest during times of higher water temperature, when growth conditions are optimum. This has been found to be the case in a number of studies (i.e.:Pannella and MacClintock 1968; Rhoads and Pannella 1970; Kennish 1980). Whyte (1975:162)

> suggests that since chemical reaction rates increase with temperature, and since the solubility of carbon dioxide decreases with increase in temperature, it might be expected that secretion of carbonate would be favored by warmer waters.

However, several authors have pointed out that the relationship between temperature and growth increment size is not clear cut. Williams et al. (1982) suggest that growth can be slowed in some

species if the temperature is too high. House and Farrow (1968) note that there was not a tight correlation between water temperature and growth rate, with growth slowing after the temperature reached a certain point. Evans (1975) notes that the cockle (*Clinocardium nuttalli*) does not seem to be drastically influenced by water temperature (see below however). Obviously, it will be necessary to know the temperature tolerance levels of a given species before the effect of temperature upon growth can be generalized.

SEASONALITY

Directly related to temperature is the seasonal growth rate. Pannella and MacClintock (1968) suggest that the season of death of a bivalve can be interpreted on the basis of the thickness of its final growth increments, with summer increments being thicker than winter increments. Berry and Barker (1975) note a similar situation in their studies. Whyte (1975) comments that growth rates should achieve their maxima during the summer and their minima during the winter if temperature is the controlling factor. Evans (1975) reports that *Clinocardium nuttalli* grows up to 25 times faster during the summer than during the winter.

However, some authors have reported the opposite situation. House and Farrow (1968) state that summer growth rates were not much faster than winter growth rates for some specimens. Jones (1980) comments that some species will exhibit winter check rings throughout part of their range and summer check rings in other parts of the range.

TIDES

Clark II (1974) reports that three types of tides are reflected in growth increments (N.B.:these are given in lunar days): Semidaily tides (occurring every 12.42 hours); daily tides (24.84 hours); and fortnightly tides (14.3 lunar days). Clark II (1974:83) suggests that daily tidal lines are unlikely to be observed in long sequences because they are really just a variation of semidaily tidal lines. A number of authors report the presence of growth lines which seem to correspond to tidal cycles. Evans (1972) notes that growth patterns in the cockle *Clinocardium nuttalli* follow a tidal cycle,and that there is a fortnightly overlap of line cycles, due to the semi-diurnal tides in his study area (coastal Oregon). These line cycles are composed of single and complex lines, with the complex lines being formed during neap tides when the individuals are exposed twice in one day. Evans (1975) also notes tidal lines with a periodicity of 24 hours 50 minutes during spring tides. Thompson (1975) reports that the bivalves in his study demonstrate a growth cycle which deviates from a daily (solar -- 24 hours) cycle by about 0.8 hours. This likely reflects a lunar, and thus tidal, cycle. Berry and Barker (1975) report clusters of fine lines which correspond to a fortnightly cycle. House and Farrow report a similar cluster of groups of 29 lines, suggesting two fortnightly clusters combined. Richardson et al (1979) report a cluster of growth lines corresponding with spring tides.

It seems unlikely that any one factor is responsible for the

formation of growth lines in shell. Most of the authors in the preceding discussion suggest that a combination of most or all of the above mentioned factors contribute to the situation. At present, it is difficult to determine which is the most important factor, although it seems that the tidal cycle is involved regardless of other variables. It is essential to try to monitor as many variables as possible when attempting to interpret shell growth patterns. It is not justifiable to assume that one variable, such as water temperature, is the dominant factor behind the observed pattern. Only with careful observation of all the variables can an understanding of the situation be attained.

CESSATION MARKS

There is one other problem which is frequently encountered in growth-line research, and that is the presence of "cessation marks" which do not correspond to seasonal or tidal patterns. These marks are usually referred to as disturbance rings, and are most frequently explained as being caused by storms (e.g. House and Farrow 1968; Pannella and MacClintock 1968; Rhoads and Pannella 1970; Berry and Barker 1975;). Rollins et al. (1986) have correlated a series of disturbance rings in South American bivalves with the 1982-83 El Niño event. However, very few other authors have actually demonstrated this type of relationship.

Occasionally individuals will exhibit anomalous growth patterns when compared to a larger group. Rhoads and Pannella

(1970:145) refer to these as private events. Clark II (1968) discusses this situation in terms of missing growth lines. He suggests that this situation also results from storm disturbance. Clark II (1968) feels that missing lines can be detected by comparing the maximum number of lines exhibited by a population for a given period, considered reflective of the actual number of lines which should have been deposited, to the number of lines observed on a given shell. Missing lines can then be "inserted" as is occasionally done in dendrochronology. However, Clark II does not explain how to determine whether the population contains individuals with missing lines or individuals with extra lines caused by storms. He instead relies on the results of his experiments which show that there are never more lines found on a shell then there were days covered by the study. This correlation was discovered by studying a rather small population (12 individuals). Clark II (1974) suggests that predator attack can cause anomalous growth. Berry and Barker (1975) suggest that local microenvironment (such as sediment size) can also cause this to happen. One of the most interesting experiments on this topic is that of Janson (1982) who demonstrated that genetics play an important role in the response of an organism to environmental change. Thus, it is apparent that a population of shells as a whole, rather than as individuals, must be analyzed before conclusions can be drawn about the nature of the variables affecting growth rates.

CHAPTER THREE: USES OF SHELLFISH IN ARCHAEOLOGICAL STUDIES.

Archaeological studies utilizing shell remains have dealt with a number of issues. Seasonality of both shellfish collecting and site occupation are of primary concern herein, and will be discussed later. Shellfish are used as indicators of environmental change (Claassen 1982, 1985, 1986a, 1986b; Clark & Straus 1983; Ryder 1963; Shaw 1978; Voigt 1975;) of cultural preference for certain species (Claassen 1986a; Drover 1974; Mellars 1978; Voigt 1973,1975); of over-exploitation by human predators (Anderson 1981; Claassen 1986a; Clark & Straus 1983; Mellars 1978; Sloan 1985; Straus, et al 1980; Swadling 1976, 1977; Volman 1978;); of culture chronology (Claassen 1982, 1986a; Russo 1988); of technological change (Claassen 1986a) and of human diet (Bailey 1975, 1978; Claassen 1986b; Erlandson 1988, Meehan 1977a, 1977b, 1982; Voigt 1975; Yesner 1980). Each of these topics will be discussed in turn.

Changes in the natural environment are recorded in bivalve shells (see chapter two). Ryder (1963:309) discusses decreasing shell size as evidence of increasing siltation on a local scale. Ham (1976) reports a similar situation in the Gulf of Georgia region. Claassen (1982:208) states that the two species most commonly found in middens in North Carolina inhabit drastically different bottom types, in terms of siltation. "Shifting sand and soft mud are the only types of bottoms which are totally unsuitable to oyster communities but *Mercenaria* [quahog] can be found in both". Claassen (1986a:133) describes some of the

effects of siltation upon oysters and clams.

> Growing in beds and bars, oysters are highly clumped and have little or no mobility. The larval requirement for an extremely high rate of water exchange results in most oysters locating in the mouths of tidal creeks and in broad coves where fast-moving water results in a sand or hard dirt bottom. The advent of silting in an oyster locale indicates a lowered rate of water turnover which reduces their reproductive success and, in some cases, smothers the entire population. Quahogs, living in amorphous beds, are far less clumped, always occur singly, and are more mobile than oysters. Furthermore, water-exchange rate is not as crucial a factor in larval survival. Migration over short distances to escape episodic siltation is also possible. The net result of these factors is that quahogs can tolerate slower water and its high silt content, and even a silty substrate.

Claassen (1982:215) reports one site (ON29 in North Carolina) where the initial layer is a mixture of fine sediment and clam shells (*Mercenaria*), the next layer is 40cm of sterile sand, followed by a layer of mixed clams and oysters and finally a layer of clams. This is suggestive of fluctuating levels of siltation, with a pattern of gradual increases followed by a slight reduction, followed by another increase. It is also suggestive of changing rates of water movement. Claassen (1985) feels that increasing siltation is the agent behind the change in species utilized at Escambia Bay, Florida.

Changing ratios of species can also be evidence of chemical content in the surrounding water. Shaw (1978) suggests using trace elements, to determine the chemical composition of the water, although I am not aware of any studies in which this has been applied in an archaeological context. Salinity levels have been studied, although not in the same manner as trace-elements.

Again, knowing the tolerance levels of the species in question is essential. Shaw (1978) correctly states that very little work has been done on this topic. This is still true today, although Claassen (1982, 1986a) has done some research in this area. Her research demonstrates that changing salinity rates may be observed, at least theoretically, by observations of changing species ratios. Claassen (1986a:132) suggests that a sudden change from quahog exploitation to oyster exploitation could be evidence of a sudden shift in the salinity of the local area (oysters apparently can tolerate a lower salinity than can quahogs). Heavy spring run-off could be responsible for such an occurrence. The major problem with this type of study seems to be that there is very little agreement among biologists about what the salinity tolerance levels are for various species. There seems to be some overlap in the case of *Crassostrea virginica* (oyster) and *Mercenaria mercenaria* (quahog), the species with which Claassen is dealing. Claassen appears to contradict herself by suggesting that oysters can survive under conditions of lower salinity (1986a:133) and reporting that quahogs have been known to survive under the same condition (1986a:132). This leaves her current results questionable. More work needs to be done on this topic before it can be of any great utility to archaeologists.

Changes in water temperature can also be detected through changes in the species found in sites. Clark and Straus (1983) suggest a warming trend in Cantabrian Spain due to the absence of

the cold-water adapted species *Littorina litorea* in the middle strata levels at La Riera cave (19,000 - 14,000 B.P.). Braun (1974) reports an oceanic warming trend in New England through a succession of species changes. He demonstrates that utilization goes from oyster to quahog to mussel (*Mytilus edulis*) to soft-shelled clams (*Mya arenaria*). The changes correspond with the reduction of ocean temperatures (Braun 1974:591). Voigt (1975) suggests that water temperatures were lower during Middle Stone Age times at Klasies River Mouth in South Africa due to the presence of the cold-water adapted species of limpet *Patella granatina*. Again, this is a topic that needs further investigation, but it is possible to posit such an event as warming or cooling water temperatures on the basis of changing frequencies of shellfish species. Oxygen isotope studies (e.g. Deith 1985; Shackleton 1971, 1973) can give more precise evidence of such changes, but is a very expensive technique to implement, and sample preparation is both difficult and time consuming (E. Nelson 1987: personal communication).

Several authors have interpreted shell deposits as a reflection of the species available to the collectors, usually in a similar proportion to what was available. That is to say that it is assumed that these deposits are an accurate record (qualitatively and quantitatively) of the available biomass.

> To argue that environmental change causes a change in shellfish collection strategies and subsequently in discarded debris is to assume that midden constituents in their proportions accurately reflect the biomass available at the time of collection. I personally favour this assumption about prehistoric foraging

(Claassen 1986a:131).

Anderson (1981:113) states that "shellfishers ought to collect most of the different shellfish species which they encounter". He bases this on the assumption that, once encountered, one species is no more time consuming to obtain than another (although personal experience shows that this is not necessarily the case). However, there is evidence which is contrary to these assumptions. Voigt (1975) reports undertaking an intensive coastal survey in South Africa to determine what species were available and in what quantities. She then excavated a modern midden for comparison.

> There is a total lack of similarity between the species list for the shore survey and for the midden. This may be explained in two ways. Either the area which we chose for the survey was not representative or had already been cleaned out, or a midden cannot be regarded as being an accurate reflection of local molluscan populations. If the latter is true, it goes some way to support the contention that a midden, although dependent on availability, is itself a reflection of dietary habits rather than availability. Most of the common species in the midden were at least present in the shore survey, but there is no similarity in numbers (Voigt 1975:94-96).

This observation certainly lends credence to Voigt's (1973) earlier comment that changing species ratios at Klasies River Mouth were evidence of changes in collection "...and therefore dietary preference" (Voigt 1973:306). She further suggests that the contents of a midden represent both meals and a cultural preference of species, which will occasionally be to the exclusion of other species. Voigt (1982) suggests that there is a definite pattern of species preference at Klasies River Mouth:

> ...It can be seen that the sequence began with a fairly even distribution of species in MSA I. Definite preferences begin to be detectable in MSA II. During the earliest Howieson's Poort stage these preferences swung completely away from the *Patella spp.* toward *Turbo*, *Perma*, and even *Dinoplax* species, which made a surprisingly large contribution to the prehistoric diet. The younger Howieson's Poort and the MSA III and IV stages exhibit a steady increase in the number of Patellidae, a pattern which persisted into the LSA period. However, in the younger LSA levels the *Patella* species again lost favour in the face of concentrated collecting of *P.perna* and *T.sarmaticus*.

Mellars (1978) makes a similar observation for middens at Oronsay Island. He suggests that the huge numbers of limpets found in middens are unlikely to reflect numbers actually present, but rather reflect deliberate selection. Likewise, the numbers of periwinkles and dog whelks encountered are considered to be less than the amounts actually available. Mellars explains this preference for limpets on the basis of their higher meat-to-shell ratio, and therefore, the shorter preparation time involved. He suggests that periwinkles and dog whelks were utilized primarily to add variety to the diet. White (1984) cites some very interesting, and unexplained, evidence from Australia. Certain aboriginal groups in southwestern Australia do not make use of shellfish, even though it is a resource which is available in abundance. He also mentions that in Tasmania, a certain species of scaled fish (parrotfish) is found in abundance in archaeological contexts prior to 3500 B.P. and is never encountered after this time period, even though it is still extant today. These observations tend to support the notion that cultures which rely on gathering do not exploit every resource

available to them, and those which are utilized may not be exploited in direct proportion to their abundance (although Dortch et al. 1984 suggest evidence for selected mollusc use in this part of Australia prehistorically). Sloan (1985:145) discusses a similar situation in Britain. Excavation at Broxmouth yielded evidence which suggests that shellfish were not a favored resource, despite the site's proximity to the coast. He suggests that they were only taken during times of famine. Drover (1974) points out that although *Chione undatella* is the most common species of clam found on modern beaches in southern California, *Chione fluctifraga* is the most common midden component, suggesting culture choice or microenvironmental change. Claassen (1982, 1986a) takes exception to the concept of identifying human choice as the agent behind species changes. She suggests that such an hypothesis is difficult to test, and that if a single species is collected above all others available for a long time period then it must be both the preferred species and the biologically dominant one. She concludes that midden dominance therefore represents biological dominance. More work must be undertaken before the contrasting views of Claassen and Voigt can be assessed.

Several authors have suggested that over-exploitation by human gatherers can be seen in the archaeological record. Decreasing shell size through time are the data of concern here.

Swadling (1976) discusses the effects of human exploitation on shellfish beds. She states that the overall age-structure

will change, becoming younger; that the size-range will decrease, as individuals will be collected before they have a chance to reach their full size; that the rate of growth will increase, as there will be fewer individuals per area unit, and thus less competition for available food. This should result in larger shells displaying juvenile characteristics. Swadling suggests that by looking at the rate of growth in individual shells, heavy exploitation should be observable, as the spacing of growth lines should increase in exploited populations, indicating faster growth. Swadling (1977) discusses evidence for periods of heavy exploitation in prehistoric New Zealand. At Otakanini Pa, Swadling reports that the level of shellfish exploitation during the latter portion of Period I was the heaviest of all, and that it was not reached again until the end of Period III (no dates are given). Materials from the early part of Period III show less evidence of heavy exploitation. During Period III, there was "constant removal of the older and larger-sized individuals [cockles], with the consequence of a general reduction in the age range and the length of the shellfish found" (Swadling 1977:15). This was accompanied by the expected increase in growth rate and presence of wider-spaced growth lines. She feels that this may imply an intermittent occupation of the site, and that the shellfish beds may have been allowed to "lie fallow", following Period I. This could explain the "relatively unexploited state of the beds at the commencement of the Period III occupation" (Swadling 1977:16).

Clark and Straus (1983) and Straus et al. (1980) report evidence of over-exploitation of limpets (*Patella vulgata*) at La Riera cave in northern Spain. Measurements of limpet-shell diameter show a marked decrease through time. Straus et al. (1980) state that the large limpet species (*P. vulgata*) decreases first in frequency and then in size. It is gradually replaced by the smaller limpet *P. intermediata*. This is seen as evidence of overexploitation of the more desirable species, and a shift to less favorable collecting areas. Clark and Straus (1983:147) comment:

> The exploitation of species typical of moderately wave-beaten coastal habitats [*P.intermediata*] only becomes evident fairly late in the sequence, and is regarded as an extension of earlier estuarine collecting into zones where edible species were smaller, less densely concentrated, and more perilous to acquire. As no climatic factors were adduced to account for this change, and as measurements of limpet diameters indicated over-exploitation of estuarine species through time, we suggest that the inhabitants of the area were moved to increase the diversity of their subsistence base (even to the extent of collecting 'less desirable', lower-yield, higher-risk foods), by an increasingly dense local population which was fast outstripping its 'traditional' resources'.

Clark and Straus support their opinion with evidence of an increasing range of food at level 19 (sea urchin and top shells are added to limpets) and again at level 24 (where mussel appears). Sloan (1985:143) describes a similar situation at Oronsay, where limpet sizes also decrease through time. Mellars (1978) posits that these limpets were either gathered at the lowest part of the tidal range, or are evidence of over-exploitation. In South Africa, Volman (1978) reports another

similar situation where the Middle Stone Age site of Sea Harvest yields larger limpet shells and lower shell density than the nearby Later Stone Age shell middens. He suggests that this could be evidence of less intensive collecting by the Middle Stone Age people.

Anderson (1981) argues that such a size trend through time is to be expected. He points out that archaeological evidence consistently shows a shift from larger to smaller species through time. While he feels that culture preference cannot be ruled out, he questions the utility of switching to smaller resources. Anderson feels that the trend towards smaller species and individuals is the result of a collecting strategy which is geared towards larger individuals which continues for a prolonged period of time. The large individuals tend to get smaller through time because they are collected before they reach full size. Anderson mentions that the observed size-change pattern in shellfish is well in keeping with other observed resources such as birds.

Claassen (1986a), on the other hand, questions the entire idea of over-exploitation of shellfish resources. She lists four commonly utilized test implications for recognizing over-exploitation. These are:

1. A decrease in mean shell length through time.
2. The modal size of exploited population is smaller than unexploited population.
3. An increase in number of less easily procured species.
4. An increase in number of less easily processed species.

> Not one of these test implications is adequate for identifying a shellfish population overharvested by

> humans. Each one individually as well as the four collectively can result from environmental change. The first and second implications are equally relevant to the hypothesis of intensive exploitation by other predators, and the third and fourth implications are equally relevant to the hypothesis ...[of]... technological innovations (Claassen 1986a:127).

Claassen (1986a) cites several instances of modern shellfishing, which have consistently removed millions of shellfish from an area without ever causing extinction of the species, but with the effect of reducing the size of the shellfish population available. She feels that aboriginal shellfishing was unlikely to have ever reached such levels as would be needed to cause such a phenomenon. However, she does not discuss the observation of decreasing specimen size, except to attribute it to environmental change. She suggests that to illustrate over-exploitation of a species, one must find evidence of "...a reduction of the mean age of the shells from bottom to top of the midden with no attendant difference in mean shell length, height, or thickness when the same age set is compared" (Claassen 1986a:130).

Catterall and Poiner (1987) have attempted to determine the effects of human gathering on shellfish beds in northern Australia. They report that the types of observations made by researchers such as Swadling (1976, 1977) will occur only if sexually immature individuals are collected. Although there is little data regarding the size of sexually mature species outside of those described by Catterall and Poiner, it appears as though individuals greater than about 30-40mm in size are sexually mature. It seems unlikely that individuals smaller than this

size could have been utilized as a food resource.

Shells have the potential to be used in a chronometric context, and Ambrose (1967:178-179) discusses some early research on this topic. Correlating shell ring patterns should allow for the construction of a tight temporal sequence. However, few authors have attempted this. Koike (1979:73) reports a Japanese midden accumulation which was formed in "...precisely 500 days...". Koike (cited in Claassen 1982; 1986b) has attempted to construct a "conchochronology", similar to a dendrochronological sequence, but the results of this study have not been published. Dillon and Clark (1980) tested the growth line patterns of shells of known age, and found some remarkable results.

> Twenty-two seasonal growth records are clearly grouped into three sets, with all the 1971 growth records in one group, the two 1969 growth records in another group, and the two 1970 growth records forming a tight subgroup within the last group, which otherwise consists entirely of the 1972 growth records. This remarkable separation of contemporaneous from noncontemporaneous growth records is convincing evidence that comparisons of growth-line records can be used to test for contemporaneity (Dillon and Clark 1980:413).

Clarke and Clarke (1974) look at species frequencies at Yuquot, and find that California Mussel (*Mytilus californianus*) is the dominant species in all levels but the most recent (contact), where it is replaced by Butter Clam (*Saxidomus giganteus*). They suggest that this change is due to a change in predator pattern; prior to contact, local sea otter populations were very high and these animals collected most of the Butter Clams. With the

advent of contact and the beginnings of the fur trade, sea otters were hunted to extinction locally, meaning that the people in the area had no competition for the Butter Clam resource.

Claassen (1986a) has attempted to demonstrate temporal patterns for the southeastern United States on the basis of changing species ratios. Her results demonstrate basic trends for several areas, but are unable to delineate the age of materials beyond assignment to a phase in the local sequence. She suggests (1986a:134) that dominant midden species may not be the most temporally useful, and that secondary species may be more sensitive indicators of time. Claassen's (1986a) ideas have recently been challenged by Russo (1988). He argues that Claassen's results are based on too small a sample size, and do not hold up under testing with materials from a large number of sites. Many authors (e.g. Braun 1974) have noted a tendency for the number of utilized species to decrease through time. Application of this observation may also be of use in determining the time of occupation.

Technological change has occasionally been cited as the reason for changes in the species of shellfish encountered in an archaeological context. Snow (1972) suggests that a change in procurement technology is responsible for the change of species encountered through time in the middens of coastal Maine.

> On the basis of current evidence, I now consider technological development to have been primarily responsible for the progressive expansion of the number of species exploited and the consequent improvement in the reliability of this resource generally. There eventually emerged a seasonal preference for common

> [soft] clams, individually more difficult to obtain than some other species, but on the whole far more numerous and widespread (Snow 1972:214).

Ritchie (1969) reports a similar situation at Martha's Vineyard, positing an early adaptation to a coastal environment with many types of molluscan resources, but with the knowledge of how best to exploit them only coming with time. Kent (cited in Claassen 1986a) notes that deep-water oysters appear at St. Mary's City, Maryland, between 1720 and 1740, corresponding with the appearance of the oyster tong as a means of collection. Thus, it would seem that the presence of new, more difficult to obtain species in a shell assemblage could be an indication of technological advancement (or of climatic change -- see earlier discussion).

Common to all the above studies is the fact that the shellfish were used as food. A number of authors suggest that collecting shellfish was an important activity, and consequently that shellfish played an important role in diet. Meehan (1977a) reports that the Anbara (of Australia) collected shellfish of several species from a variety of habitats throughout the year. Shellfishing trips were undertaken on 81% of the days during the period of July and August. This decreased to 36% for the period of September to December, and increased again to 71% from January to July. Only one species was important throughout the year (*Tapes hiantina*), accounting for 61% of the collected food weight and 64% of the collection days. Meehan (1977a:367) reports that this species is fairly easy to obtain, high in calories, and

"thus a woman could provide enough calories for herself for a day by gathering *Tapes hiantina* for two hours". Diet was studied for the month of April, and shellfish was found to contribute 51% of the gross weight consumed, and comprised 22% of the net flesh eaten. This figure dropped to 15% during monsoon season (Meehan 1977a:369). Meehan cautions that although shellfish is an important resource, especially during the wet season, it is not crucial and could be replaced by other resources if necessary. Meehan (1977b) reports data which indicate that shellfish never provide more than 9% of the caloric intake of the Anbara. However, shellfish can provide up to 26% of the protein of the diet, and is thus important in that manner. Meehan (1977b) suggests that shellfish were a constant source of fresh protein (and the Anbara consider freshness to be of prime importance in their meals), and a reliable one. While mammal protein is higher in calories, it is encountered on a much more limited basis than shellfish. Thus, shellfish are a dependable part of the Anbara diet, and could be relied upon if other methods of procurement failed. Meehan (1982) further demonstrates the importance of shellfish to the Anbara by mentioning that distances of up to 3km are traveled to gather this resource. According to her earlier work (Meehan 1977b), the Anberra were unwilling to travel this distance to collect meat from a freshly killed buffalo, which would have yielded over 500kg of meat much higher in calories than that of shellfish.

Other authors have suggested that shellfish play an

important role in human diet. Yesner (1980) points out that shellfish have a very high biomass per area, especially when compared to terrestrial fauna, and thus collection is not considered labour intensive. He also suggests that shellfish can withstand a higher culling rate than land animals (14% as opposed to 2.5%), although this was criticized by Dewar (1980). Raymond (1981) calculates that shellfish contributed 42% of the calories of the diet of Andean civilization and was the single most important source of meat. Larson (1980:226) suggested that the bulk of winter protein at the Pine Harbour site (Florida) came from oysters, with all other species, including deer, playing only a supplemental role. Claassen (1986b:33) suggests that shellfish are more important to the diet of horticultural groups than to hunter-gatherer groups, as the preceding examples suggest.

The importance of shellfish in human diet has been questioned. Wing and Brown (1979:139-140) indicate that shellfish are an important source of protein. Claassen (1986b:34) adds that the protein, calorie, carbohydrate, and mineral values of shellfish all fluctuate seasonally. Her results suggest that the season of collection in the American southeast was during the time of greatest carbohydrate value. Yesner (1980:733) comments "fish and shellfish provide an excellent source of calcium, iodine, electrolytes, and other minerals. However, except for oily fish...these foods are notoriously low in calories". He adds that a diet based on such

foods would by dangerously low in calories. Parmalee and Klippel (1974) studied several varieties of freshwater mussel from the Mississippi drainage region and concluded that

> the animal is not particularly high in food energy.... In fact, if the two species analyzed generally reflect the food energy value of mussels during the prehistoric period...it is apparent that this subsistence resource contains far fewer calories per given unit than provided by most other meat animals that would have been available in eastern North America (Parmalee and Klippel 1974:432).

These authors suggest that the mussels represented a dietary supplement rather than a staple. Meighan (1971:416), however, defines a staple food as one which contributes to the survival of the people on a regular basis. It need not comprise a significant portion of the total diet. Parmalee and Klippel (1974) go on to mention that it would require in excess of 50,000 mussels to feed a group of twenty-five people for one month, and thus conclude that the relatively large shell mounds encountered in riverine systems played a small role in the total diet. This point of view is echoed by Bailey (1975), who suggests that the visual impact of a shell midden may be causing researchers to feel that shellfish were much more important to diet than they actually were. He suggests that shellfish played a very limited role in the diet of prehistoric Australian peoples, comprising no more than 10% of the total annual economy. Bailey (1975:52) claims that oyster, which make up the bulk of the middens in question, contain 50kcal per 100 grams of meat. On the basis of this estimate, he contends that the dietary contribution of the

oysters on the site would have equaled 15% if the population was twenty-five people, and only 2% if the population was one hundred (which he considers to be more likely). Hence, Bailey suggests that the middens in his study were specialized oyster consumption areas, probably not occupied for more than a few days of the year. Bailey (1978) made a similar conclusion at Terra Amata. Here, he suggested that the population was approximately 40 people per mound of shell. Using this estimate, and assuming a dietary requirement of 2000 kilocalories per person per day, Bailey suggests that "...the relative contribution of shellfood to the annual diet is only 1.8%" (Bailey 1978:48). If the population were 25, the percentage would increase to 2.7%, and if the population were 5 people, the contribution of shellfood would increase to 13.7%. "These results are substantially lower than the initial estimate of 31.9% [based on meat weight percentages]" Bailey 1978:48).

This matter is unresolved, and likely to remain a topic of debate for some time. If any conclusions can be drawn at this point they are simply that shellfish was likely a more important resource (in terms of dietary contribution) to horticultural groups who utilized them as a seasonal dietary supplement than it was to hunter-gatherers; and that shellfish were unlikely to have ever been the major portion of a diet, due simply to their lack of calorific content. Obviously, a great deal more study is needed, particularly in the area of mollusc food value and its seasonal variation. Until such work is undertaken, estimates of

the proportion of prehistoric diet accounted for by shellfish are of dubious credibility.

SEASONALITY STUDIES

Seasonality studies utilizing shellfish have been applied to archaeology since 1969 (Claassen in press), and a review can be found in Monks (1981). This pioneering work occurred in California. Since then it has been applied on a limited basis to sites on the east, west, and gulf coasts of North America, in Japan, and in New Zealand. A variety of techniques of examination have been utilized, including: surface examination (Aten 1981; Clarke and Clarke 1980; Drover 1974; Ham and Irvine 1975; Ham 1976, 1982; Keen 1979; Weide 1969; Wessen 1982); thin sectioning, and acetate peels (Coutts 1970, 1975; Coutts and Higham 1971; Clark II 1979; Deith 1983; Ham and Irvine 1975; Ham 1989; Hancock 1982; Koike 1973, 1975, 1979, 1980; Lightfoot and Cerrato 1988; Monks 1977; Quitmyer et al 1985; Sanger 1989), and thick sectioning (Claassen 1982, 1983, 1985, 1986b, 1987: pers.comm.).

The early studies, undertaken in California by Margaret Weide (1969) and Paul Chace (cited by Claassen 1987:pers.comm.) involved examining the surface of each animal and assuming that the band observed was equivalent to the annual winter band. Weide (1969) "candled" the shells, which is to say she held them before a lamp, and the translucent bands observed were assumed to be annual rings, which were assumed to be formed during the

winter (November). Shell added since that time was measured and compared to that observed in previous years' growth, in order to determine the season of death. This technique assumes that the winter band is deposited at the same time each winter and that the growth rate is constant throughout the year. Weide (1969) suggests that late winter was the season of shellfish gathering at ORA-82 in southern California.

Drover (1974) determined that 4-Ora-119 (California) was occupied during winter by utilizing a similar technique. Drover examined the surface of *Chione undatella* and counted the number of annual and biweekly growth rings. He found that the number of biweekly rings decreased as age increased. Counts dropped from 16.9 to 4.0 (on average) over four years of life. Drover (1974:227) states that

> winter death is marked by the presence of a readily discernable incipient annual groove comprised of extremely thin daily growth laminae...thus winter growth is readily determinable, but fixing the time of death in other seasons requires examination of the growth rings between annual winter grooves.

Drover suggests that the number of biweekly lines in each age group be divided by 3 to infer season, and concludes that winter was the season of collection. No modern collection is used as a comparison, and again constant growth throughout the year is assumed.

Ham (1976) utilizes a similar technique for determining the seasonality of *Mytilus edulis* at the Glenrose Cannery site. He suggests that the presence of an accumulation of check rings on

the external edge of the mussel represents winter, a single check ring represents autumn, and that a check ring with growth beyond it represents spring or summer. This study utilizes no comparative collection. Spring or early summer gathering is suggested.

Keen (1979) uses a similar technique, without the assumption of constant growth rates. She divides the year into quarters, with expected growth rates (based on percentage of previous growth) of 25% for the spring, 25%-75% for summer, and 75%-100% for autumn. No growth (0%) is expected for winter. The problem inherent in such a technique is that it becomes difficult to know what to do with a specimen which exhibits greater than 100% of the previous years' growth. Should it be assigned to autumn or to winter? Keen does not explain this, nor are her seasons clearly defined. Her data (Keen 1979) suggest year round collecting, with an emphasis on spring through late summer.

Wessen (1982) calculates the average rate of growth of individual specimens for at least the last three years of their life. This is done by selecting specimens which clearly display annual check lines, and measuring the distance between these lines. A modern collection of 35 usable individuals established the seasonal growth pattern. Growth observed beyond the most recent check line was then measured, and was compared to the modern collection to determine the season of death. Wessen feels that growth percentages of less than 30%-40% suggest late winter to spring, 40%-70% suggest late spring to summer, 70%-85% suggest

fall, and 85%-100% suggest early winter (Wessen 1982:145). His results indicate near year round collecting at Ozette, with an emphasis on late winter to early spring.

Clarke and Clarke (1980) assume a constant rate of growth throughout the year, and have difficulty determining season, even with a modern collection of over 3000 individuals. They try to correlate the amount of growth past the last winter check ring with the amount of growth observed in the previous year. There is virtually no correlation observed. They suggest that collecting at Yuquot occurred throughout the year.

Aten (1981) employs an interesting variation of the external examination technique. In studying *Rangia cuneata* from Texas, he developed a technique which consists of comparing shell length with a length/age table, to determine age, and then comparing the amount of growth after the last annual growth interruption line to the previous year's. This allows for the placement of a particular individual into early, middle, late, or interrupted growth phases. There is also an indeterminate category. The determined growth period for a sample is then compared to a frequency distribution, and the season of death is then determined. He suggests that this technique will be accurate to within ±1 month. This technique is a great improvement over the other surface examination techniques described because it deals with a population rather than individual specimens. By so doing, it takes into account individual variation in growth, something which none of the other techniques do. It also expects

a certain amount of "unreadable" shells, and incorporates them into the expected frequencies. Aten (1981) cites unpublished data which suggest that nearly all coastal middens along the upper Texas coast were occupied during the early summer for 2-6 weeks.

There are several problems associated with the techniques presented above. Many of these authors assume that shell growth occurs at a constant rate throughout the year. The review of shell growth presented in chapter two of the thesis demonstrates that this is not the case. Others feel that there will be a correlation between the amount of growth observed in the most recent year and the amount of growth present in previous years. This assumes both constant growth and that the annual band is deposited at the same time each year. Clark II (1974:81) makes it quite clear that annual bands are "...annual in the sense of happening once a year, and not in the sense of occurring at intervals of 365 days". Sanger (1983:232) states quite succinctly that "estimates of season of death ...involve more than a simple ratio of last growth against previous years". Constant growth rates, either through the year or during the life of the mollusc, have not been demonstrated by any study which I am aware of, and should not be assumed. One of the most glaring problems is the assumption that annual bands can be readily distinguished from other bands (i.e.: storm disturbance bands) through examination of the surface of the shell. This was considered implicit by Weide (1969:134), but is now widely

recognized as false. Although a number of researchers have discussed ways in which storm disturbance bands can be distinguished, these all entail sectioning the shell. Clarke and Clarke (1980:51) note that annual and disturbance lines could not be differentiated between, even with the use of x-rays. Aten's (1981) technique can eliminate many of the problems encountered in the other surface examination techniques, but has been criticized for using comparative frequencies which were constructed using modern data from a number of different collection localities, and thus different microenvironments (Claassen 1986b). Claassen (1986b) also points out that Aten does not have a sample for a full year, as several time periods are missing. A modern collection should be compiled in one locality, in order to control for environmental fluctuations over geographic areas, and all collection periods must be represented, rather than extrapolated.

In a review of techniques, Ham and Irvine (1975) recognized that external examination was rather unreliable, and tended to be subjective in nature. They suggest using sectioning, considering it to be a more reliable technique. However, like many others, they assume that growth will be more or less uniform in rate throughout the year.

A number of researchers have used sectioning as a means of studying seasonality in shellfish. Coutts (1970) suggested the use of this method in one of the early papers on the subject. He claimed it provided an accuracy of within three months.

Utilizing this technique, Coutts and Higham (1971) made acetate peel microphotographs to observe the growth increments of several specimens of *Chione stutchburyi*. They determined site seasonality by counting daily lines back from the shell margin to the last macro-ring (winter check mark). They suggest that the sites studied in New Zealand were occupied during the summer, again with an accuracy range of about 3 months.

Koike (1973, 1975) utilized thin sections to study growth lines. Sections were examined using both optical and scanning electron microscopes. Her experiment involved observing growth patterns in marked clams, to determine the number of bands formed, and the interval at which they form. Using this data, she was able to define five types of growth lines, based on thickness. The thickest of these have been demonstrated to be daily in nature, and correspond exactly to the number of days since marking took place (16). Utilizing this knowledge of the rate of formation, Koike (1979, 1980) was able to demonstrate that collecting at Natsumidai (Japan) occurred throughout the year, and was further able to demonstrate concentrations of collecting during late winter and early spring. Her technique also allows for precise tracing of periods of occupation throughout the year demonstrating that one pit was filled over the period of one and one half years (see earlier discussion on chronometry using shells).

Monks (1977) utilized sections to determine the seasonality of the Deep Bay Site (Vancouver Island). However, he used a

technique for determining season of death which is reminiscent of surface observation, and averaged the distances between annual growth checks (for the last five growth years) and then compared observed with expected growth. He encountered problems noted earlier with Keen's (1979) study in the fact that many specimens observed showed greater than 100% of previous growth. He suggests site occupation during late winter to early spring.

Clark II (1979) offers some valid reasons for using thin sections to observe growth in bivalves. He also suggests techniques for preparing and producing thin sections and acetate peels. In this study, he observes a population (*Mercenaria mercenaria*) which forms a check ring during the summer, rather than the winter as is commonly assumed. This has been noted by other authors as well, most notably Claassen (1982). Unfortunately, Clark II (1979) does not have enough prehistoric shells to offer a determination of site seasonality for St. Catherine's Island (Georgia).

Ham (1982) used thin sections to determine the seasonality of the Crescent Beach site (Fraser river delta). Like Monks (1977) he compares present growth with previous growth. Unlike Monks, Ham used modern comparative data, collected in the early spring. Most of the prehistoric shells observed demonstrated less growth than those collected in the spring, and thus a late winter collection date was decided upon for the site. Ham (1989) has applied the same methodology at Cohoe Creek, with similar results.

Hancock (1982) used thin sections and acetate peels in a slightly different way than most researchers. She observed growth lines on the umbo of the shell (*Mya arenaria*), instead of the ventral margin as most researchers do. The reasons for doing so are not specified, although one might suggest that this portion of the shell would be more likely to preserve well, as it is more robust. Hancock's technique of assigning season is similar to that of many other students, comparing observed growth with expected growth based on measurements of previous growth. Unfortunately, her work does not yield fine resolution of seasonality, with only two broad seasonal categories: Category I, (June to September) active growth, with the most recent increment equal to 100% or less of previous growth, and Category II, (October to May) slow growth, with the most recent increment equal to more than 100% of previous growth. Not surprisingly, the majority of the archaeological specimens observed were of Category I (less than 100%), indicating a collection period somewhere between May and September (there were some archaeological shells which showed greater than 100% growth, and these are responsible for the expansion of the range of season).

Deith (1983) used thin sections and acetate peels to determine seasonality at the site of Morton (Scotland). She analyzed modern data to determine the rate of line deposition, and concluded that it was tidal. Using statistical analyses she demonstrates that growth ceases for the winter on September 25 ±21 days, and resumes again on April 22±10 days. Winter

collected shells show a wide variety of profiles, ranging from no stoppage of growth to an indentation and a change in pigmentation. Deith suggests that the variation may relate to the positioning of the section cut through the shell.

> The replicas from ...[a]... single shell cover the entire range of edge configurations, together with intermediate stages. Some indicate that the shell was already starting to move into its new growth phase and had formed the second side of the groove, while others suggest that winter growth was just beginning. In the face of this degree of variation within a single shell, the possibility of distinguishing different phases of the winter episode, by examining the shell edge, is remote (Deith 1983:433).

Deith (1983:433) admits that the resolution in the shells she is working with is only good during the summer months, and that for the remaining seven months of the year, the "blanket category" winter growth must suffice. Unfortunately, the archaeological shells studied suggest primarily winter growth.

Quitmeyer et al. (1985), also used thin sections and acetate peels to observe the growth patterns of *Mercenaria mercenaria* (quahog) in coastal Georgia. They describe six stages of growth increments, three each for translucent (slow) growth and opaque (fast) growth. Modern specimens were assigned to these catagories, and month by month histograms were constructed showing the percentages of each growth stage. This technique is quite similar to that of Aten (1981) and Claassen (1982 -- see below). Unfortunately, some of Quitmyer's stages of growth are rather intuitive, and may be difficult for anyone other than the author to distinguish. When archaeological specimens were

compared, differences in collection seasons were found. At Kings Bay, collection was year round, with a fall emphasis during the Savannah component, and no specific emphasis during the Swift Creek component. Archaic shells from nearby St. Simon's island showed spring collection characteristics. However, there was some variation from site to site.

Lightfoot and Cerrato (1988) use thin sections of *Mercenaria mercenaria* from the Sungic Midden Site on Shelter Island, New York. While this study utilizes no modern comparative material, it is undertaken in an area where the species under analysis has been widely studied. Their technique is based upon counting daily or fortnightly growth increments occurring between annual check rings (thought to occur sometime between mid-December and mid-January). Their results suggest shellfish harvesting during all seasons of the year, with an emphasis on the early winter. Unfortunately, the method of specimen collection is not described. While the sample size (52) is adequate for statistical analysis, it is broken into three time periods, and thus becomes error prone and problematical. Lightfoot and Cerrato (1988) acknowledge this fact, and suggest that their results are only preliminary at this time.

There are a number of advantages and disadvantages inherent in the technique of thin sectioning and using acetate peels. Disadvantages include the time and cost involved in sample preparation. Obviously, if all one needs to do is examine the external surface of a shell, it will be considerably less costly

than sectioning the shell and creating an acetate peel. On the level of interpretation, a major problem is that observed by Deith (1983), where sections from different regions of the same shell yielded different edge-growth characteristics.

However, the advantages associated with thin sections and acetate peels far outweigh the disadvantages. Of primary importance is the fact that daily (or tidal) lines can only be seen using thin sections and acetate peels. This means that any kind of precise temporal resolution -- seasonal or otherwise -- will only be observed through the use of this technique. Another advantage is the ability to distinguish between annual increments and disturbance increments. As suggested by Pannella and MacClintock (1968), disturbance increments will appear suddenly, with no gradual decrease in the size of the increments beforehand. This is of considerable importance when trying to determine seasonality. Acetate peels have the advantage of being directly related to the structure of the shell itself, and therefore permit one to observe growth lines in certain species (such as the ocean quahog) in which the growth lines are not easily distinguishable (Ropes 1985:55). Thin sectioning of the entire shell allows for the preservation of pigmentation, which can be important in distinguishing phase of growth (Clark II 1979). Thin sectioning of certain portions of the shell (i.e.: the umbo or the chondrophore) are both accurate and efficient, but limited to certain species (Ropes 1985). Thin sections also provide a sample of shell which is of proper size for study with

a Scanning Electron Microscope (Ropes 1985).

Another sectioning technique which has been applied with considerable success is that of thick sectioning, used by Claassen (1982, 1983, 1985, 1986a, 1986b, in press). The technique is similar to that of Quitmyer et al (1985) presented above, but less subjective. Sections of quahog shells (or broken valves) are polished, and the colour of the ventral margin is recorded. The colour will be either grey (slow growth) or white (fast growth). Modern specimens collected on a monthly basis are broken into percentages of fast and slow growth and plotted as histograms. These histograms characterize growth for a particular month (in much the same manner as Aten (1981) above). Claassen (1982:174-183) has been able to demonstrate that there is a very clear pattern if one looks at growth characteristics for a population on a monthly basis. She suggests that slow growth occurs between July and October. Archaeological results for North Carolina show primarily winter collection (late fall to early spring) for the prehistoric periods, with a shift to summer collecting after contact (Claassen 1983; 1986b), presumably a result of rescheduling for access to European goods. Other results using this technique demonstrate fall-winter collecting in South Carolina and Georgia, and late summer-fall collecting in Florida (Claassen 1986b). Recently, Sanger (1989) has applied a similar technique to *Mya arenaria* in coastal Maine middens.

Claassen's technique has several advantages. It is faster

than any other technique available, with up to 150 shells classified per hour (Claassen 1983). It can utilize broken shells, alleviating the need for whole specimens from an archaeological content (Claassen 1987: pers.comm.). It requires little equipment, and classifications can easily be made in the field if so desired. Most importantly it examines a population, rather than individuals, and in this manner takes into account the natural growth variation likely to be encountered. Disadvantages are primarily related to archaeological material. This technique is designed for comparison of a population of contemporary shells (i.e.: a single depositional incident). Such a situation can be difficult if not impossible to define in a shell midden, especially if large (thick) lenses of a single species are present. Thus, specimens must be collected from a site excavated with careful stratigraphic control. It could be very problematic to attempt to apply this technique to a shell sample which was drawn at random from areas of the site. At the very least, column samples would be essential. Another problem is the technique's inability to divide the year into more than two seasons (Claassen 1989: personal communication).

A number of authors (i.e.: Koike 1980) have mentioned the use of a Scanning Electron Microscope to observe growth lines, but no one has ever published a detailed account of such a study.

CHAPTER FOUR: MODERN CONTROL COLLECTIONS AND SAMPLING

Modern control or comparative collections are an important aspect of shellfish season of death studies. These modern collections provide a record of the seasonal growth pattern which must be used as the basis for all season of death estimates made upon prehistoric materials. A valid characterization of the growth pattern of each season of the year can only be made through the use of a collection that was gathered at known points in time and space. Despite this fact, modern collections are often ignored, or poorly prepared prior to use. Deith (1983:423) notes

> the determination of seasonality from shells requires the use of data and techniques developed in other disciplines, whose concerns and objectives might not, however, be identical with those of archaeology. It is essential that the archaeologist should formulate the questions that are basic to understanding the specific set of problems he or she is addressing. It is almost certain that independent fieldwork will be necessary to answer such questions.

Deith's remark is valid, and it is apparent that archaeologists must endeavour to collect their own comparative data for study. This has been the exception rather than the rule to date in seasonality studies involving clam shells. Claassen (1986c) reports that "... not one of the 10 investigators in 17 studies of shellfishing in southern California has assembled a control collection". The situation on the Northwest coast is somewhat better, with at least three reported control collections (Clarke and Clarke 1980; Ham 1982; Wessen 1982).

Claassen (1986c) points out that many researchers assume

that growth begins when water temperatures begin to increase, or rely on published descriptions made by malacologists. They also assume uniform growth in all shells in a population. These assumptions are problematic, as has been discussed in chapter two.

Some authors (e.g. Ham 1982; Wessen 1982) have recognized a need for modern comparative material, but collect for neither a sufficient amount of time nor a sufficient number of individuals to make the comparison meaningful. Ham (1982) compiled a modern collection of 18 individuals, collected during April of 1980 and March of 1981 at Crescent Beach. Wessen (1982) collected 35 individuals (5 per month) for seven months during 1978-1979 at Ozette. These sample sizes are too small to be submitted to any kind of meaningful statistical analysis, and collection was too infrequent to characterize all the months of the year (or even all the seasons) without extrapolation. Other comparative collections have been sufficiently large in size, but have not covered the entire year in one locality (Aten 1981). At least one large sample, collected at regular intervals throughout the year, has been compiled on the northwest coast. Clarke and Clarke (1980) built a monthly comparative collection of 3000 individuals for Yuquot. Unfortunately, they attempted to compare the amount of growth between check rings, assuming constant growth throughout both the year and the life of the clam, and could find no correlation.

Claassen (1987:pers.comm.), suggests that a control

collection should comprise 30 to 50 living individuals; and should be gathered on a monthly basis from the same locality for at least one year, with two years being even better, and three to five years (or more) optimal. This will allow observation of both population growth for a given time period, and of monthly fluctuations likely to occur. The utility of such a collection is demonstrated by Claassen (in press), who ran blind tests to determine the efficiency of her technique. Shells of a known collection date were analyzed, and compared to existing control collections. Using only a one year collection, the season of death of the test shells was determined to be between January and April. When compared with a two year collection, the test shells resembled January or February, while a three year collection strongly suggested February. The actual date of collection was February 17. This demonstrates that the greater the number of annual samples represented in the control collection, the greater the accuracy of the method.

MODERN DATA COLLECTION

Many studies (e.g. Aten 1981) have been called into question because of problems in the collection methods employed. Factors which must be considered prior to the commencement of collecting include the goals of the study, the species to be retained, the area of interest, and the local microenvironment.

SAMPLING THE INTERTIDAL ZONE

The intertidal zone is an area which is not ideally suited for the employment of formal sampling techniques. Nonetheless, a

modern collection of shellfish should be gathered in a systematic fashion. Ideally, a specific sampling area will be defined prior to collection, and sampling will not deviate from within this area. The sampling area should be stratified if possible, to attempt to treat each microhabitat separately. Stratification may be done on the basis of beach matrix, tidal height, vegetation, or any other convenient means. Each sampling stratum should be sampled at least twice during each collection period to test for intra-stratum variance. Cluster samples will be removed from each strata. These clusters will undoubtedly vary in number, but should total a minimum of 60 individuals. This will ensure a normal distribution of sampling error. Ideally, 60 specimens of each species under study will be gathered during every collection period. However, this may prove problematic, as repeatedly removing such a large number of shellfish from a small area may lead to overexploitation and a decreasing population through time. The collection interval should be constant. I recommend following a lunar calendar, rather than a solar calendar due to the fact that the lunar cycle seems to play a considerable role in shell growth (see chapter two).

SAMPLE COLLECTION FROM SHARK COVE (DeRt 1)

The modern collection compiled from this locality was not collected in the manner described above. The procedure used was as follows.

Samples were taken from the Shark Cove location every 28

days, with sample size varying with collection period. The standard size of the sample was between 60 and 70 individuals, although various constraints did not always permit collection of so large a sample. Collection began February 21, 1987, and was continued until January 24 1988. Table 1 provides the dates of collection, low tide height, and numbers of specimens for each species. These data are shown graphically in Figure 2. Collection was always undertaken during the lowest possible tide, provided it was possible to be at Shark Cove at that time. When this was impossible, the collection was made as close to low tide as possible.

The choice of *Macoma, Mya, Protothaca,* and *Saxidomus* for collection was made strictly on the basis of their availability during the initial collection period. *Clinocardium* and *Tresus* were added when they were available. There was no conscious effort to collect any particular species to the exclusion of others. Search time was spent attempting to locate a particular species only during the autumn collections, when *Macoma* inexplicably became absent from the beach.

Blue mussels, *Mytilus edulis*, were not included in the collection for two reasons: this species is not especially common to the study area, being encountered only in small quantities and only during the months of November and December; *Mytilus* tends to preserve poorly. While it is often encountered in midden sites, *Mytilus* is usually highly fragmented (see Muckle 1985). On those occasions when whole examples of *Mytilus* are collected, they tend

to disintigrate in the laboratory. This latter factor makes *Mytilus edulis* seem a poor choice for season of collection determination.

The only other species of bivalve encountered during modern sample collection was *Crassostrea virginica*, the Atlantic oyster, which is not native to the area. Gastropods and other types of univalves were seldom encountered, and were not collected.

Table 1
Shark Cove Comparative Collection Data

Date	Tidal Hgt (ft)*	Time	n	Cl	Ma	My	Pr	Sa	Tr
02/21/87	2.5	17:00	69	0	20	14	23	12	0
03/20/87	2.2	14:20	63	0	11	19	19	13	1
04/17/87	0.7	12:55	40	0	4	11	12	13	0
05/16/87	-0.4	12:35	59	5	6	1	15	29	3
06/12/87	-1.1	10:45	79	6	33	9	24	7	0
07/09/87	-0.4	08:55	63	2	13	15	21	12	0
08/09/87	0.0	10:15	70	6	18	9	26	9	2
09/06/87	1.2	09:10	65	0	13	3	34	13	2
10/04/87	2.9	07:55	30	0	0	13	11	6	0
11/01/87	4.3	06:20	62	0	2	24	24	12	0
11/29/87	5.6	19:20	1	0	0	0	1	0	0
12/27/87	5.7	17:45	9	0	0	0	9	0	0
01/24/88	5.4	15:55	46	0	2	13	19	12	0
			655	19	122	131	237	138	8

n = number of specimens
Cl = *Clinocardium nuttalli*
Ma = *Macoma spp.*
My = *Mya arenaria*
Pr = *Protothaca staminea*
Sa = *Saxidomus giganteus*
Tr = *Tresus capax*

* Lowest tide of the day. (Fisheries and Oceans 1987; 1988)

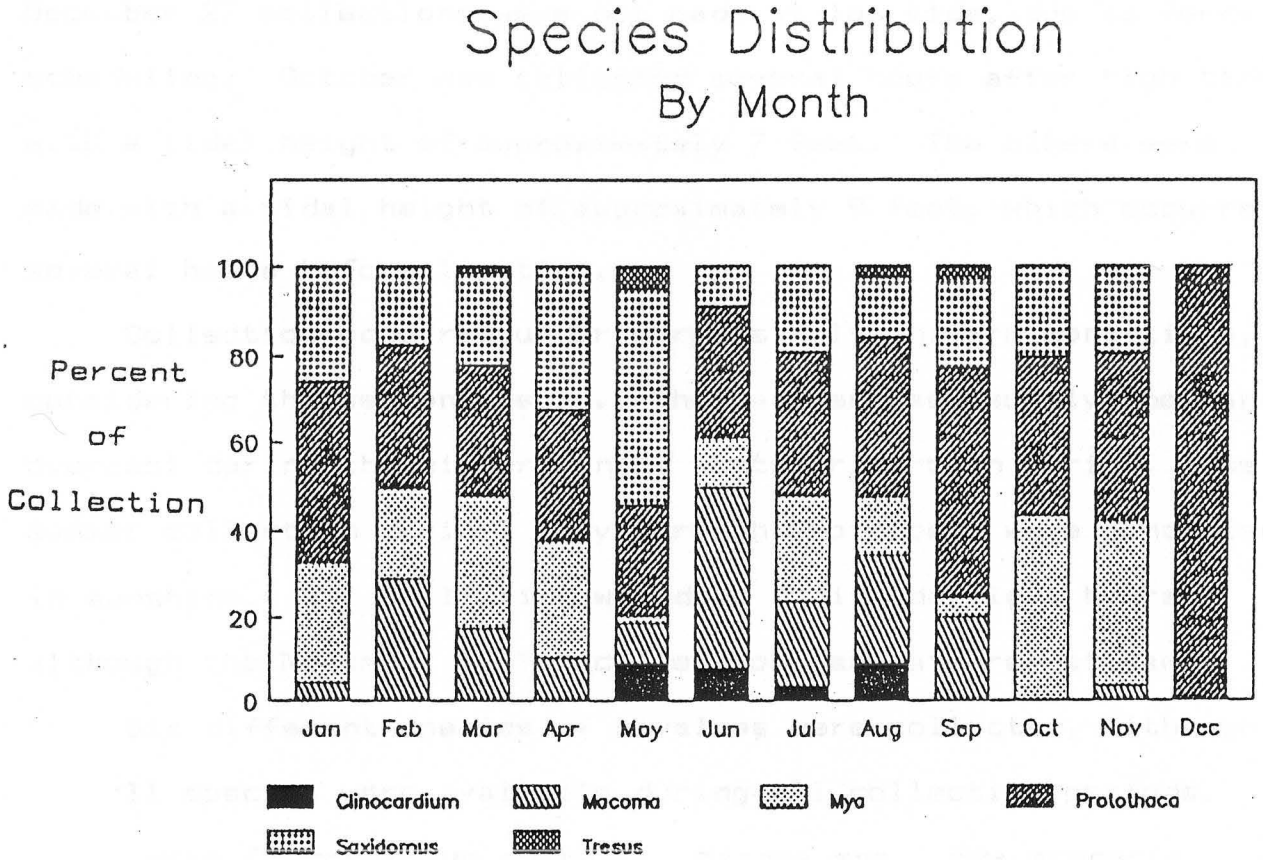
Species Distribution
By Month
Percent
of
Collection
100
80
60
40
20
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Clinocardium
Macoma
Mya
Protothaca
Saxidomus
Tresus

Figure 2

It should be noted that the October 4, November 29 and December 27 collections were not made at low tide, due to ferry scheduling. October was collected several hours after high tide, with a tidal height of approximately 7 feet. The others were made with a tidal height of approximately 9 feet, which occurred several hours before low tide.

Collection occurred under surprisingly uniform conditions, considering the seasonal span. The weather was usually cool and overcast during the winter months (October through April). The summer collection periods (May through September) were conducted in sunshine. All collecting was done during daylight hours, although the November 1 1987 collection was gathered at dawn.

Six different species of bivalves were collected, although not all species were available during all collection periods. These were *Clinocardium nuttalli*, *Macoma spp.*, *Mya arenaria*, *Protothaca staminea*, *Saxidomus giganteus*, and *Tresus capax* (Quayle 1960).

The technique used to gather specimens could best be described as haphazard, owing to my initial lack of familiarity with digging for shellfish. A protected area of the beach was chosen, and digging commenced in a small area, usually two to three feet square. Digging continued to a depth of about eighteen inches, or until water was encountered. All specimens encountered were collected, unless they were damaged during digging. Unfortunately, no record was kept of how many specimens were damaged. Digging moved to a new area when the initial one

no longer seemed productive. All specimens were stored in plastic bags, and plastic containers. No water was included in these containers, save any that entered with the shellfish. When a sample size deemed adequate was reached, or when it was time to leave for the ferry, digging ceased. Unfortunately, sample size requirements were not investigated until after the entire sample had been collected, and thirty specimens was considered to be a minimum sample size. The collections from November 29, 1987 and December 27, 1987 are especially small, due to the tidal height during the time I was able to be on Pender Island. The November 29 specimen has not been included in the analysis.

Two important confounding variables have been recognized. There is no provenience data for the specimens. Shellfish from different areas of the beach were combined in the original collection procedure. The intertidal area of collection varied with the tide. Collection was always carried out as close to the tide as possible. Different collection periods represent different tidal zones. Thus, there is no way of examining the effects of beach habitat on growth coloration. Second, no environmental data were recorded, although some is available from Environment Canada. As a result, it is virtually impossible to assess the roles of various environmental variables on shell growth coloration.

CHAPTER FIVE: METHODOLOGY AND PILOT STUDY

After collection, each shellfish was immediately taken to Simon Fraser University and killed by freezing. This was undertaken as soon after collection as possible, but owing to travel time, the shellfish were not usually frozen until between three and ten hours after collection. Some time later, specimens were removed from the freezer and each given a six digit catalogue number, weighed, and measured. The catalogue number was used as a descriptive measure. The first two digits correspond with the month of collection (i.e.: January is labelled 01). The next two digits record the year of collection (in most cases 87), and the final numbers recorded the specimen number (i.e.: 17). Processing was done to remove all soft tissue. Each shellfish was cooked in hot (but not boiling) water until the soft tissue became removed from the shell. Because the specimens were difficult to distinguish when not in their catalogue bags, only one example of each species could be processed in a single container at any given time. It is for this reason that the catalogue numbers rotate through the species, rather than all individuals of a given species being catalogued in sequence. All shells were allowed to air dry, and re-weighed.

Each specimen was mounted in a clamp and sectioned using a Buehler Isomet 11-1180 Low Speed Saw, with a five inch blade. The clamp used was specifically constructed for this project. It allows the orientation of the valve to be changed as needed

relative to the saw blade. Each species requires a different angle of orientation, due to the different shape of the valves. Completed sections were stored in gelatin capsules. Each month was chosen at random (without replacement) for sectioning, to reduce any bias which may have been imparted by my expertise (or lack thereof) with the saw. After a month had been selected, the shells were sectioned in numerical order, by catalogue number. The time required to section each valve was recorded for seven of the monthly collections.

In order to determine the most productive method of specimen preparation a random sample of twenty shells was chosen for study. The time required to select, obtain, prepare and section each specimen was recorded. The sample was selected using a table of random numbers (Blalock 1972). The sample consists of the following catalogue numbers:

1087-09	0587-48	0887-42	0787-57
0787-62	0887-62	0987-49	1087-28
0887-36	0587-48	0787-63	0188-25
0987-53	0487-14	0987-40	0287-29
0787-32	0787-08	0587-26	0787-50

Selecting and obtaining samples for study took 30 minutes. Sectioning originally proceeded from the ventral margin to the umbo of the shell. However, it was decided after 9 specimens that this was too costly a method, both in terms of time and potential damage to specimens and equipment. From that point on, all sections proceeded from the ventral margin towards the umbo, but only penetrated 1 to 2 centimetres. The following table lists the results of the pilot study.

Table 2
Pilot Study Sectioning Time

Cat. Number	Time (min)	Comments
0587-26	26	Complete
0487-14	27	Complete
0887-06	15	Complete
0887-36	30	Complete
0887-42	not recorded	Incomplete
0787-50	14	Complete
0887-42	45	Incomplete
0787-62	not recorded	Fractured -- Too Small
0787-57	21	Complete
0587-48	13.1	Incomplete
0787-32	12.8	Incomplete
0787-08	16.6	Incomplete
0188-25	08.4	Incomplete
0787-63	09.5	Incomplete
1087-09	13.2	Incomplete
0987-40	18.1	Incomplete
0987-49	08.5	Incomplete
0987-53	04.8	Incomplete
0287-29	05.8	Incomplete
1187-20	not recorded	Incomplete

Complete section = Ventral Margin to Umbo
Incomplete section = Ventral Margin to 2 cm.

The average time needed to completely section a specimen from ventral margin to umbo is 25 minutes and 26 seconds. Full valve sections had a tendency to cause the blade to lock within the shell. Another problem with cutting the full valve was orientation. Due to the limited amount of space between the mounting arm of the saw and the blade itself, full valves were often difficult to orient. For the sake of consistency, I had hoped to cut all valves along the axis of maximum growth. This was often rendered impossible by the size of the valve in question. The average time needed to produce a small (1-2 cm long) section of the ventral margin is 11 minutes and 5 seconds for the pilot study. Since the technique of observation planned

required looking only at the growth coloration of the ventral margin, it was decided that the latter technique was more time efficient. While specimen orientation was occasionally problematic, it was less so than when attempting a full valve section. Producing small sections also lessened the likelihood of the blade jamming within the valve itself. All other specimens used in the study were short-sectioned.

The observations were made on each section using an American Optical binocular stereoscope at 30 power. The amount of time required to remove the section from the gelatin capsule, place it under the stereoscope, observe and record the colour of the ventral margin, and replace the section was recorded for as many specimens as possible. This practice was undertaken for two reasons: first, to determine how long it took to analyze a specimen; and second, to look for correlations between the amount of time needed to analyze a specimen and the coloration of the ventral margin. This will be discussed in more detail below.

Specimens were analyzed by month, with each month chosen at random (without replacement), as in the manner described above for sectioning. The same practice of proceeding in numerical order by catalogue number was also used. Reflected light works best to distinguish colour at the ventral margin, although the same results were obtained regardless of the light source. Using reflected light seems to allow one to distinguish the coloration faster than transmitted light, although no data were recorded on this aspect of the study. The high power magnification made the

sections and the coloration easier to see, although there did not seem to be any difference in the results when a lesser magnification was used.

The coloration of the ventral margin was recorded. This coloration was described as being Translucent if reflected light could penetrate it, or Opaque, if there was no such penetration. Some sections were difficult to judge, and were labeled Indeterminate.

CHAPTER SIX: RESULTS

For the initial analysis, all species were combined for each collection period. The results are as follows:

Table 3
Growth Coloration by Month
All Species Combined

MONTH	n	NS	TRANSLUCENT		OPAQUE		INDETERMINATE	
			n	%	n	%	n	%
January	46	(3)	24	55.8	8	18.6	11	25.6
February	69	(1)	29	42.6	23	33.8	16	23.5
March	63	(1)	19	30.7	29	46.8	14	22.6
April	40	(1)	11	28.2	20	51.3	8	20.5
May	59	(0)	21	35.6	34	57.6	4	6.8
June	79	(3)	21	27.6	37	48.7	18	23.7
July	63	(2)	15	24.6	33	54.1	13	21.3
August	70	(0)	23	32.9	32	45.7	15	21.4
September	65	(0)	20	30.8	34	52.3	11	16.9
October	30	(2)	7	25.0	14	50.0	7	25.0
November	62	(0)	22	35.5	31	50.0	9	14.5
December	9	(3)	2	33.3	3	50.0	1	16.7
Totals	655	(16)	214	33.1	298	46.1	127	19.7

n = Number of Specimens
NS = No Section Produced

When these percentages are plotted in graphic form, they reveal a distinctive pattern of clusters (Figure 3). The bulk of the collection periods cluster in one area. These are the months of March through December, with the exception of May which is an outlier. The months January and February lie in a different area of the graph. While there is some difference between the two collection periods, January and February cannot be distinguished statistically. This can be seen through the use of a simple chi-square statistic.

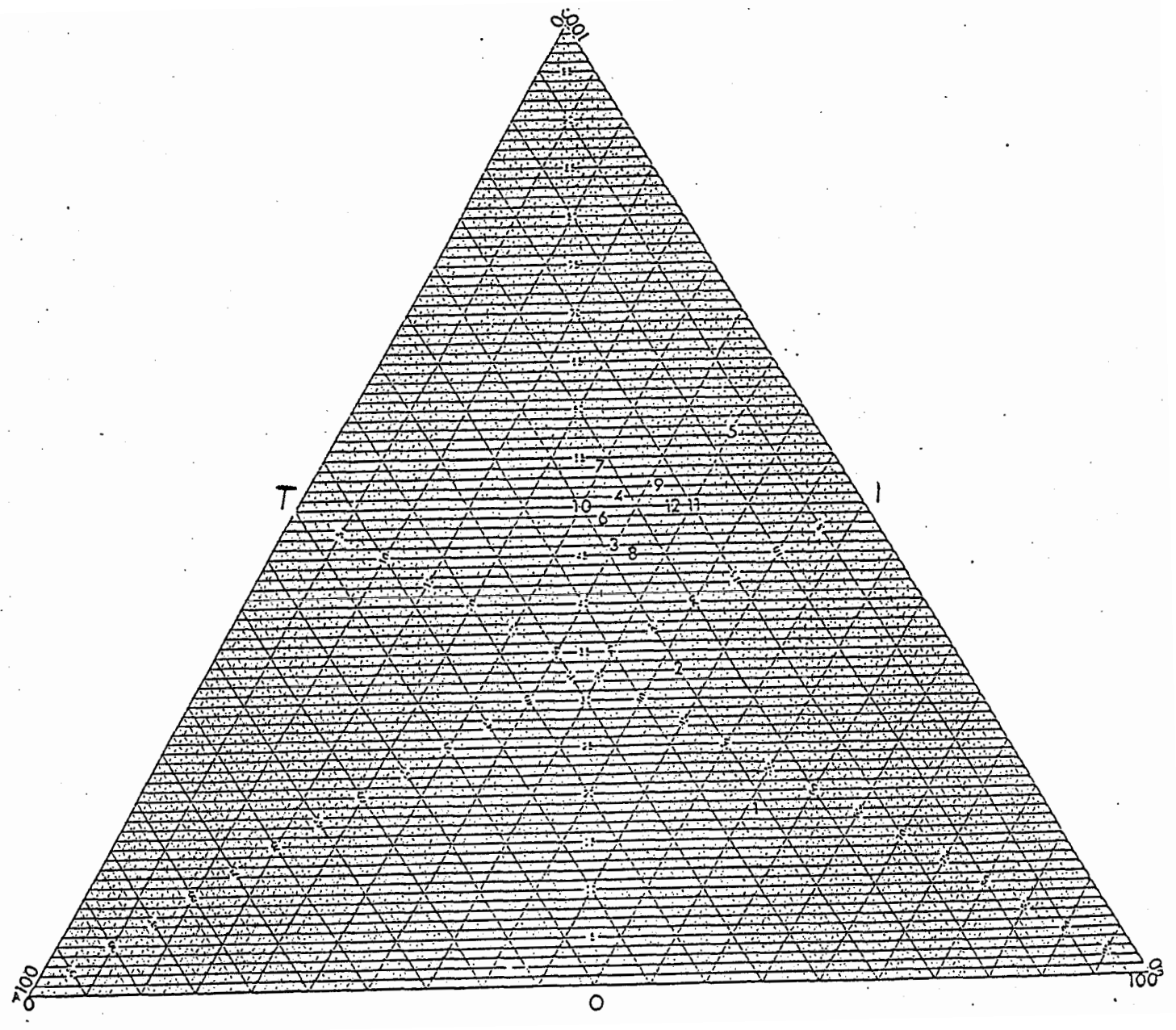

Figure 3
Point Distribution by Growth Type

	January	February	Total
Translucent	24 (19.9)	29 (32.2)	53
Opaque	8 (11.8)	23 (19.2)	31
Indeterminate	11 (10.3)	16 (16.7)	27
Total	43	68	111

Expected Values are in Parenthesis

Oij	Eij	Oij-Eij	(Oij-Eij)²	(Oij-Eij)²/Eij
24	19.9	3.1	9.61	0.48
8	11.8	-3.8	14.44	1.22
11	10.3	0.7	0.49	0.05
29	32.2	-3.2	10.24	0.32
23	19.2	3.8	14.44	0.75
16	16.7	-0.7	0.49	0.03
				2.85

$\alpha = 0.05$ df = 2 $X^2 = 5.99147$

Oij = Observed Value Eij = Expected Value

Thus, there is no significant difference between the months of January and February.

When February is compared with August, its nearest neighbor, the results are interesting.

	February	August	Total
Translucent	29 (25.6)	23 (26.3)	52
Opaque	23 (27.1)	32 (27.9)	55
Indeterminate	16 (15.3)	15 (15.7)	31
Total	68	70	138

Expected Values are in Parenthesis

Oij	Eij	Oij-Eij	(Oij-Eij)²	(Oij-Eij)²/Eij
29	25.6	3.4	11.56	0.45
23	27.1	-4.1	16.81	0.62
16	15.3	0.7	0.49	0.03
23	26.3	-3.3	10.89	0.41
32	27.9	4.1	16.81	0.60
15	15.7	0.7	0.49	0.03
				2.14

$\alpha = 0.05$ Df = 2 $X^2 = 5.99147$

Oij = Observed Value Eij = Expected Value

On the basis of this chi-square statistic, it can be concluded that there is no significant difference between the August and February collections. January and August are significantly different ($\alpha = 0.05$ $df = 2$ $X^2 = 9.06$).

As mentioned earlier, the month of May seems to be an outlier. Using another chi-square test, it can be determined if there is any significant difference between May and November, its nearest neighbor.

	May	November	Total
Translucent	21 (20.9)	22 (22)	43
Opaque	34 (31.7)	31 (33.3)	65
Indeterminate	4 (6.3)	9 (6.7)	13
Total	59	62	121

Expected Values are in Parenthesis

Oij	Eij	Oij-Eij	(Oij-Eij)²	(Oij-Eij)²/Eij
21	20.9	0.1	0.01	0.0005
34	31.7	2.3	5.29	0.17
4	6.3	-2.3	5.29	0.84
22	22	0	0	0
31	33.3	-2.3	5.29	0.16
9	6.7	2.3	5.29	0.79

$\alpha = 0.05$ $df = 2$ $X^2 = 5.99147$ 1.96

Oij = Observed Value Eij = Expected Value

There is no significant difference between May and November, thus, the collection periods other than January and February can be added together to form a single statistical "season" of growth. The next test is to determine if there is a difference between the months of January and February and the rest of the year.

	Jan/Feb	Other	Total
Translucent	53 (37.2)	161 (176.8)	214
Opaque	31 (51.8)	267 (246.2)	298
Indeterminate	27 (22.1)	100 (104.9)	127
Total	111	528	639

Expected Values are in Parenthesis

Oij	Eij	Oij-Eij	(Oij-Eij)²	(Oij-Eij)²/Eij
53	37.2	15.8	249.64	6.71
31	51.8	-20.8	432.64	8.35
27	22.1	4.9	24.01	1.09
161	176.8	-15.8	249.64	1.41
267	246.2	20.8	432.64	1.76
100	104.9	-4.9	24.01	0.23
		$\alpha = 0.05$ df=2	$X^2 = 5.99147$	19.55

Oij = Observed Value Eij = Expected Value

The results of this chi-square test show that there is a highly significant difference between the winter collection periods of January and February and the spring-summer-fall collection periods of March through December. Thus, the year can be divided into two distinctive seasons, based on shell growth coloration (Figure 4).

Dispite the statistical significance of the seasonal differences in growth patterning, there is still a problem with obtaining results from a combination of species. The monthly growth curves shown in figure 4 are the result of the ratios of species within them. It is questionable whether they are truly representative of the collection period in general. It seems plausable that collections with different species ratios throughout the year would produce different growth curves.

All species were combined in the attempt to find an overall

tendency for growth coloration to change seasonally. Initially it was hoped that seasonal patterns would be clear regardless of the species under observation. As will be discussed below, this does not appear to be the case.

GROWTH COLORATION AND SPECIES

Six different species of bivalves have been under study in this project. The month by month results presented above combine all the species together. When treated separately, the species reveal different patterns of growth. Figure 5 shows the proportions of each type of growth coloration for each species.

Clinocardium nuttalli, the basket cockle, shows a very low percentage of specimens throughout the year which exhibit translucent growth (9%), while 45.5 percent of *Clinocardium* specimens exhibit opaque growth (Figure 6). At the same time, 45.5 percent are indeterminate. However the sample size for this species is quite small at only 19. This species was only encountered during the summer months (May through August), when the tides were very low.

Macoma spp., on the other hand, shows a high proportion of specimens exhibiting translucent growth. 68.6 per cent of all *Macoma* individuals in the collection died during translucent growth. At the same time, *Macoma* specimens contained 9.9% opaque growth, and 21.5% indeterminate (Figure 7). *Macoma* are included in all collection periods except October and December (Figure 2). 122 individuals are included. Throughout the

Growth Variation Curve

All Species

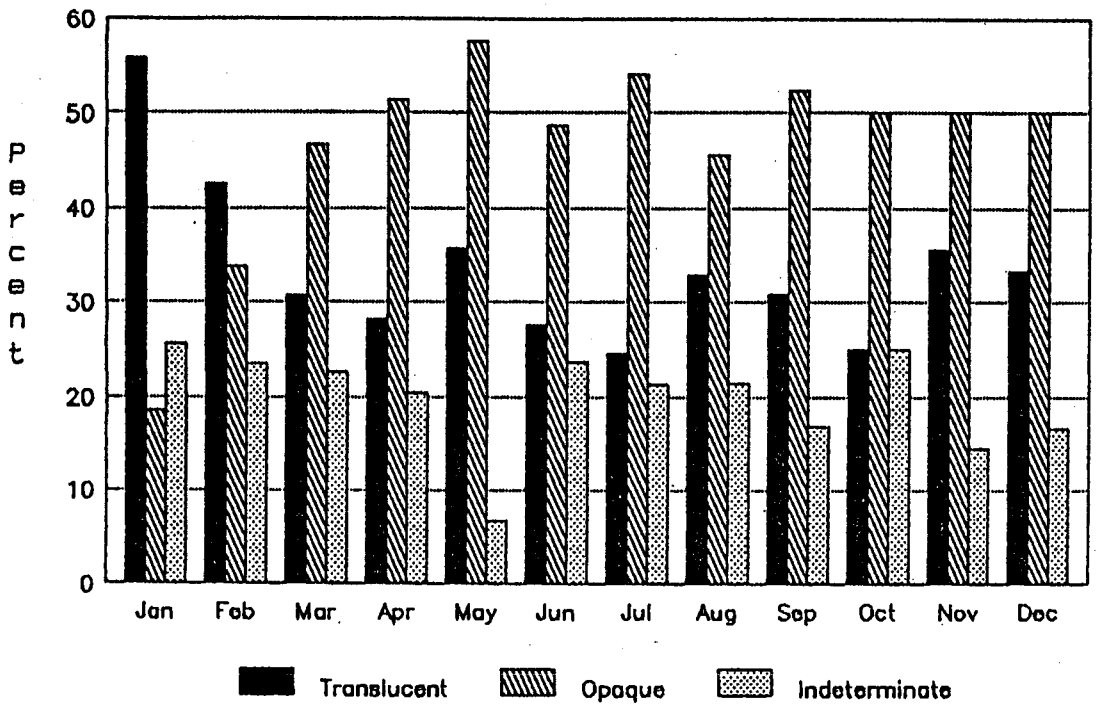

Figure 4

Growth Coloration Distribution

All Species

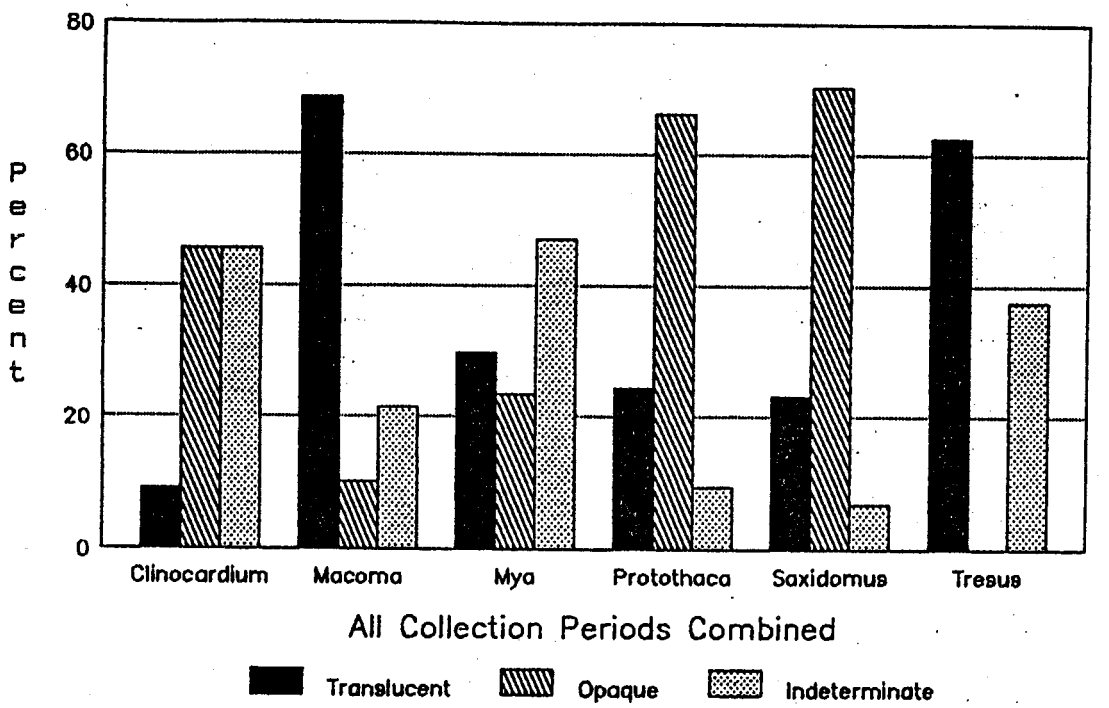

Figure 5

year, the proportion of translucent specimens for this species rarely diminishes below 60 percent. In fact, June is the only collection period in which this occurs. Opaque growth, on the other hand is limited almost exclusively to the months of April through August (with a single example from November). Indeterminate *Macoma* specimens remain at a more or less constant rate of 18-25% throughout the year. Thus, taken alone, *Macoma* does not seem to be a dependable indicator of season. It is possible that the presence of a moderate proportion of specimens with opaque growth is indicative of the summer months. However, the presence of a single opaque specimen from the November collection casts doubt over this suggestion. More work with *Macoma* specimens is needed before a conclusion can be reached. A small collection of *Macoma* from San Juan Island (approximately 14 km southeast of Shark Cove) with a collection date of July 28 exhibits a translucent growth percentage of 82 (Claassen 1987:personal communication). While this is based on only eleven individuals, it substantiates the observation of Opaque growth being a summer month phenomenon.

Mya arenaria is also a well represented species, with 131 individuals in the collection. Of these, 29% died during translucent growth, 22.9% died during opaque growth, and 45.8% were indeterminate (Figure 8). 2.2% produced no usable section. *Mya* was represented in every collection period except December (Figure 2). The percentages of growth coloration listed above suggest that *Mya* is a poor choice for season of

Growth Variation Curve

Clinocardium nuttalli

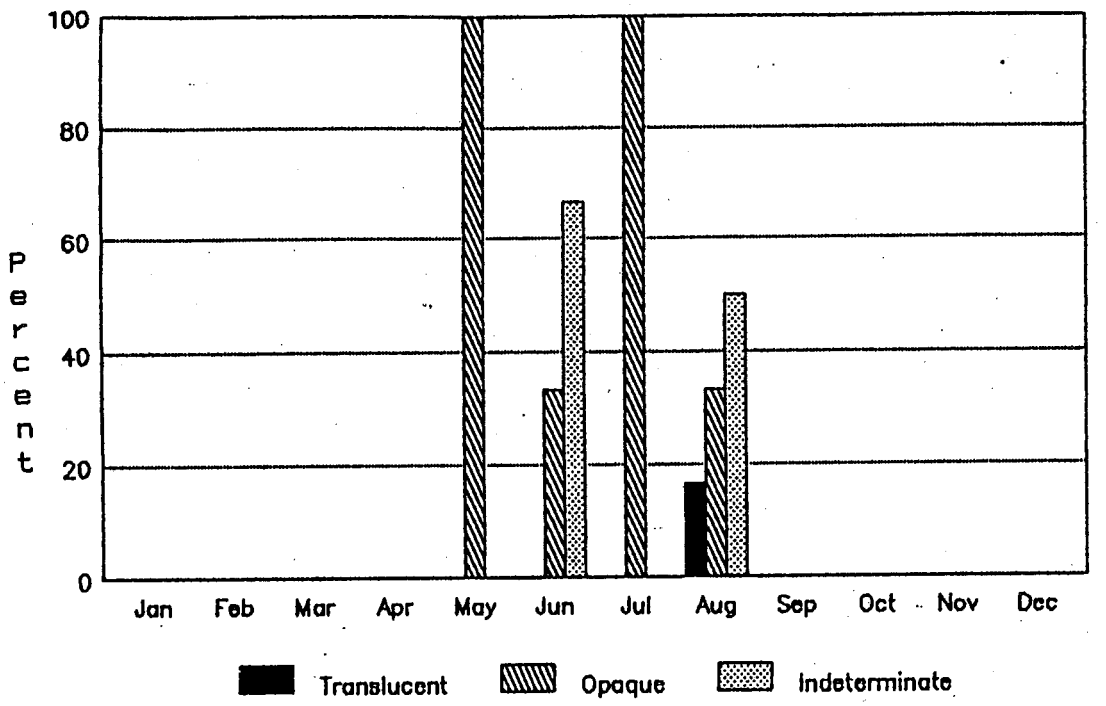

Figure 6

Growth Variation Curve

Macoma spp.

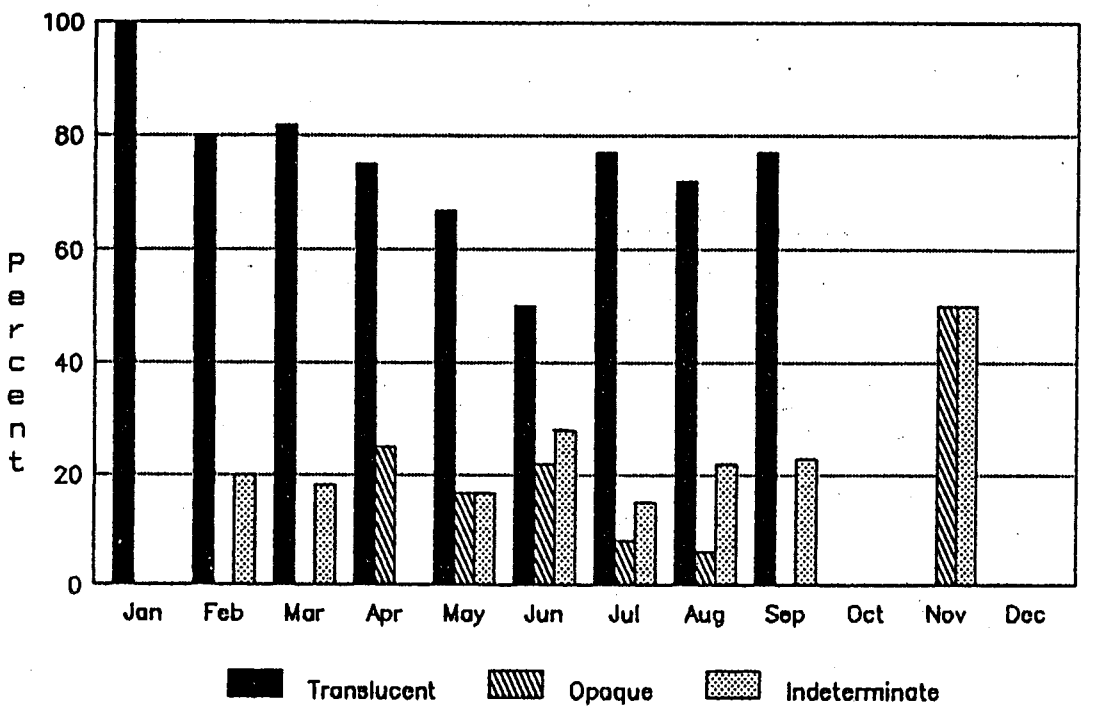

Figure 7

death research in this area. Nearly half of the specimens collected were indeterminate, suggesting that the species is not amenable to the type of analysis undertaken. Of specimens which were usable, there is a trend towards a higher proportion of translucent growth during the winter months (August to April), and a high proportion of opaque growth between May and July. The proportion of indeterminate specimens is always above 30%, and frequently above 40%. With indeterminate rates of this size, it seems that *Mya* would be difficult to use in an archaeological context, especially in light of its highly fragile nature. It should be emphasized that these results were obtained through observation of the ventral margin. Hancock (1982) and Sanger (1989) have had some success using the chondrophore in coastal Maine sites. It may be worthwhile investigating the chondrophore on the pacific coast.

Protothaca staminea, the native littleneck, is by far the most abundant species in the collection, with 237 specimens. It is also the only species encountered during every collection period (Figure 2). *Protothaca* yielded 55 specimens (23.2%) which died during translucent growth (Figure 9). These were spread throughout all collection periods, but were concentrated in the winter months of January and February. May also saw a high percentage of translucent growth. 62.9% of all *Protothaca* specimens died during opaque growth (Figure 9). This type of growth falls into three distinct periods. In January, opaque growth is very low at less than 20%. Between February and May,

Growth Variation Curve

Mya arenaria

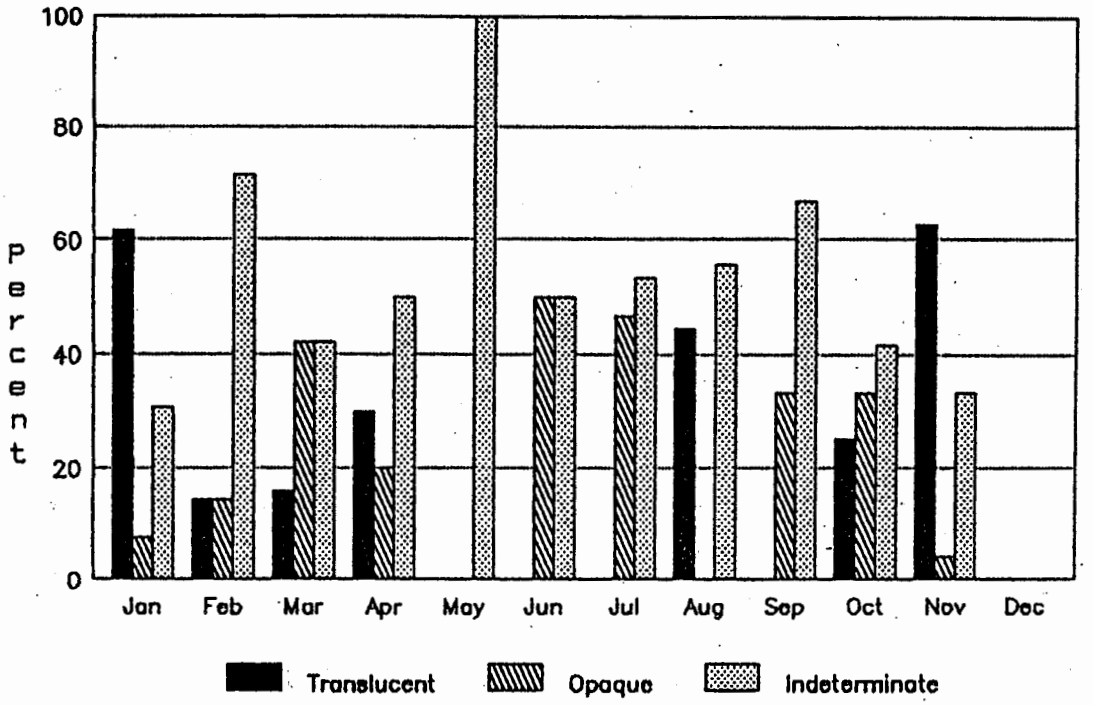

Figure 8

this proportion changes to between 45% and 60%. The months of June through November see consistently high ratios of opaque specimens, usually between 75% and 90% (with September at an anomalous 65%). December, with a very small sample size (9), shows only 50%. Only 8.9 % of all *Protothaca* specimens were indeterminate (Figure 9). This was evenly spread throughout the year, with only January and April having rates of over 20%. A total of 5.1% of *Protothaca* specimens produced no usable section. This was the highest rate of any species studied. These results tend to indicate that *Protothaca staminea* is likely a good indicator of season of death, capable of dividing the year into three distinct time periods.

Saxidomus giganteus, the butter clam, is also well represented in the collection, with 138 specimens. Of these, 23.2% died during translucent growth, compared with 70.3% dying during opaque growth, and 6.5% indeterminate (Figure 10). *Saxidomus* was represented in every collection period except December (Figure 2). Two trends are detectable in the growth curve. Translucent specimens show a moderate growth curve which begins at 35% in January and decreases to 15% during March and April. The curve then builds again between May and July to 35%, drops to under 20% during August and September, peaks at 50 percent during October, and diminishes to 10% during November. This suggests that proportions of translucent growth in *Saxidomus* specimens alone are not good indicators of the season of death, as very different times of the year (i.e.: January and July)

Growth Variation Curve

Prototheca staminea

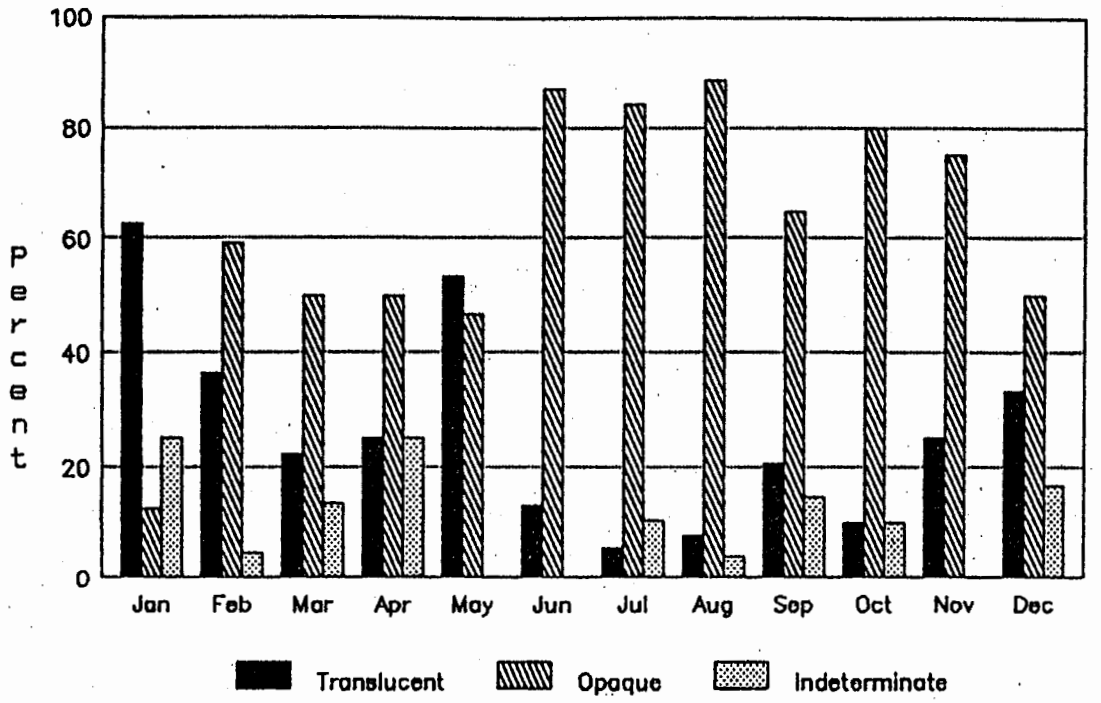

Figure 9

appear almost identical. Opaque growth, on the other hand, may be a better season of death indicator. Only the months of January, October and November have opaque growth percentages of less than 50% (33.3%-41.7%). The period of February to September shows opaque growth varying between 58.3% and 84.6%, with most months showing well over 60% opaque. Thus, opaque growth in *Saxidomus* specimens could be used to divide the year into two general seasons: a winter season of October through January, and a summer season of February through September. Unfortunately, the sample sizes for each month are not vary large (see table 3). Indeterminate specimens are uncommon in *Saxidomus*, with only 6.5% overall. This is concentrated in the winter and early spring months (October through March), with representation in July and August as well.

The horse clam, *Tresus capax*, is poorly represented in the collection, with only 8 specimens. Of these, 5 are died during translucent growth (62.5%), and 3 (37.5%) were indeterminate. This lack of variability, combined with the fact that only four months of the year are represented (Figure 2), make *Tresus* a difficult species to interpret. The species is contained only in spring and summer collection periods. More work is needed before any decision on the practicality of doing season of death estimates on *Tresus* individuals can be assessed.

RELIABILITY

The following specimens were selected using a table of random

Growth Variation Curve

Saxidomus giganteus

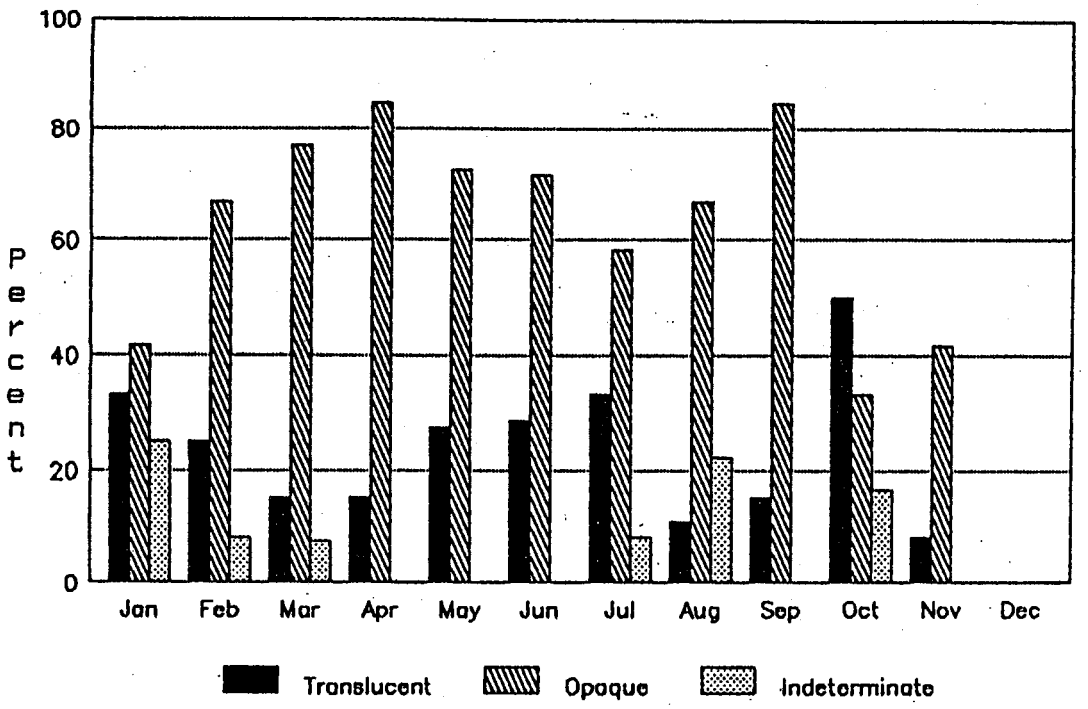

Figure 10

numbers (Blalock 1972), and were re-examined for growth coloration. The values were recorded, and compared with the original assessment.

Table 4
Results of Reliability Test Using Random Samples

Sample #	Score 1	Score 2	Sample #	Score 1	Score 2
0287-09	O	O	0787-14	T	T
0287-10	T	T	0787-46	T	T
0287-18	O	O	0787-56	I	O
0287-52	O	O	0887-05	O	O
0287-54	T	T	0887-12	T	T
0287-59	T	T	0887-31	T	T
0387-06	O	O	0887-37	I	T
0387-12	T	O	0887-39	O	O
0487-06	O	O	0887-49	T	T
0487-21	T	I	0887-53	T	T
0587-05	T	T	0987-05	T	T
0587-06	I	I	0987-25	O	O
0587-30	O	O	0987-39	O	O
0587-31	O	O	0987-41	O	O
0587-51	O	O	0987-52	O	T
0687-15	O	O	1187-03	O	O
0687-27	O	T	1187-04	I	I
0687-29	T	O	1187-05	I	I
0687-31	T	T	1287-01	O	T
0687-35	I	I	0188-13	T	T
0687-38	O	O	0188-14	T	T
0687-47	O	O	0188-37	T	I
0687-53	O	O	0188-38	O	T
0787-14	T	T	0188-44	I	O

The results are as follows: (">" = "changes to" or "becomes")

Total	48
No Change	37
T > I	2
T > O	2
I > T	1
I > O	2
O > I	0
O > T	4

Thus, there is an 77.08% rate of replicating the color judgement

on the second attempt. The rate of achieving the same results in both the first and second examinations, allowing for chance occurrences, is 62.2% ± 0.162 (Cohen 1960; Reynolds 1977). This suggests that the technique is moderately accurate, with an passable degree of reliability. To test this conclusion statistically, the Bowker Extension of the McNemar Change Test was utilized (Marascuilo and McSweeney 1977:171). This test yields the following results:

Bowker Extension of McNemar Change Test
Random Sample

	Translucent	Opaque	Indeterminate	Total
Translucent	15	2	2	19
Opaque	4	18	0	22
Indeterminate	1	2	4	7
Total	20	22	6	48

$$X^2 = \frac{(4-2)^2}{4+2} + \frac{(1-2)^2}{1+2} + \frac{(2-0)^2}{2+0} = 3.00$$

$$\alpha = 0.05 \quad df = 3 \quad X^2 = 7.81$$

Thus, there is no significance in the changes which occur from one examination to another.

A second test was undertaken, using a single collection period. The June sample was chosen at random, and re-analyzed. The results are as follows:

Table 5
Reliability Study Using One Month

Sample #	Score 1	Score 2	Sample #	Score 1	Score 2
0687-01	I	I	0687-41	O	O
0687-02	O	O	0687-42	O	O
0698-03	O	I	0687-43	-	-
0687-04	T	T	0687-44	I	T
0687-05	I	T	0687-45	O	O

Table 5 (Continued)

0687-06	I	T	0687-46	I	T
0687-07	T	T	0687-47	O	O
0687-08	O	I	0687-48	T	T
0687-09	T	T	0687-49	O	O
0687-10	T	O	0687-50	T	T
0687-11	I	O	0687-51	O	O
0687-12	O	T	0687-52	T	T
0687-13	I	I	0687-53	O	O
0687-14	O	I	0687-54	I	O
0687-15	O	O	0687-55	O	O
0687-16	I	I	0687-56	T	O
0687-17	T	T	0687-57	O	O
0687-18	O	I	0687-58	T	T
0687-19	I	O	0687-59	O	O
0687-20	O	O	0687-60	I	T
0687-21	O	O	0687-61	O	O
0687-22	O	O	0687-62	T	T
0687-23	O	I	0687-63	O	O
0687-24	T	O	0687-64	I	O
0687-25	O	O	0687-65	O	O
0687-26	I	I	0687-66	I	O
0687-27	O	O	0687-67	O	O
0687-28	I	I	0687-68	O	O
0687-29	T	O	0687-69	O	O
0687-30	T	T	0687-70	I	T
0687-31	T	T	0687-71	O	O
0687-32	I	O	0687-72	T	T
0687-33	O	T	0687-73	T	T
0687-34	O	O	0687-74	I	O
0687-35	I	I	0687-75	T	T
0687-36	T	T	0687-76	I	O
0687-37	O	T	0687-77	O	O
0687-38	O	O	0687-78	I	T
0687-39	-	-	0687-79	-	-
0687-40	T	T			

Total	76
No Change	48
T > I	0
T > O	4
I > T	6
I > O	7
O > I	5
O > T	3

This yields an accuracy rate of 63.2%, which is somewhat lower than that of the random sample. When this figure is corrected for chance error, an accuracy ratio of 43.9% ± 0.098 is achieved,

suggesting that the reliability is somewhat questionable. This could likely be explained by the fact that June was one of the earlier months examined the first time, and the second examination had occurred after more practice. The random sample would be less likely to reflect this due to the fact that it contained specimens from throughout the study, and thus from both early and later attempts to identify the coloration. Perhaps the most interesting aspect of the June restudy is the fact that the most common change in identification was from indeterminate to either opaque or translucent. This suggests a greater knowledge of what to look for during the second examination.

Once again, the Bowker Extension of the McNemar Change Test was used to determine the significance of the changes observed from one test to another. This yields the following results:

Bowker Extension to the McNemar Change Test
June Sample

	Translucent	Opaque	Indeterminate	Total
Translucent	16	4	0	20
Opaque	3	27	5	35
Indeterminate	7	8	6	21
Total	26	39	11	76

$$X = \frac{(3-4)^2}{3+4} + \frac{(7-0)^2}{7+0} + \frac{(8-5)^2}{8+5} = 8.26$$

$$\alpha = 0.05 \quad df = 3 \quad X^2 = 7.81$$

Thus, there is a statistical significance in the changes observed in this second reliability test. It seems plausible that this is caused by the fact that June was one of the earlier months

examined in the study, and the changes are the result of an increasing familiarity with recognizing growth colorations.

THE EFFECTS OF SIZE ON GROWTH COLORATION

An important consideration to be made in this study is the effect of shell size on growth coloration. If there is a correlation between size and the colour of the ventral margin, it would obviously be an important confounding variable. Indeed should there be a strong correlation between these two variables, it is entirely possible that the method itself is invalid. A series of difference of means tests (Blalock 1972) were conducted to test the correlation of these two variables

The equation used is as follows:

$$t = \frac{\bar{X}_1 - \bar{X}^2}{O\bar{x}_1 - \bar{x}^2}$$

There appears to be very little correlation between the length of the shell and the colour of the ventral margin. This is demonstrated statistically. When the length of Translucent and Opaque sections are compared, the resulting T value is 0.509, with 496 degrees of freedom. This figure is not significant at the 95% confidence level (t = 1.960). Indeterminate and Translucent sections are not significantly different in length (t=0.022 df=323); nor are Indeterminate and Opaque sections (t=0.423 df=413). However, those shells which produced no usable section are all significantly smaller in length than are other valves. The following T values were obtained:

Translucent vs No Section	t = 3.697	df = 217
Opaque vs No Section	t = 3.512	df = 307
Indeterminate vs No Section	t = 4.149	df = 134

Specimens which produced no usable section cluster at the lower end of the length scale, having a mean of 30.13mm and a standard deviation of 19.016mm. This suggests that on the whole, specimens larger than 30mm in length are needed. It should also be noted that those specimens which exceeded 160mm in length were all opaque in colour.

When the weight of the valve is compared, there is more correlation with colour. While there is no significant difference in weight between Translucent and Opaque specimens (t = 1.37 df = 509), there is a significant difference between Translucent and Indeterminate specimens (t = 2.442 df = 338) and Opaque and Indeterminate (t = 2.012 df = 423) specimens. Thus, it appears that Indeterminate specimens weigh less than those which can be attributed to either Translucent or Opaque growth. This may be a function of the fact that a high number of specimens of *Mya arenaria* are considered indeterminate. This species is often referred to as the soft shelled clam, due to the thinness of its shell. Valves which produced no usable section all weighed significantly less than those which produced sections. The T values are as follows:

Translucent vs No Section	t = 2.079	df = 227
Opaque vs No Section	t = 2.520	df = 312
Indeterminate vs No Section	t = 1.885	df = 141

Thus, it can be suggested that specimens should weigh more than 6 grams if they are to be used in a study of this nature. Valves

which weigh very little tend to produce no usable section (mean=5.806, sd=9.505). Indeterminate readings are centered on valves which average 26.557 grams with a standard deviation of 43.583 grams. Opaque valves overlap this considerably, with a mean of 36.664 and a standard deviation of 48.775. Translucent valves have the largest range, and average 44.084 grams, with a standard deviation of 73.270 grams. This large range seems to be associated with a small number of extremely heavy valves, most likely examples of the largest species studied, *Tresus capax*.

Thus, the size of the valve under study does not seem to exert any undue influence on the coloration of the ventral margin, and seems unlikely to be a confounding variable. However it is worth noting that smaller valves tend not to produce usable sections. It seems likely that a minimum specimen size will need to be observed when compiling modern control collections.

TIME

Time measurements were made for two aspects of this study: (a) The amount of time needed to section a valve, and (b) the amount of time needed to determine the colour of the ventral margin. Each of these will be discussed in turn.

The time needed to section the valve was recorded for six collection periods. These data have been broken down both by species and by ventral margin colour, and suggest some interesting trends. The following table shows the mean sectioning time, and the standard deviation for each species.

Table 6
Average Sectioning Time (in Seconds) by Species

Species	n	Mean	SD
Clinocardium	12	401.33	122.76
Macoma	56	403.14	125.06
Mya	64	426.53	125.06
Protothaca	105	434.24	163.51
Saxidomus	48	587.88	188.31
Tresus	2	641.00	21.21

Difference of Means tests produce the following results. There is no significant difference between *Clinocardium* and *Macoma* (t = 0.047 df = 66). There is also no significant difference between *Mya* and *Protothaca* (t = 0.291 df = 167). These species were tested because they seemed to be very similar in weight. The middle species, *Macoma* and *Mya* also show no significant difference in sectioning time (t = 0.839 df = 118). There is no significant difference between *Saxidomus* and *Tresus* (t = 0.391 df = 48). However, there is a significant difference between *Protothaca* and *Saxidomus* (t = 5.103 df = 151). These results suggest that there is very little difference in the amount of time needed to section *Clinocardium, Macoma, Mya,* or *Protothaca.* However, both *Saxidomus* and *Tresus* individuals take a significantly longer amount of time to section (although the latter has a very small sample size). Alone, these data suggest that the latter two species are less productive in terms of preparation time.

When the amount of time needed for sectioning a specimen of

a given coloration is examined, the following results are obtained.

Table 7
Average Sectioning Time (in Seconds) by Growth Coloration

Coloration	n	Mean	SD
Translucent	95	474.38	161.57
Opaque	120	452.67	167.36
Indeterminate	63	442.08	183.41

Difference of Means tests produce the following results:

Translucent vs Opaque	t = 0.955	df = 213
Translucent vs Indeterminate	t = 1.158	df = 156
Indeterminate vs Opaque	t = 0.391	df = 181

None of the T values obtained for growth coloration are significant at the 95% level. These observations demonstrate that, on average, a section with a Translucent ventral margin will take slightly longer to produce than will a section with an Opaque or Indeterminate ventral margin. This may suggest that Translucent shell is slightly harder than Opaque shell. It is doubtful that the difference is significant enough to use the time needed for margin preparation as a means of determining the coloration, especially in light of the fact that the sections produced were not a uniform size.

The amount of time needed to analyze a section and determine the coloration of the ventral margin was also recorded for many specimens. The following table shows the results by species.

Table 8
Average Analysis Time (in Seconds) by Species

Species	n	Mean	SD
Clinocardium	12	44.08	17.38
Macoma	50	40.58	13.36

Mya	42	40.24	20.71
Protothaca	85	28.95	8.83
Saxidomus	77	33.24	17.01
Tresus	2	36.50	3.54

The following T scores were obtained:

Saxidomus vs Tresus	t = 0.27	df = 37
Macoma vs Mya	t = 0.095	df = 90
Clinocardium vs Macoma	t = 0.754	df = 60
Protothaca vs Saxidomus	t = 1.812	df = 120

These measurements show significant differences in the amount of time needed to analyze certain species. *Protothaca staminea* requires significantly less time to analyze than does any other species under study. It is interesting that the two species which take the longest to section (*Saxidomus* and *Tresus*), take relatively little time to analyze.

When broken down by coloration, the time needed for analysis yields the following results.

Table 9
Average Analysis Time (in Seconds) by Coloration

Coloration	n	Mean	SD
Translucent	77	32.17	12.50
Opaque	98	33.60	13.58
Indeterminate	51	43.86	18.16

Indeterminate vs Opaque	t = 0.391	df = 181
Indeterminate vs Translucent	t = 1.158	df = 156
Translucent vs Opaque	t = 0.995	df = 213

Thus, there is no significant difference between the amount of time needed to analyze any type of specimen. However, it takes longer, ten seconds on average, to decide that the specimen is

indeterminate.

FRACTURE ANALYSIS

A common occurrence when sectioning a valve for study was fracturing. This often occurred despite the greatest precautions during cutting. It is important to try to avoid fracturing of specimens for two reasons. First, the fracturing of the shell can potentially result in damage to the sectioning equipment. Second, if the shell fractures, it may not be amenable to other types of study. Whole shells are needed for most other types of analysis, and fragmentary shells may give misleading results.

A number of different types of fractures were recognized, and are briefly described here. General fractures, are defined as a fracture which removes greater than one third of the total valve. This type of fracture is found in all species to some degree, but predominates in *Protothaca*. Fracture during section removal is defined as a fracture which is caused wholly by the researcher, rather than the process of cutting the shell, and occurs as the result of difficulty in removing the section after the cut has been made. This is recorded for all species except *Tresus*, and is most common in *Protothaca*. The third type of fracture defined is the ventral margin fracture, which involves fracturing off a portion of the ventral margin, usually adjacent to the section. This is recorded in relatively equal proportions for all species except *Tresus*.

Other problems which were recorded during the sectioning process are as follows. When the valve being sectioned is quite

large, and its weight causes undue friction on the saw blade, the valves are held back manually. This situation predominates in *Saxidomus* individuals. Some specimens also produced short sections, which are defined as occurring when the cut section breaks into pieces. While these sections are still usable, they can be somewhat difficult to maneuver. This condition was recorded for *Mya, Protothaca,* and *Saxidomus* individuals. Some specimens also produced thick sections, which are defined as being wider across the ventral margin than in the thickness from the internal to the external surface of the valve. These were most common in the thin shelled *Mya arenaria*, although they were recorded for all species except *Clinocardium*. Some specimens also yielded sections which were unusable for one reason or another, usually because the ventral margin of the section was damaged during sectioning. This was most common in *Mya* specimens.

When broken down by valve length, there is relatively little relationship between size and fracture type, with one notable exception. Hand held specimens tend to range well above the size range noted for all other types of fracture. The following table summarizes the means and standard deviations of the variables length and weight for each fracture type.

Table 10
Length and Weight Measurements by Fracture Type

Fracture Type	n	LMean	LSD	WMean	WSD
General	34	40.23	30.21	13.50	18.30
Hand Held	19	111.03	16.09	191.90	113.05
Section Removal	22	48.03	30.13	32.71	57.83
Short Section	19	62.09	31.27	53.83	86.77
Thick Section	10	78.08	22.23	58.21	48.05
Unusable	6	70.87	29.29	48.78	72.95
Ventral Margin	37	51.93	23.66	33.11	53.07

LMean = Mean Length
WMean = Mean Weight
LSD = Standard Deviation Length
WSD = Standard Deviation Weight

Difference of Means tests were conducted for several fracture types. Both lengths and weights were considered. The following T values resulted:

Length

Hand Held vs Thick Section	t = 5.064	df = 26
General vs Section Removal	t = 0.969	df = 51
Thick Section vs Short Section	t = 1.329	df = 26

Weight

Hand Held vs Thick Section	t = 3.448	df = 27
General vs Section Removal	t = 3.264	df = 42
Thick Section vs Short Section	t = 0.143	df = 27

The pairings were made on the basis of similarity of means. Those most similar were chosen for comparison. It is clear that there is a considerable amount of overlap in most categories. Only Hand Held specimens differ significantly from the other specimens in both valve length and weight. However, there is

also a significant difference in the weight of valves producing general fractures. General fractures tend only to occur in small shells, while larger shells experience ventral margin fractures or fractures which occur during section removal. Short or Thick sections tend only to occur in larger shells, while Hand held valves are very large. This data suggests that a certain size range of shells be collected -- namely shells which average at least 40 mm in length, and at least 15 grams in weight, but are less than 110 mm in length, and 190 grams in weight.

CHAPTER SEVEN: DISCUSSION

The technique of constructing a seasonal growth sequence through the examination of the growth coloration of the ventral margin of marine bivalves has a number of advantages and disadvantages.

Perhaps the foremost advantage to using the growth coloration ratio technique is the inherent speed. Tables presented in the previous chapter demonstrate that the average amount of time needed to section a specimen ranges from 6 minutes and 40 seconds to 9 minutes and 48 seconds. The amount of time needed to analyze a section ranges from 29 to 44 seconds. I argue that the technique is productive from the perspective of research time. It is possible to section fifty or more valves in one day, and to analyze three to four hundred in the same time period. Thus, this technique will allow the rapid analysis of large numbers of specimens. This is essential, as large numbers of specimens are needed for modern comparative data to be reliable. The speed of this technique makes it conceivable that large numbers of specimens -- in the order of thousands -- can be removed from archaeological contexts and analyzed, which is essential if season of death estimates are to be of use in the understanding of midden formation or changes in seasonal occupation.

Another advantage of the technique is its reliability. While the percentage of agreement from reliability tests done on this material is not as high as one might hope (i.e.: less than

90 percent), they do suggest that the technique is reliable enough to warrant further use. With practice, the researcher can become quite proficient and consistent at recognizing growth coloration.

At the same time, there is a certain amount of bias inherent to the technique. There is a high degree of subjectivity in interpreting the growth coloration of a valve. There is a tendency for valves to appear Indeterminate on first examination, and either Opaque or Translucent on the second examination. Although the reliability study shows that this bias is not statistically significant, it is still worth noting. While it would be possible to measure the degree of bias imparted by the researcher (see Nicholson 1980), it is difficult to suggest a solution to the problem. Perhaps scanning electron microscopy or image digitization would be useful.

Another problem inherent in this technique is its destructive nature. Sectioning a shell is destructive. While the damage is minimal in most cases, it can be problematic in others. Although some would not consider this to be important in an archaeological context, especially in light of the number of shells contained in a midden, it does pose some problems. Fragmenting the shell could render it unsuitable for other types of analysis. Approximately 16 percent of the modern shells used in this study fractured in one manner or another during preparation or analysis. One would expect that the proportion would be the same or higher with prehistoric shells, due to their

often friable nature (Muckle 1985). This potential for destruction of materials will require large samples of archaeological shell, in order to carry out types of analysis other than season of death estimates.

The biggest disadvantage to using this technique is its inability to divide the year into short, discrete seasons. Research on the Atlantic coast has demonstrated that this technique and others similar to it typically divide the year into only two seasons, which may or may not be of equal duration (Claassen 1989; Sanger 1989; Belcher 1989: personal communication). This appears to be the case on the Pacific coast. When all species are combined, only two seasons can be distinguished. Even *Protothaca staminea*, apparently the most seasonally sensitive species in the study, can only be broken into three distinctive seasons. It seems unlikely that comparing ratios of Translucent, Opaque, and Indeterminate valves will ever provide a highly sensitive means of looking at short term seasonal change.

The determination of season of death using shellfish appears to have some potential, at least in the Gulf of Georgia region. Despite the shortcomings mentioned above, it would appear that a valid, if general, approximation of the season of shellfish collection could be made using this technique.

ESTIMATING THE SEASON OF COLLECTION OF PREHISTORIC SHELL

After the growth coloration ratios have been determined for

the year, the researcher can use them to make an estimate of the season of collection of prehistoric materials. Two hypothetical examples will be used to demonstrate the procedure.

For the first example, a prehistoric sample of forty specimens of *Protothaca staminea* were removed from a single depositional context of a midden. After sectioning, this sample yielded 12 specimens which died during Translucent growth, 21 specimens which died during Opaque growth, and 7 specimens which were Indeterminate. These values are equal to 30 percent, 52.5 percent, and 17.5 percent respectively. The procedure would be to compare these ratios with the modern data, and ascertain which month they most closely resemble. After comparing with the values in figure 9, it is apparent that this hypothetical collection falls somewhere in the early spring, between the months of February and April. Thus, this collection period would be suggested, with March appearing to be the most similar month.

For the second example, a prehistoric collection of 31 specimens of *Saxidomus giganteus* and 51 *Protothaca staminea* are removed from the same context of a midden. After sectioning, the *Saxidomus* specimens contain 8 Translucent specimens, 19 Opaque specimens, and 4 Indeterminate specimens, while the *Protothaca* specimens contain 11 Translucent, 33 Opaque, and 7 Indeterminate examples. Again, these values would be compared with the modern data. For all individuals combined, there are 23.2 percent Translucent, 63.4 percent Opaque, and 13.4 percent Indeterminate specimens. By species, there are 25.8 percent Translucent, 61.3

percent Opaque, and 22.7 percent Indeterminate *Saxidomus* and 21.6 percent Translucent, 64.7 percent Opaque, and 13.7 percent Indeterminate *Protothaca* individuals. These figures can be compared to the modern data either combined, or by species. Combined, these ratios do not closely match any collection period, but could likely be assigned to the time period between April and September, due to the high proportion of Opaque specimens. Treated individually, *Saxidomus giganteus* could be assigned to any month between February and September, with May through July being the most similar months. *Protothaca staminea* would appear to fall between February and November, with June through November being the closest matches for the proportion of Opaque specimens, and February through April most resembling the Translucent values.

The technique of comparing prehistoric to modern coloration ratios is quite simple in theory, and somewhat more complicated in practice. It is difficult to suggest whether it is more important to closely match Translucent or Opaque ratios. The ratios used in the examples do not closely match any of the modern values, likely because the modern data provided was compiled in only a single year. Annual variations in growth rates are thus not taken into account. A multi-year study would be needed to establish the range of variability to be expected during any given collection period.

RECOMMENDATIONS FOR FURTHER RESEARCH

Based on the findings of this study, a number of potential

lines of research can be suggested. First, it seems that *Protothaca staminea* is the species with the greatest potential for providing seasonal data. *Protothaca* seems to be the species most sensitive to seasonal change, as its growth coloration patterns break the year into three distinctive seasons. It is also a productive species in terms of preparation and analysis time. *Protothaca* requires the least amount of time to analyze, and does not require significantly more time to section than any other species. While *Protothaca* does have the highest fracturing rate (5%) of any species in the study, it also has the largest sample size, and the greatest range of sizes studied. *Protothaca* also is easily obtained, being the dominant species in every collection period in this study, except for May, June, and October. For these reasons, I would recommend that future research in this region be aimed primarily at *Protothaca staminea*.

Both *Macoma* and *Saxidomus* also seem to be potentially useful for season of death studies. While neither has the sensitivity to change found in *Protothaca*, it is possible that they could be used to supplement *Protothaca*. *Macoma* is capable of dividing the year into two seasons, and is most abundant during the summer months. This is useful, as it is apparently during the summer that the most distinctive seasonal coloration change occurs. *Macoma* also has the advantage of being easy to section, although it is one of the more difficult species to analyze. If specimens of *Macoma* are available for study, they should be utilized.

Unfortunately, *Macoma* is uncommon in archaeological contexts. *Saxidomus*, while much less sensitive than *Protothaca*, appears generally to parallel its growth pattern. Thus, *Saxidomus* could be another useful species to use as a supplement. While it is a slow species to section, it is very easy to analyze. *Saxidomus* would seems to be another good choice for study, as it is frequently encountered in midden sites.

The other species under study here are less useful. I would recommend that researchers avoid both *Clinocardium nuttalli* and *Mya arenaria*. *Mya* is a poor choice, having an extremely high proportion of Indeterminate specimens, and a high fracture rate, both during preparation and specimen collection. Only the chondrophore is commonly encountered archaeologically. *Clinocardium* is also difficult to analyze, with sections often being rather pinkish in colour, and is awkward to section, due to the pronounced ridges of its valves. This is unfortunate, as several sites in the Gulf of Georgia region contain large lenses composed almost exclusively of *Clinocardium*. *Tresus capax* was not gathered in sufficient numbers to properly analyze its potential as a seasonal indicator. However, further work on this species could be worthwhile, as it is frequently found in association with burials in the Gulf of Georgia, and could potentially be used to assess the season of inhumation (assuming that live shellfish were included with the burial).

Caution should be used when only one or a limited number of species is used for making season of collection estimates of

archaeological shell. If, for example, *Protothaca staminea* is chosen as the modern species to be monitored at a particular site, any estimates of season of collection will only be applicable to this species. It would be erroneous to apply seasonal data from one species to any other species, regardless of how similar their ecology may be. This holds true even if a second species is found in direct association with *Protothaca* within a midden. The degree of accuracy with which one can assess the season of site utilization using this technique is questionable. It must be remembered that only a very particular activity is being monitered through this type of study, and not the full range of cultural activities which occurred at the site. Even if the season of collection of all species of shellfish at a given site could be precisely determined, it would still be invalid to assign an estimate of the season of site utilization on the basis of only shellfish data. Assigning a season of utilization to a multi-component site on the basis of an estimation of the season of shellfish collection is even more misleading.

Also apparent from this study is the fact that there is a distinct size range for specimens which will be useful in determining season of death. The valves of the specimen should not be less than 30 mm in length, or weigh less than 6 grams (paired valves). Small shells often produce no usable section, and are very difficult to cut, due to the fact that they are difficult to secure without breaking. Specimens measuring more

than 100 mm in length have the greatest tendency to need extra support during sectioning.

The effect of the environment on shell growth needs additional study. A number of types of environmental data need to be recorded by the researcher while the modern specimens are being collected. These data include: air temperature; wind speed and direction; sea surface temperature; water salinity and nutrient counts; and pollution counts. Unfortunately, during the time of collection I made no attempt to record any data of this nature, assuming that government agencies keep track of such things. This is not the case. While weather records are kept, many types of data, such as sea-surface temperature, are not routinely recorded. Future researchers should try to record such data.

The effect of geographic variation on seasonal growth patterns also needs investigation. The collection used in this study comes from a single locality. Therefore, there is no way of determining whether the results can be applied to any other locality. What is needed is a research project which will collect specimens from several different locations -- preferably at the same time -- to assess the degree of difference or similarity of seasonal growth patterning. The Pender Island collection can only be used for other sites if it can be demonstrated that there is no significant difference in the growth patterning of the region. Microgeographic variability should also be explored. It is important to determine that there

is no difference in the growth patterns observed in specimens inhabiting different areas of the intertidal zone.

Finally, it may be necessary to re-examine the entire concept of seasonality in regard to shellfish. The use of calendar month designations should probably be abandoned for coastal sites. It appears unlikely that any technique other than Koike's labour-intensive growth line studies will ever allow for more than a rough estimation of the season of death of marine bivalves, at least in the Gulf of Georgia area. While the use of a lunar calendar is an obvious solution to the inadequacies of the Christian calendar, it is still not truly reflective of the types of patterning observed in this study. It appears that some other type of calendrical system would be preferable, one which is directly related to the factors controlling shell growth. A seasonal calendar based on changes in salinity levels, water temperature, or nutrient levels would likely be the most realistic way of looking at seasonality. A good working knowledge of the seasonal variation of these types of factors could likely lead to a very good estimate of the season of death of shellfish, and hence their season of collection. This type of scheme has recently been proposed by Claassen (1989) for the Atlantic coast, and would seem to have utility on the Pacific coast as well. It is important to remember that while we are asking questions based on what could be called cultural seasonality -- such as a seasonal collection round, we are attempting to answer these questions through the use of data

which is indicative of non-cultural seasonality. Shellfish will respond in the same fashion to ecological stimuli regardless of whether or not they are a food source to humans. Therefore it seems logical that, at least for the time being, archaeologists content themselves with what information shellfish can actually give us about the season of their death. Dividing the year into two unequal growth seasons may not be as satisfying as knowing the exact date of an occurrence, but it is the best we can do at present.

CHAPTER EIGHT: CONCLUSION

Archaeological season of death studies undertaken on the Pacific coast have tended to be based upon incorrect assumptions about shell growth. Rather than using large comparative collections to build a monthly growth sequence, researchers have relied on the ability to recognize winter check-lines, and estimate the season of death based on the amount of growth which occurs after this line. This thesis has questioned this line of reasoning, and has attempted to utilize a different technique of season of death determination, which has been developed on the Atlantic coast.

It has been demonstrated that specimens of several species of bivalves can exhibit the type of growth characterized as indicative of spring by researchers such as Ham (1982; 1989) during any month of the year. This result alone suggests that the studies based on the annual check-line technique undertaken previously are in desperate need of re-examination.

Shell growth visible at the ventral margin can be characterized as being of two distinctive types: Translucent or Opaque. It is questionable whether these two colorations represent slow and fast growth, as suggested by Claassen (1986b). However, the two types of growth do tend to be found in different proportions throughout the year. This is true in all species in which both types of growth have been recognized. This suggests that attempting to use the variations in ratios as a means of recognizing the season of death has some validity.

The degree of variation recognizable in the collection under study is not sufficient to demarcate the year into distinctive monthly growth periods. The precision of the technique is in fact disappointingly low, capable only of dividing the year into two or perhaps three growth periods. This is due in part to the limited sample sizes of each species gathered during each collection period. However, it also seems likely that the variability would be insufficient to break the year into lunar-month length growth periods regardless of the sample size.

The technique of examining ratios of growth coloration appears capable of providing a season of death, or season of collection, estimate for the species *Macoma spp.*, *Protothaca staminea*, and *Saxidomus giganteus*. Other species of bivalves examined in this thesis do not provide results worthy of the time expenditure needed to obtain them, and should be avoided in future studies.

Despite the fact that an estimate can be made for the three species mentioned, it is questionable whether the results are worthy of the time and costs which must be invested to obtain them. Estimates may fall into a narrow time span of only two to three months, but they may also be as general as February through November.

Generating an estimate, precise or otherwise, requires an investment of at least one calendar year for the collection of specimens. These specimens will require between one and three hours of physical labour to collect from the area under study.

Processing the specimens prior to sectioning will require another five to six hours, as cataloguing a collection of sixty or more shellfish normally takes one to two hours, and processing the same collection takes three to four hours. Specimens require an average of seven to eleven minutes to section, meaning the collection of sixty would require seven to eleven hours to section. The final coloration analysis would require an additional twenty nine, to forty five minutes. Thus, two and one half to three days (excluding the day needed to air-dry the specimens after processing) of full-time work would be necessary every twenty eight days to compile a modern collection for a single area. This figure assumes that only one species is collected. The same amount of time will be needed for each additional species.

The costs and time required for proper midden sampling are also prohibitive. A minimum sample size required to assess the season of collection of a single lense is forty to sixty usable valves. For a thorough understanding of the role of seasonal collection strategies throughout the site, samples of this size must be removed from virtually every recognizable lense. Even within a small shell midden, one could expect to encounter thousands of lenses. Even with a comprehensive sampling stratagy, the recovery rate of material would be astronomical, requiring years of laboratory research. Only a large-scale archaeological project devoted solely to the understanding of the role of seasonal collection as a factor of midden formation would

have sufficient funding for such an expensive undertaking.

The results obtained through the use of this technique are simply not precise enough to warrant the expense of its use in most cases, and suggest that it is not especially practical for archaeology. Small projects will have neither the time nor the resources to compile a comprehensive modern collection, and larger projects are unlikely to spend large amounts of money on a study which produces only a general estimate of the season of collection. It seems unlikely that this technique will ever be widely applied on the Pacific coast.

Future work may provide more precise results. A multi-year study which uses larger sample sizes from each collection period may produce a seasonal growth coloration curve which would be capable of distinguishing shorter growth periods. However, Claassen's (1989) multi-year sampling of the same locality has found that annual variation tends to make the different collection periods more homogeneous, rather than more distinctive. Deith (1983), has similar results in England. Additional research would be necessary to determine if the same trend is found on the Northwest Coast.

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