PRELIMINARY ASSESSMENTS ON THE AGES OF GEODUCKS, *PANOPE ABRUPTA (CONRAD)*, IN SOUTHEAST ALASKA USING THIN SECTION OF SHELL HINGES

by

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ABSTRACT

Samples of commercially harvested geoduck clams obtained from four locations in southern Southeast Alaska during October 1994 through January 1995 were examined to develop methodology for aging, to provide recommendations for future collections, and to draw inferences from the population age structures. A multiple thin-sectioning approach was developed for obtaining acceptable samples from cross-sections of the shell hinge. Annuli counts were made through a transmitted light microscope. Observations indicated that annuli counts might be censored depending on the location on the hinge from which the section was taken. Field measurements of whole wet weight and shell lengths were compared with laboratory measurements of shell length, width, height, hinge thickness. Although the sample sizes were small (ranging from 25 to 50 geoduck shells per site), there was generally a significant difference in mean age, weight, and shell measurements between areas. For all areas combined the ages ranged from 11 to 89 years with a median age of 40 years. Linear growth in weight, hinge-thickness, shell depth and shell-height was similar between areas, though growth in shell length appeared different between areas. Hinge-thickness had the highest correlation with age ($r = 0.75$), and is suggested as an appropriate structure for stratifying shell samples. The age distributions imply that recruitment can be periodic. A rough estimate of natural mortality rate is given at 0.01 $yr.^{-1}$.

INTRODUCTION

The geoduck species, (*Panope abrupta* (Conrad, 1849)), which prior to 1983 had the scientific name *P. generosa* (Gould 1850), is a bivalve found in the subtidal substrate of the northwest coastal waters of North America from Baja, California to Southeast Alaska (Sloan and Robinson 1984, Goodwin and Pease 1991, Andersen 1971 [cited in Goodwin and Pease 1987]). The geoducks live buried up to 1.3 m below the surface of the sediment, occur from the zero tide level down to 100 m, and remain in the general substrate area of settlement following metamorphosis from the veliger to the juvenile stage.

In British Columbia Canada, geoducks reach sexual maturity at 5 years of age, can have viable gonads for over one century, and appear to lack 'reproductive senility' at the upper end of the age scale (Harbo et al. 1983, Sloan and Robinson 1984). Rapid increase in shell length and body growth (weight) occurs during the first 10 to 15 years, after which shell length nearly ceases to increase and body weight, shell thickness and shell weight increase at a slow rate (Harbo et al. 1983).

The commercial fisheries for both species in British Columbia and Washington coastal waters began in the 1970's, and have developed into major fisheries of over 1 million lbs. per year. In comparison, the commercial fishery for geoducks in Southeast Alaska began in the early 1980's, and has only reached a maximum annual harvest of approximately 200,000 lbs.

The primary method of harvesting geoducks is via divers (with either SCUBA or hooka gear) using a water jet to dig the clam out of the substrate (Harbo et al. 1986). In Southeast Alaska, the harvested geoducks are then transported to processing plants in Ketchikan or Petersburg, where the product is dressed and frozen for shipment. The potential for expansion of the geoduck fisheries may be spurred by the increasing ex-vessel price of geoduck, which has steadily risen from $0.20 per pound in 1985 to $2.70 per pound in January 1995, and by increased interest in shipping live geoducks, which have significantly higher value than the frozen product.

While the demand is growing for the geoduck product, there is a need to determine the sustainability of the stocks in Southeast Alaska. This requires an understanding of the population age structure. Age information is used to determine growth rates, it can provide indications of natural mortality rates, and it can give insight into recruitment patterns through age-frequency distributions.

Geoducks, which have been aged in British Columbia and Washington, are reported to reach up to 146 years of years old (Harbo et. al. 1986). The process of determining the ages involves counting the internal growth rings present in cross sections of the shell's hinge area. The conclusion that these growth rings form annually is based on the work of Shaul and Goodwin (1982) who report on four methods, including preliminary analysis of natural radionuclides (^{226}RA and ^{210}Pb), in support of the hypothesis of annular growth.

The purpose of this project was to develop an efficient method for accurately aging geoduck clams collected from the commercial harvest. In addition, measurements of shell dimensions were collected to determine the relationship of size to age, and to draw comparisons between growth rates from different locations. The age data is presented as an initial estimate of the population age structure, and possible recruitment schedules, and the size measurements are examined to determine an appropriate structure for establishing an age-length key.

MATERIALS AND METHODS

ADF&G personnel collected geoduck shells along with information on harvest location, shell length and body weight at processing plants in Ketchikan during the 1994/95 season. A subsample of these collections was then shipped to the Coded Wire Tag and Otolith Processing Laboratory in Juneau. The geoduck shells examined were stocks at Kah Shakes, Little Steamboat Bay, Ulitka Bay, and West Gravina in Southern Southeast Alaska (Figure 1). A total of 145 pairs of shells were examined as part of this study.

Appendix A contains detailed information about shell handling, processing, and the collection of measurements, along with observations and recommendations specific to the equipment used in this study.

In the laboratory the right shell of each individual was measured for length, width, and height. If the right shell was broken the left shell was examined. Both left and right shells were examined from a subsample of geoducks to determine if there is a systematic difference in size. The shell length and width measurements were made at right angles to each other and in reference to the center of the umbo (Figure 2). Shell height was measured perpendicular to the length and width measurements and represents the maximum depth of the shell when it is placed on a flat surface. Shell height was not measured in the West Gravina samples.

After measurements were taken, the shells were prepared for aging. A survey of the literature indicated that for many bivalves, annuli are best examined by taking cross sections of the hinge area of the shell and using either acetate peels or thin sections to obtain the counts. The acetate peel method is most often reported in the literature. It is the method that has been applied to geoducks in Washington State (Shaul and Goodwin 1982) and is the approach currently used to age geoducks at the Canadian Department of Fisheries and Oceans' Pacific Biological Station (Alan Campbell personal communication). The acetate peel method involves placing a strip of acetate paper over the exposed hinge section after it has been polished and etched with acid. The acetate is slightly softened to record an imprint of the surface topology. The peels are then placed between two glass slides and the pattern of rings are magnified and projected on a screen or viewed directly with transmitted light microscopy. See Ropes (1987) and Kennish et. al. (1980) for more detail on the acetate peel method.

A limitation in using the acetate peel method is that due to time constraints, generally only one peel is made per specimen, and the counts taken from that peel are dependent upon having an optimum cut through the hinge section of the shell. Because of uncertainty about the best location for making accurate counts, a thin sectioning approach was used which allowed for multiple sections to be taken from each shell. Thin sections are made by taking close parallel cuts along the shell hinge. The sections are viewed directly with a transmitted light microscope. As opposed to acetate peels which provide a record of surface topology, the banding in the thin sections reflect changes in the internal transparency of the shell with the translucent annuli appearing in sharp contrast to the opaque growth increments. Thin sectioning has been used for routine aging of other shellfish (Ropes and Jearld 1987).

We prepared the samples using a two-stage method. First the bulk of the shell was removed using a coarse cut-off saw with an abrasive blade. This was followed by controlled cuts along the hinge using a low speed diamond saw with a micrometer adjusted stage holder to control the thickness of the sections. The sectioned samples were then lightly polished and cleaned to remove the blade marks, placed on a glass slide and viewed with a transmitted light microscope.

Experimentation with the test samples suggested that 0.35 mm was the optimum thickness for the thin section. At that thickness breakage was minimal during the cutting, yet the section was thin enough to allowed adequate transmission of light for viewing.

The annuli counts were made through the microscope with the occasional assistance of an imaging system which displayed the hinge section on a color monitor. An example of geoduck thin-section is given in Figure 3. Following Sloan and Robinson (1984), three independent annuli counts were made on each section and the average count was used as the age for that specimen.

The location of the cuts along the hinge can be quite critical. Based on interpretation of reports in the literature, the thin sections were initially taken at the center of the umbo and included the shell's hinge tooth to insure that the first annuli is present. As a check on this location, a sequence of thin sections proceeding from the umbo center to the thickest section of the shell hinge was collected on four of the shells. The cuts were made perpendicular to the shell hinge. We found that in two of the four specimens, the section from the center of the umbo could have up to 15 annuli rings less then those made at the thicker part of the hinge. The first annuli was still present in sections up to 3 mm from the center.

This apparent censoring of the annuli counts at the umbo's center in at least some of the shells, has not been reported in the literature. Our observations suggest that it may be the result of either abrasion or a cessation of shell growth associated with locations where the hinge tooth of the opposing shell resides. We do not believe it was an artifact of the thin-section method. When both shells are joined this location appears as a cavity that houses the interlocking hinge teeth. Annuli counts at this location may contain only the first 20 to 30 years of growth, while farther down the hinge the counts may exceeded this by 10 to 15 years.

Based on this observed dependency of ring count with the location of cuts, the procedure for the remaining samples was to collect three thin sections from each sample and use the section that had the most ring counts as providing the best record of the specimen's age. From this section the average of three ring counts was used as the age of the clam.

The analysis methods used include graphical exploratory analysis approaches and confirmatory statistics using PC based statistical software. The natural mortality estimate followed the catch-curve method of Ricker (1975) and was based on the declining slope of log frequency with age.

RESULTS

The shell length measurements taken in the field were found to be comparable with those taken in the laboratory ($p = 0.15$; paired t-test). Unless otherwise stated the length measurement data presented are from those taken in the laboratory.

Lengths from the left and right valves of the same individual as measured from a subsample ($n = 22$), indicated no systematic difference within an individual in growth along that axis ($p = 0.782$; paired t-test). In contrast shell width, height and hinge thickness were found to be significantly different between pairs ($p = 0.001$, $p = 0.021$, and $p = 0.009$ respectively), though the actual magnitude of the differences were small (< 3.0% of the mean).

Summary statistics of length, width, height, hinge thickness, wet weight and the estimated ages from the four locations are presented in Table 1. For each measurement there are significant differences that can be attributed to the location of capture ($p < .003$; ANOVA). Little Steamboat Bay samples were largest and had the highest mean age.

All shape measurements were positively and significantly correlated with each other and with estimated age (Table 2). Hinge thickness had the highest correlation with age, while shell length and width had the highest correlation with wet weight.

The age - frequency distribution for each location is presented in Figure 4. With the exception of West Gravina age samples, in which 80 percent of the samples were within ages 30 to 40 years old, the data is approximately normally distributed.

Table 1. Statistical compilation of wet weight, length, width, height and estimated age of geoducks sampled from four locations in SE Alaska.

Harvest Site		Kah Shakes	Little Steamboat Bay	Ulitka	West Gravina
Age (years)	mean	36.73	49.7	47.72	39.2
	std. dev.	10.35	14.71	12.7	15.7
	range	(11-52)	(11-84)	(18-88.7)	(31-87)
	N	29	24	27	40
Length (mm)	mean	134.7	141.4	150.5	132.4
	std. dev.	8.2	13.5	10.5	13.8
	range	(114-152)	(125-169)	(123-176)	(108-175)
	N	30	24	27	40
Width (mm)	mean	86.3	93.0	98.1	85.1
	std. dev.	5.1	9.0	7.1	6.3
	range	(76-97)	(79.5-118.5)	(84-111)	(72-100)
	N	30	24	27	38
Height (mm)	mean	27.24	31.9	31.95	NA
	std. dev.	1.83	2.78	2.25	NA
	range	(22.2-30.8)	(26-37.1)	(28.1-35.4)	NA
	N	30	24	27	NA
Wet Weight (g)	mean	1015.9	1164.0	1235.7	922.5
	std. dev.	233.3	281.9	226.2	211
	range	(461-1497)	(651-1920)	(716-1644)	(645-1556)
	N	30	25	50	40

Table 2. Pearson correlation matrix of shell height, width, length, hinge thickness, weight and estimated age. All correlation significant at $p < 0.05$, using Bonferroni adjustment for multiple tests of significance.

	Weight	Length	Width	Height	Hinge	Age
Weight	1.00					
Length	0.75	1.00				
Width	0.77	0.80	1.00			
Height	0.59	0.59	0.69	1.00		
Hinge	0.61	0.50	0.51	0.31	1.00	
Age	0.64	0.62	0.59	0.49	0.75	1.00

To determine if there is a difference in linear growth rates between the locations, an analysis of covariance approach was applied in separate models for the different measurements of size. The model was of the form,

Variable = Constant + A + L + A*L + error

Where A is age, and L is location and A*L is the interaction of age with location. The results in Table 3 show that for all measurements, the estimated age of the individual was a significant factor in explaining the size of the geoduck. Location and the interaction of location with age was not a significant in any of the measurements with the exception of shell length, in which both were significant. The results were similar when the West Gravina samples were excluded.

*Table 3. Probability results from Analysis of covariance models testing for the effects of Age A, Location L, and the interaction of Location and Age L * A, on the size of shell measurements.*

Variable	*L*	*A*	*L * A*
Weight	0.446	0.000	0.439
Length	0.001	0.000	0.011
Width	0.196	0.000	0.116
Height	0.382	0.017	0.203
Hinge Thickness	0.760	0.000	0.358

For shell width, height, and hinge thickness, the non-significant effects of location and the interaction of location with age implies that the geoducks are growing at a common linear rate in the separate areas. The exception of shell length indicates that for that type of measurement there are regional differences in linear growth rates that are not attributed to the age of the samples.

This analysis of growth is limited to the geoducks that are vulnerable to commercial harvest; no specimens were found younger than age 11. For prerecruit geoducks growth must be more rapid in those first 10 years than observed here, as has been reported by Breen and Shields (1983). Figure 5 shows a pairwise plot of age with weight, shell length and hinge thickness, for all areas combined. A power curve is fitted to each pair to illustrate this rapid initial growth. The display is not meant to imply that such a curve is necessarily the most appropriate growth model for geoducks.

Because the sample sizes were small, all areas were combined for estimating a mortality rate using the regression of log frequency verses age. The regression was applied to the declining limb of the age distribution which had a modal peak of 32 years. Based on the assumption of constant recruitment and survival for these older ages, the estimate of mortality rate was 0.01 $yr.^{-1}$.

DISCUSSION

In developing an approach for aging the geoducks in this study, we were surprised to find that in some specimens the thin-sections had fewer ring counts at the umbo than did sections that were taken closer to the thicker part of the hinge. The hinge is thinner at the umbo in both valves and this forms a cavity that houses the interlocking shell teeth. All our sections were made perpendicular to the shell hinge and it is not clear whether the same protocol was used in other aging studies, most of which cite Goodwin and Shaul (1982) for the methodology. By reducing the angle of the cut it is possible to include both the center of the umbo and a thicker portion of the shell hinge. The angle however would have to be quite acute which maybe a problem with some diamond saws. Since we found that the first annuli was present up to 3 mm from the center, we continued to make our cuts perpendicular to the shell hinge, and did multiple cuts to monitor whether or not the counts were censored. Approximately 25% of the thin sections made were rejected either due to obvious censoring of annuli or the outer annuli were too obscure for viewing.

It is not clear why only some of the specimens examined had censored annuli counts at the umbo and not others. We don't believe however it was an artifact of our viewing method. and that the same phenomena necessarily occurs in populations elsewhere. We do suggest that future aging attempts carefully consider the location of cuts, and use multiple cuts to help identify if the annual counts are consistent along the shell hinge. The ability to select an "acceptable" cross section to determine the age of the individual geoduck gave us confidence that our age estimates were, at least, consistent. For the accuracy of the age estimates our results rely on the validation work of Shaul and Goodwin (1982).

In this study, we found that there was no difference in shell length, between the left and right valves of individuals, but there was a difference in shell width, height and hinge thickness. The magnitude of the differences are not large, however, and likely represent a negligible source of error. None-the-less, asymmetry in valve morphology should be considered when designing studies and drawing comparison's between different studies.

Maximum hinge thickness had a higher correlation to age than body weight or shell length, similar to the findings of Sloan and Robinson (1984). Shell length, and wet weight are the measurements most commonly collected from geoduck catch samples. Some studies (e.g. Breen and Shields 1983, Harpo et. al. 1983) have concluded that growth in shell length essentially ceases after age 10 to 15. In addition, wet weight, which continues to slowly increase after age 10 (Been and Shields 1983), is thought to be subject to significant measurement error when collected from commercial catch samples (Harbo et. al. 1986), due to the high percentage of water in the flesh (Andersen 1972).

Based on our results and the findings from other studies, we suggest that hinge thickness is a good candidate for routine collection in conjunction with the continued collection of wet weight. The shell hinge continues to get thicker with age and from the analysis of covariance, the relationship with age did not appear to vary significantly with the location of capture. Hinge thickness information might be useful for constructing age-length keys which can help reduce sample sizes. By stratifying geoducks into groups of different hinge thickness, subsamples can be drawn, aged, and inferences on the age structure applied to the population. Such approaches are useful when the method of aging is time consuming.

There were differences in mean ages from the different sites. Drawing further comparisons of the age distributions is not recommended due to the small sample sizes. The West Gravina samples however do stand out because a high proportions of clams were estimated between 30 and 35 years. We don't believe selective harvesting is responsible for this limited age distribution because the size ranges of the clams are similar to that in the other areas. One likely explanation for a paucity of older or younger ages is that recruitment of new clams into the West Gravina area is episodic.

For all areas there were few young geoducks present. In an ideal population, if recruitment to fisheries and natural morality rates were constant, the age distributions would show a decline, and the age of full recruitment to the fishery would be indicated by the mode of the distribution (Ricker 1975). The modal age in this study was 32. We suspect that full susceptibility to the commercial fisheries occurs at younger ages, such as when the growth curve flattens out (Been and Shields 1983). However without a systematic effort to sample geoducks of all sizes it is difficult to determine if selective harvest or episodic recruitment is responsible for the lack of younger geoducks.

If low or periodic recruitment into the harvestable populations does occur, it would be a concern for management of the stocks. The extent that it presents a problem however depends, in part, on whether it is a function of the availability of the young for settlement or function of density dependence. Density dependence in the form of competition for settlement sites can, in theory, also produce periodic population cycles when there is a time lag that results from different juvenile and adult growth rates (Bence and Nisbet 1989). The effects of harvesting can be quite different depending on which mechanisms regulate population abundance and are responsible for the age distributions. Differentiating between alternative hypotheses can be addressed through further research, possibly including adaptive management strategies (Walters 1986).

Mortality rate estimates are frequently drawn from age distributions, even though annual recruitment and mortality rates are not constant, because it remains an important parameter for estimating stock productivity and other alternatives for estimation are frequently lacking (Ricker 1975). From our data, the presence of older geoducks in the samples (> 80), implies that mortality rates are low. Because these stocks have not been harvested for very many years, the underlying population age structure has probably not been affected by fishing pressure. Pooling the data, and using the modal age of 32 as the starting point, the regression of log frequency on age provides an estimate of natural mortality of 0.01. This rate is similar to that calculated from stocks in Washington and Canada: 0.02-0.05 in Washington (Shaul & Goodwin (pers. comm.) in Breen and Shields 1983) and 0.01 - 0.035 for British Columbia (Sloan and Robinson 1984, Breen and Shields 1983).

For future studies we recommend that effort be directed toward aging samples gathered from surveys, Attempts should be made to obtain all sizes and age classes with in a given area. Younger samples would provide estimates of juvenile growth rates, help determine the size and age selectivity of commercial harvest, and help clarify the observations made here that recent recruitment has been poor.

SUMMARY

1. The location of the cross section used in aging the geoducks can be critical for obtaining accurate ages. We found that multiple cuts using the thin-sectioning approach was useful for obtaining consistent age readings.

2. Maximum hinge thickness had the highest of correlation with age than the other shell measurements and the relationship did not vary with location. We suggest that shell hinge-thickness might be a good candidate to use in the construction of age-length keys for future age readings.

3. The average age from the four areas varied significantly (36, 39, 47, and 49 years). Each site was characterized by the general absence of younger ages and in three of the four sites a few older geoducks were present.

4. Based on the presence of the older ages, a pooled estimate of the natural mortality rate is 0.01 .

REFERENCES

Anderson, A. M. 1972. Growth of the geoduck clam in Hood Canal, Washington. Abstracts of technical papers presented at the 1971 NSA Convention. *In* Proceedings of the National Shellfisheries Association. Vol. 62:1.

Bence, J.R. and R.M. Nisbet. 1989. Space-limited recruitment in open systems: the importance of time delays. Ecology. 70(5): 1434-1441.

Breen, P. A. , and T. L. Shields. 1983. Age and size structure in five populations of Geoduc [sic] clams (Panope generosa) in British Columbia. Canadian Tech. Rept. Fish. Aquat. Sci. No. 1169. 62 p.

Goodwin, C. L., and B. C. Pease. 1991. Geoduck, *Panope abrupta* (Conrad, 1849), size, density, and quality as related to various environmental parameters in Puget Sound, Washington. J. Shellfish Res., Vol. 10(1):65-77.

Harbo, R. M., B. E. Adkins, P. A. Breen, and K. L. Hobbs. 1983. Age and size in market samples of Geoduc [sic] clams (*Panope generosa*). Canadian Manuscript Rept. of Fisheries and Aquatic Sciences, No. 1714. 77 p.

Harbo, R. M., C. M. Hand, and B. E. Adkins. 1986. The commercial geoduck clam fishery in British Columbia 1981 to 1984. Canadian Manu. Rept. of Fisheries and Aquatic Sciences, No. 1873. 59 p.

Kennish, M. J., R. A. Lutz, and D. C. Rhoads. 1980. Appendix I. Preparation of acetate peels and fractured sections for observation of growth patterns within the bivalve shell. *In* Rhoads, D. C., and R. A. Lutz (eds.), Skeletal growth of aquatic organisms, p. 597-601. Plenum Press, N. Y.

Ricker W. E. 1975, Computation and interpretation of biological statistics of fish populations. Bulletin of the Fisheries Research Board of Canada No. 191. 382 p.

Ropes, J. W. 1987. Preparation of acetate peels of valves from the ocean quahog, *Arctica islandica*, for age determinations. NOAA Tech. Report NMFS 50. 5 p.

Ropes, J. W., D. S. Jones, S. A. Murawski, F. M. Serchuk, and A. Jearld, Jr. 1984. Documentation of annual growth lines in ocean quahog, *Arctica islandica* Linné. Fish. Bull. 821-19.

Shaul, W., and L. Goodwin. 1982. Geoduck (*Panope gererosa*: Bivalvia) age as determined by internal growth lines in the shell. Can. J. Fish. Aquat. Sci. 39:632-636.

Sloan, N. A., and S. M. C. Robinson. 1984. Age and gonad development in the geoduck clam *Panope abrupta* (Conrad) from southern British Columbia, Canada. J. Shellfish Res., Vol. 4:131-137.

Walters, C. 1986. Adaptive management of renewable resources. Macmillan Publishing Co. New York. NY. 374 p.

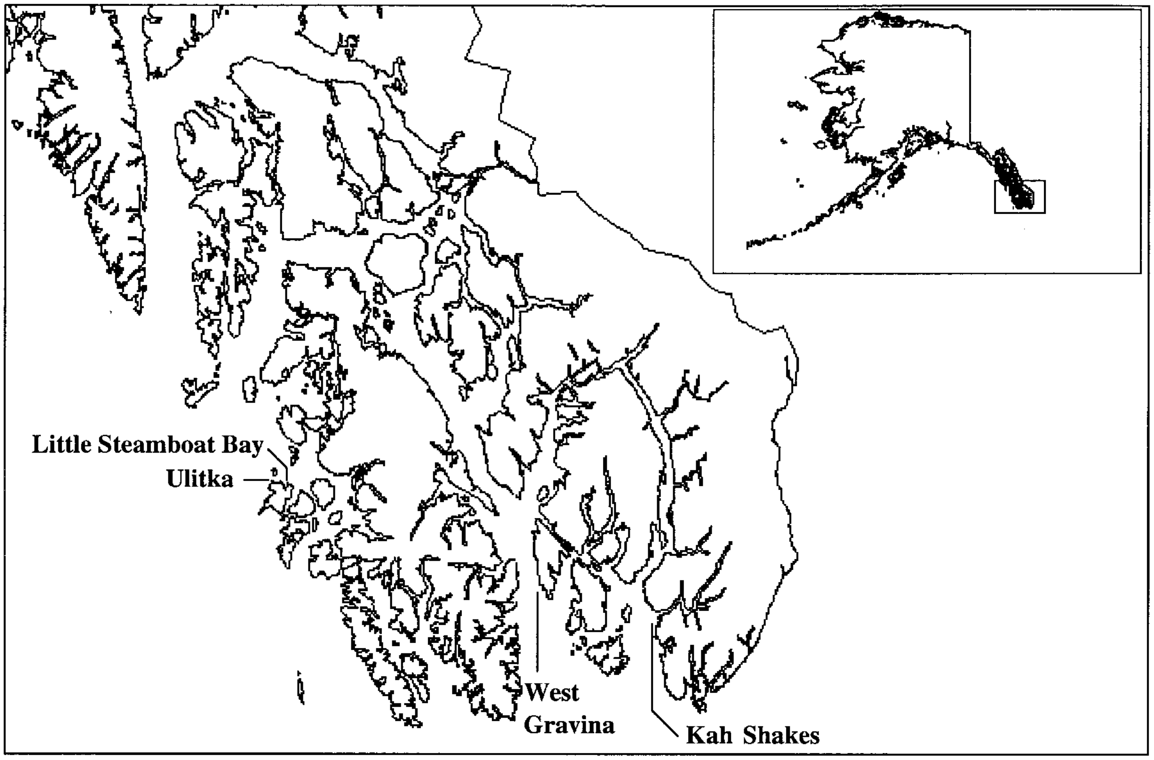

Figure 1. Four locations in SE Alaska where geoducks examined in this study were commercially harvested.

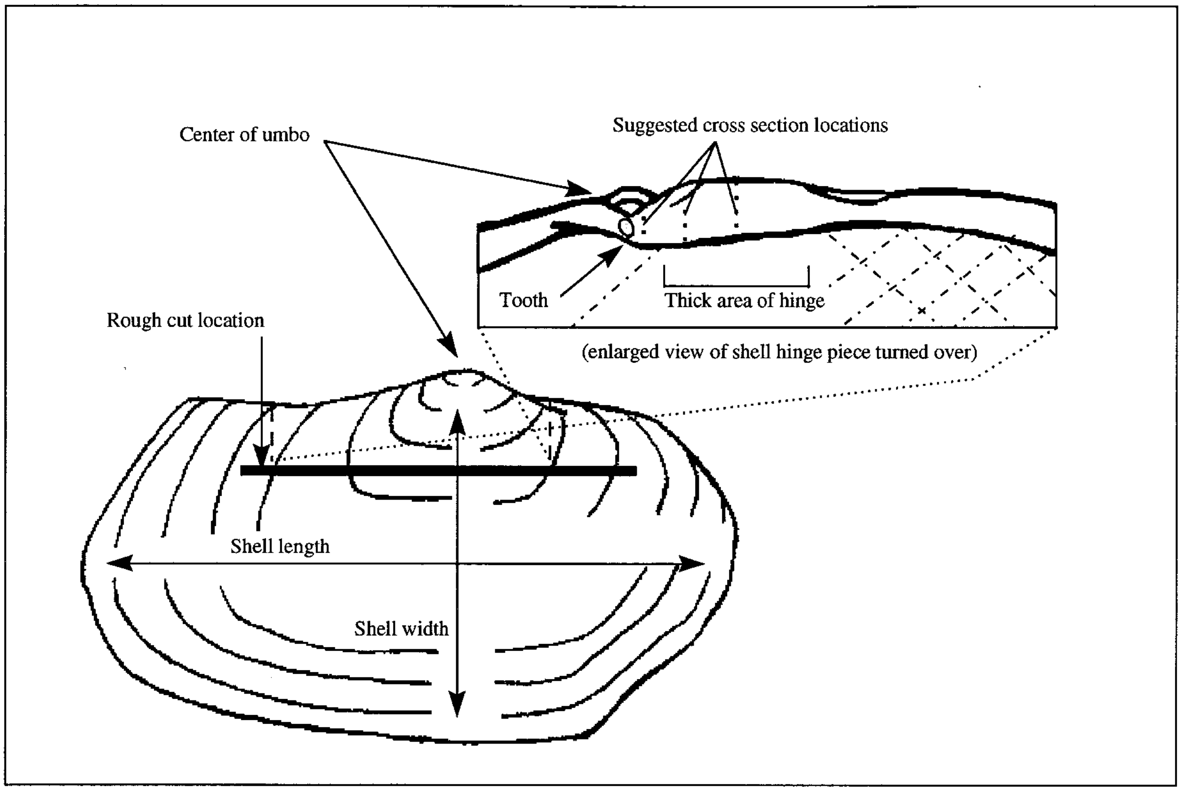

Figure 2. Diagram of a geoduck shell indicating measurements, location of rough cut, and the shell hinge piece required for cross sectioning.

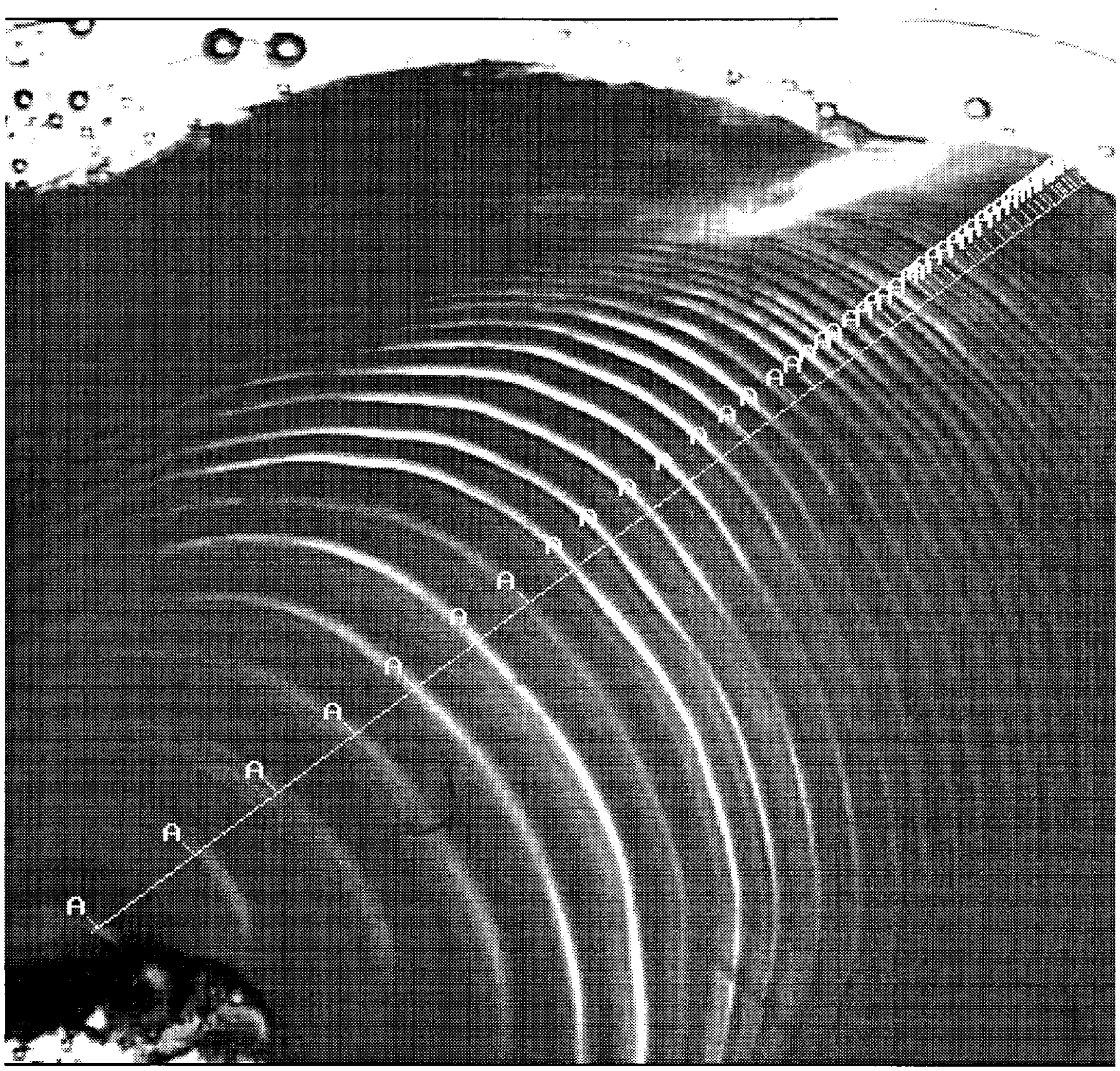

Figure 3. Thin section of a geoduck shell hinge viewed with transmitted light. The letter A identifies the location of annuli

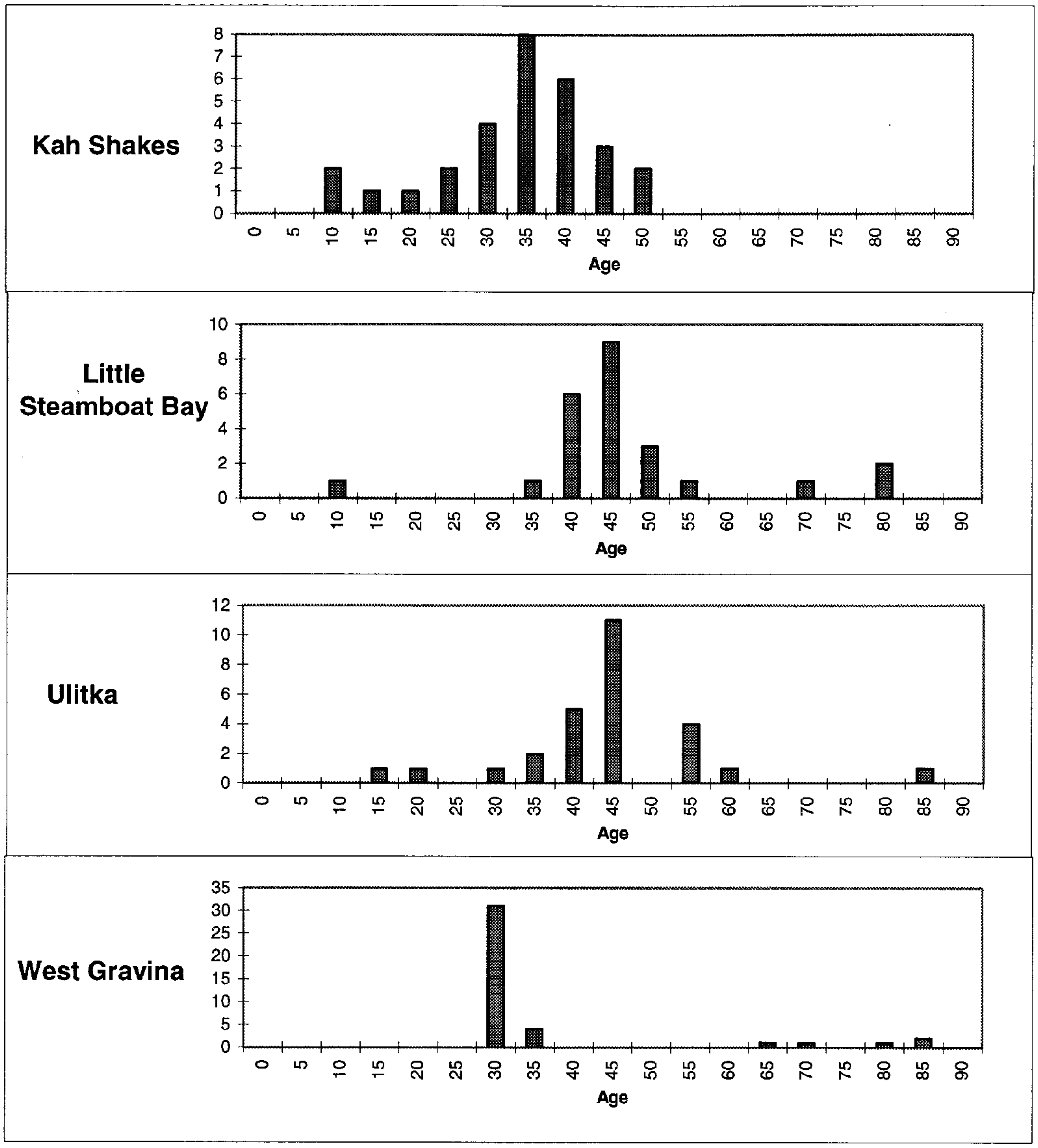

Figure 4. Geoduck age distribution at four locations.

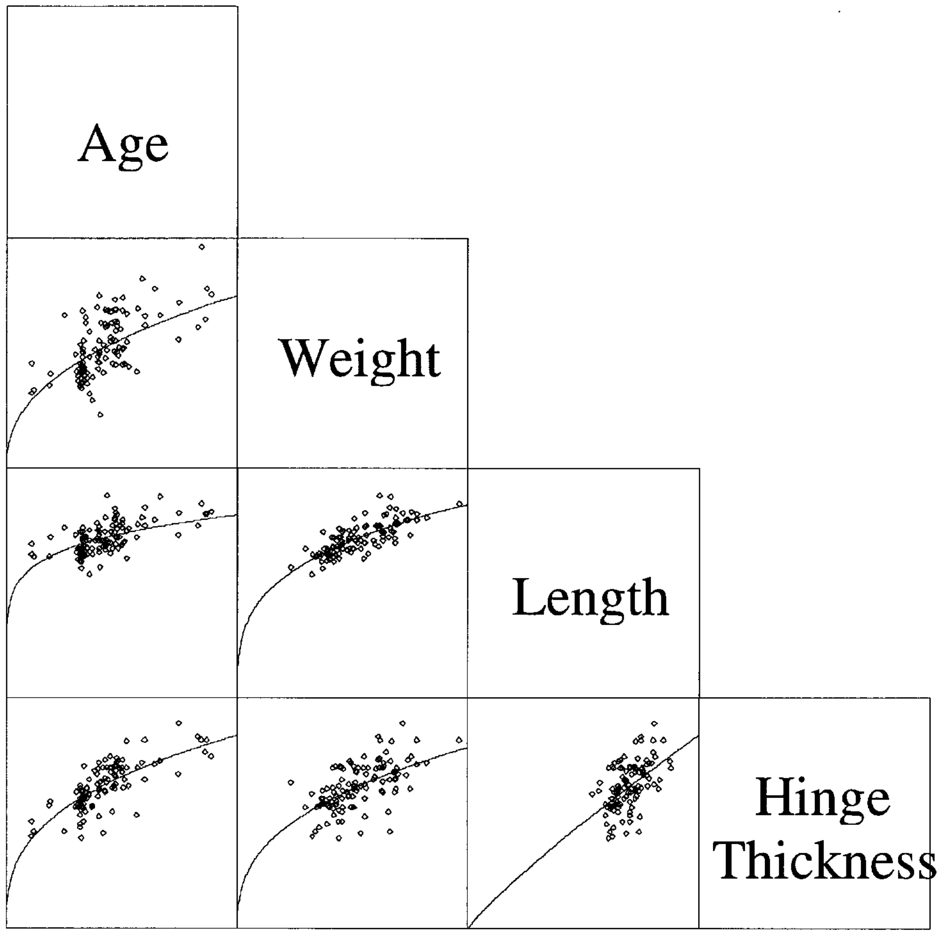

Figure 5. Pairwise plot of age, weight, shell length, and hinge thickness for all locations combined. Each plot includes the origin. A power curve is fitted to illustrate rapid initial growth.

APPENDIX A: METHOD AND MATERIALS FOR THIN-SECTION AGING OF GEODUCKS

A. Field sampling and shipping process

The identification number and sampling area code (e.g., #15 K, implying number 15 from Ketchikan) were written with permanent ink on the individual shells selected for sampling. Field personnel recorded the wet weight (nearest 1 gram) of the geoduck prior to processing, and the maximum length (nearest 1 mm) of the right valve for each specimen. After the geoduck's meat was removed in the processing line, the shells were cleaned of excess soft tissue, dried out, and stored for future shipment.

Each shell was wrapped in newspaper, and placed in a cardboard box for shipping. Shell breakage due to shells rubbing against each other was minimal. Unfortunately, the lower layer of shells in boxes containing many specimens (40 or more) tended to have a greater tendency for breakage, either due to the greater weight of shells pressing down on the lower layers or due to rough handling during the shipping process. It is recommended that additional cushioning (e.g., newspaper or Styrofoam peanuts) be placed in the bottom of boxes, individual shells be double wrapped in newspaper, and that care be taken not to rough handle the boxes.

While both shells from an individual geoduck was shipped, in order to be consistent the right valve shell was selected for measurement and aging. If the right shell was absent in the shipment, or broken to the extent that measurements or aging was not possible, then the left shell was selected for the measurements and aging. It is recommended that both shells continue to be shipped, as this assures that each specimen will be measured and aged.

B. Laboratory measurements

The preliminary laboratory work required taking measurements of the length and width of the shells (Fig. 2). In order to be consistent, only the right shell from each specimen was measured and aged. If the right shell was broken or missing, then the left shell was selected for measuring and aging.

A simple measuring board can be constructed to measure the length and widths of the shells. Obtain a small wooden board with dimensions of approximately 6 x 1 x 12 inch. Attach a small block of wood (dimensions: 6 x 1 x 4 inch) to one end of the board, such that there is a perpendicular "wall" formed. Tape a metric ruler firmly to the top surface of base of the measuring board, with the beginning of the ruler touching the vertical wall board.

The necessity of a measuring board was derived from the fact that many of the geoduck shells had lengths greater than 130 mm, which was the maximum measurement possible on the calipers present in the laboratory. While the use of larger calipers may solve this problem, the use of the measuring board provided an efficient method for measurements.

The shell was laid down on the measuring board, convex side up. To obtain the length measurement, the upper edge of the shell was placed against the "wall" of the board, and the center of the umbo was oriented at a right angle to the "wall". Similarly, to obtain the width measurement, the center of the umbo was placed against the "wall" and the entire shell was oriented such that the shell length was parallel with the "wall". The length and width of the shell were thus measured to the nearest millimeter.

It was felt that being consistent with the orientation of the length and width measurements was more important than obtaining the maximum length or width measurement. There exists a great deal of variation of shell shape, from uniform width and length to one end of the shell being wider than the other.

C. Review of aging methodology and selected method

The predominant aging method of geoduck species described in the literature (Shaul and Goodwin 1982) is that of making acetate peels of a cut, polished, and etched surface of the hinge area. The procedure involves the following steps: cutting through the hinge plate near the center of the umbo (Fig. 2), polishing the surface, etching the surface with dilute hydrochloric acid for 30 seconds to a minute, laying a piece of acetate paper on the etched surface, and then placing the removing the acetate paper and placing it between 2 glass slides. The prepared acetate peel is then examined under a microscope with transmitted light, and the annuli are counted. For an indepth description of the acetate peel method, refer to Ropes (1987) and Kennish et al. (1980).

Although the literature recommended using the acetate peel method, a slightly different approach was pursued for this study. Instead of depending on one cut and polished surface of the hinge area to provide a view of the growth rings, it was decided to take multiple thin cross sections from several areas of the hinge area. The thin cross sections could be polished and mounted on slides, and viewed under a microscope via transmitted light. The benefit of this approach was believed to be that examining the cross sections of several areas of the hinge would provide a more accurate evaluation of the true age of the specimen, instead of relying on just one view of the hinge area.

In order to obtain a thin cross section of a geoduck shell, there are two cutting phases required: rough cutting and thin sectioning. The rough cutting phase requires relatively little time (1 minute per shell), while the thin sectioning may take up to 30 minutes per shell.

D. Laboratory rough cutting

A large chop block with an abrasive blade was used for the initial rough cutting phase. The shell is placed firmly on the saw's cutting area, oriented in a lengthwise position and parallel with the saw blade. The goal is to make a lengthwise cut approximately 2-3 cm away from inner edge of the shell (Fig. 2). Note that the cutting process results in a 5 mm wide cut in the shell, so this needs to be taken into consideration when deciding where to make the cut. The cutting process may not cut through the entire length of the shell, especially for the specimens with shell length greater than 140 mm. Thus, up to 1/4 of the shell may be uncut on the two ends of the shell length. If the cut is not complete, then use tile clippers to crunch the uncut areas of the shell.

The rough cutting process should provide a long, narrow piece of the inner edge of the shell, which contains the umbo and hinge area. The potential problem with this rough cutting process is shell breakage, due to either thin weak shells or presence of major fracture planes in the inner edge of the shell. Remember to slowly cut through the shell, as then the chances of fracturing the shell are reduced. Even with slow cutting, there will still be cases of shells breaking or splintering.

Prior to cutting each shell, use an extra fine pointed permanent ink pen (e.g., Sharpie pen made by Sanford) to write down the sample number, shell half (right or left; R or L), and sample location code (K-Ketchikan, LS-Little Steamboat Bay) on the hinge surface of the shell section. For example, a code of 30 L K would indicate specimen number 30, left shell, from the Ketchikan' sample. The hinge pieces are generally small (5 cm long x 2 cm wide), so the code will have to be written in small lettering on an undesired area of the hinge, such as several cm away from the center of the umbo. Store the hinge pieces in a one gallon Ziplock plastic bag (maximum capacity of approximately hinge 100 pieces), with the pertinent information written on the plastic bag, such as Ketchikan geoduck cross sections, 10-5-1994, left shell hinge areas.

This method causes dust and fine particles to fly up from the chop block, as well as producing a loud noise. Use a safety mask, ear protection, face mask, and gloves to protect yourself from flying debris and inhalation of toxic dust, which contains trace amounts of arsenic and other dangerous substances.

As an added safety tip with regard to the dangerous dust produced by the sawing process, it is advisable to do the chop block sawing outside if possible. The dust will be carried away with the wind, and you don't have to worry about the dust lingering in an enclosed environment such as a workshop area. If a breeze in blowing, position yourself so that your back is to the wind and the saw dust is shooting out in front of you and being carried off by the wind.

Additionally, the shell dust tends to collect in your clothing, even if you are cutting upwind of the prevailing breeze. Wear a plastic body apron over your clothing to reduce the amount of shell dust that collects on your clothing. After completion of rough cutting with the chop block, remember to brush off as much of the shell dust from your clothing as possible.

E. Laboratory cross section cutting

Once the desired section of shell is acquired from the rough cutting process, the next step is producing a thin cross-section of the shell. The Buehler Isomet low speed saw has a diamond-studded blade which will cut through the shell section and provide you with the desired cross-section.

1) Hinge area with best annuli record

It may initially be thought that the cross section with the "best" information (in terms of the completeness of the annuli record) would be out from center of the umbo. While such a cross section does indeed ensure that the first annuli will be included, it doesn't necessarily mean that the outer annuli will be included. The area of the hinge located at the center of the umbo is where each shell's tooth is located, and these teeth appear to help interlock the shell's together. As this interlocking area requires a cavity in the hinge area for the opposing shell's tooth to occupy, there is usually only the first 20 to 30 years of growth rings in the hinge at the center o f the umbo. Whether the reduced hinge area at the umbo center is due to the interlocking teeth or simply wearing down of the hinge area, this presents a problem.

Look closely at the hinge coming out from the center of the umbo. If this center of the umbo area appears to be significantly thinner than the hinge area to either side of the center of the umbo, then chances are that the best cross section will be obtained from the location with the thicker hinge area. The distance from the center of the umbo to the best hinge cross section area may be up to 30 mm. Examination of a series of cross section from the umbo center to a distance of 3.2 mm away indicated that the first annuli is still present in the off-centered cross section. If cross sections need to be taken further than 3 mm away from the umbo, than remember to realize that the first annuli may be missing.

The cross section of the hinge area of a geoduck shell near the center of the umbo can be easily identified by the elliptical annuli pattern. Cross sections of the hinge area taken several millimeters (3 to 5 mm) away from the center of the umbo will have the first annuli appear as a flat band near the edge of the shell's origin, and the next four annuli will also be greatly flattened and have less elliptical shape.

2) Use tile clippers to reduce size of hinge area

The hinge piece size after the initial rough cutting with the chop block saw is generally too large, in terms of both length and width (Fig. 2), for the thin sectioning process. The maximum distance between the chuck's outer edge and the saw blade is 20 mm, thus requiring that the center of the umbo and the thickest part of the hinge area be within that 20 mm area. The excess lengthwise ends of the hinge piece can be snipped off with the tile clippers. The width between the two screws of the chuck's jaws is 26 mm; in order to avoid possible damage to the screw threads, the maximum width of a hinge piece should be approximately 20 mm.

3) Ideal chuck to use

The best chuck to use is the one with the single jaw to clamp down on the hinge piece. The saw arm could then be moved over (via rotating the dial at the fulcrum of the arm) to what ever point desired, even if this means moving over several millimeters. The single jaw clamped tightly down on the hinge piece and allowed for uniform cross section widths. Wrap a layer of thin foam padding around the area of the hinge piece being clamped down upon to avoid scratching the inner surfaces of the chuck's jaws.

Tightening down the chuck's jaws on the hinge piece requires a bit of practice. When tightening down the jaws onto the hinge piece, make sure the inner jaws of the chuck are parallel with each other to avoid unequal pressure bearing down on the hinge piece. The hinge piece must be tightly secured between the chuck's jaws, or else the saw blade during the sawing process may bind up and result in a blown fuse (quick blow 1.5 amp).

Hinge pieces with weak shells or major fracture planes may have a tendency to break when tightening down the chuck's jaws; however, it is absolutely essential that the chuck's jaws be tightly clamped down on the hinge piece. After up to several attempts of tightening down and breaking the hinge piece, there is usually a sturdy piece of hinge area that will not break under the pressure of the chuck's jaws. As long as the hinge area is still intact, the hinge piece will probably produce a useful cross section.

4) Best positioning of hinge piece in chuck

Previous work on geoduck cross sectioning suggested the following positioning of the hinge piece with the chuck:

i) The concave, inner surface of the shell toward the saw blade
ii) The shell's tooth should be oriented toward the front of the saw machine
iii) The shell should be positioned to cut from the mark on the ventral margin through the middle of the tooth, or immediately beside the posterior edge of the tooth

I found that this position resulted in frequent breaking of the cross section. The hinge area is the critical area where the annuli are to be read. By first cutting into the hinge, it tends to put too much pressure on the hinge area. An alternative positioning I decided upon was:

i) The convex, outer surface of the shell toward the saw blade
ii) The shell horizontal plane should be parallel with the saw edge's plane.

The saw cuts first through the shell beyond the hinge, and eventually cuts through the hinge. The occurrence of cross-section breakage was greatly reduced by this positioning method.

Due to the varying amount of shell left on the hinge area, as well as the thickness and shape of the hinge, placing the hinge piece within the chuck will not always allow for an "ideal" positioning. Try to evaluate each hinge piece, determine the few possible positions, and decide upon which one will provide the best quality cross section; i.e., the cross section which will remain intact and possess readable cross sections. It may be necessary to use the tile clippers to remove excess shell material to ensure good positioning in the chuck. Be sure to remove any weak structures presents in the hinge piece, e.g., jagged shell edges or thin brittle shell edges jutting out from the hinge area

5) Best saw speed and saw arm weights to use

There are three weights (45, 75, and 150 g) available to place on the arm to increase the force that the hinge piece has on the saw's blade, and thus decrease the amount of sawing time required. Sawing was done with the 75 g and without any weight, and the sawing time with the 75 g added onto the saw arm reduced the sawing time by approximately 30%.

The two major problems with using weights on the saw's arm is that of splintering of the entire cross section or chipping at the end of the process. The splintering of the cross sections was primarily due to hinge pieces with weak shells or major fracture planes, but the addition of weight on the saw's arm did increase the chances of the splintering. The chipping of the cross section; i.e., the thin cross section piece would break off prematurely at the end of the sawing process, also increased with the additional weight added to the saw's arm. The cross section piece would thus contain a sheared-off upper layer from the intact hinge piece still clamped down in the chuck's jaws. The chipping can be minimized if the person doing the cutting applies some upward pressure on the saw arm as the sawing process nears it's completion, as this reduces the weight bearing down upon the saw blade.

The sawing speed on the Buehler Isomet saw ranges from 0 to 10. Various speeds were explored to determine the optimum speed setting. The optimal speed selected was between 7 and 8. Although at first one might think that the fastest speed level (10) will provide the quickest cutting time, the cutting time appeared to be more influenced by the amount of weight added to the saw arm. Additionally, speeds of 9 and 10 tended to increase the following:

a) chances of the cross section being flung away from the saw at the end of the cutting process,
b) the amount of water that sprayed off the blade and hinge piece during the cutting process, and
c) the frequency of chipping at the end of the cutting process.

The time required to make each cross section will vary with the thickness of the hinge area being cut. The average cutting time when using a sawing speed of 8 and a 75 g weight on the saw arm will be approximately 3-4 minutes per cut. At least 2 cuts are necessary to obtain a cross section; i.e., the initial cut to obtain a flat surface, and then the cutting of the thin cross section. On average, I would make at least 3 cross sections (center of umbo, half way to thickest part of hinge, and from the thickest part of the hinge) of each hinge piece in order to obtain an accurate reading. Two cuts per cross section were thus necessary, as the distance between each cross section was up to 10 mm. Therefore, 6 cuts were essential per specimen, resulting in a time consumption of between 18 and 24 minutes per specimen.

6) Best cross section thickness

The thickness of the cross section must be thin enough for the transmitted light to pass through the cross section, yet not too thin so that it easily breaks during the sawing process. I experimented with various thickness': 0.25 to 0.60 in 0.05 increments. The narrowest width which could be cut without the cross section usually falling apart was 0.30 mm, and even then there were instances when the cross section did fracture. It is possible to transmit light through the 0.60 mm cross section, although the drawback is that the tightly packed annuli in the outer region are difficult to observe and count.

The major influence on the occurrence of breakage at the 0.30 and 0.25 mm thickness cross sections was the structural integrity of the individual shell; i.e., presence of major fractures in the area of the umbo tended to increase chances of breakage.

As a general practice, I elected to go with a cross section width of 0.35 mm due to the following circumstances:

a) the 0.35 mm width was often the minimum width I could obtain from difficult hinge pieces (i.e., brittle shells which would keep splintering off the cross section throughout the cutting process, providing only fragments of the cross section),

b) while the 0.35 mm width wasn't the "ideal" thickness in terms of ease of counting the annuli, the annuli in the thinner cross sections (0.25 and 0.30 mm) were sometimes too faint to be easily identified.

7) General set up of sawing station, in regard to water spillage

The first step is to fill the saw bath tub with approximately 240 ml of water. Without the water bath for the saw blade, the blade might overheat or get jammed in the shell piece being cut. Don't fill the tub with a water level closer than approximately 5 mm from the top of the tub, as otherwise during the sawing process the water will be spilling out of the tub.

CAUTION: Without the water to act as a lubricant, the saw blade will jam during the sawing process and the fuse (quick blow 1.5 amp) will blow. Water will splash out of the tub during the cutting process during the course of the day; therefore, keep track of the water level in the tub and add more water when necessary.

Once the saw blade has finished cutting through the hinge area, the cross section will either fall into the water bath or be flung out in front of the saw machine. I generally place a small barrier, such as a piece of wood (12" x 5" x 1") approximately 8 inches in front of the saw machine. It is a good idea to wrap the board with a layer of paper towel, to dampen the impact of the cross section into the barrier board. Additionally, I place some paper towel on the bench surface between the saw machine and the barrier board, to act as a cushion for the fragile cross section.

Even with the above barrier, occasionally a cross section piece may go flying off the saw blade and onto the floor. The speed of the saw had some influence on this event, with the very fast speed settings (9 to 10) tending to fling the cross section pieces frequently. When this occurs, stand still and try to locate the cross section piece on the floor prior to walking around and possibly crushing the cross section. The ultimate solution is to not avoid setting the speed dial to above 8, unless you need to get a quick cross section and are willing to take the chance of breaking the cross section if the hinge section is too brittle.

Water can drip or be flung from the saw machine at several places:

a) immediately behind the saw machine, where the water from the hinge piece in the chuck on the saw's arm may drip off when the arm is extended away from the saw machine,

b) along the right side of the saw machine, where water may be spouting off the hinge piece during the cutting process.

These two water problems can be alleviated by placing either paper towel or small trays to collect the falling water at the appropriate locations.

8) Saw station clean up at end of day

At the end of each day, remember to dispose of the water in the water bath tub. The water collects all the dust and larger particles from the sawing process, and results in a very chalky liquid. Carefully lower the tub and swing it out so that it is perpendicular to the saw machine. Lift up the tub slowly, and carry it over to the sink. Then, pick up the screen in the tub, and with a paper towel collect the cross section fragments, and throw these into the garbage can. Pour the murky water down the drain. Then, clean off the screen and wash out the tub with warm water. Replace the empty tub back into the saw.

9) General comments about sawing process

One needs to be careful about the saw finishing it's cut through the top of the hinge piece. There is a safety switch near the base of the arm, which allows one to dial the maximum distance that the arm will lower. Once this level is reached, the saw turns itself off. It is a good idea to lift the arm slightly as it approaches the end of the cut, as this will decrease the pressure forcing down the shell piece onto the saw blade. This will control the end of the cut, and make the event less abrupt. Frequently, if the arm isn't being lifted up slightly at the end of the sawing process, the majority of the cross section will break off into the water bath, leaving a small edge on the hinge piece. This is unfortunate, as the outer hinge area contains the latest annuli.

F. Laboratory polishing and mounting of the cross section

The surface of the cross section is generally crisscrossed with lines resulting from the saw blade rubbing against the surface during the cutting process. Additionally, there may be discoloration on the surface of the cross section due to either possible rust on the saw blade or from remnants of the resilium along the hinge outer edge. The lines and discoloration must be removed to allow for easy reading of the annuli rings in the cross section.

The final processing of the cross section involves the mounting onto microscope slides and polishing of the surface. Two approaches to this step were evaluated.

1) Mounting the cross section, and then going through several polishing and cleaning steps.

a) Cross sections of the entire sample were cut and stored in Corning plastic trays, which had 24 circular cells (4 rows[A to D] by 6 columns[1 to 6]) each with a diameter of 16 mm. The lids of the trays were properly labeled to keep track of sample area, harvest date, specimen number, and cell code; e.g., Ketchikan, 10-4-92, 1A-2B #34; 2C-3D #15, etc.

b) Mounting the cross sections on slides

i) place a slide on a hot plate set at a medium heat level (use forceps)

ii) place a small piece of thermal plastic resin onto the hot slide (use forceps)

iii) allowing the resin to liquefy

iv) removing the slide from the hot plate (use forceps)

v) allow the resin to cool for approximately 10 seconds

vi) placing the cross section onto the resin (use forceps)

vii) tapping down on the cross section with a pair of forceps to ensure no air bubbles are below the cross section and that the cross section is firmly imbedded in the resin.

viii) allow the slide to cool down on a paper towel for at least 2 minutes before handling again.

c) Placing a piece of tape at the top of the slide and writing down the appropriate information;

e.g., Geoduck #23 2C
Ketchikan
10-12-92

d) Use of a Buehler Minimet Polisher to polish the slide-mounted cross section on three grades of paper (first 400 grain, nylon finishing paper, and finally Buehler micropolish on a cloth pad). Place a few drops of water onto the bottom of the slide stage holder, as this will create a suction when the slide is placed over the water drops. Squirt a few drops of water onto the surface of the three polishing paper, to ensure enough lubrication during the polishing process steps. Place the slide holder down in the center of the bowl, and place the arm of the stirrer into the hole in the top center of the slide holder. Adjust the load dial to set a small load on the arm so that the slide is pressed down onto the polishing paper. Set the polish time to 1, which is approximately 10 seconds. Set the speed dial to 1. Push the start switch to begin the process. Make sure during the micropolish powder polishing step that enough powder is on the circular cloth glued to the bottom of the glass circle, and that enough water is present to make a wet paste of the powder. The polished slides were then washed off with tap water.

e) Use of an Ultrasonic Cleaner (by Branson) to do the final cleaning of the slides, and to remove the micropolish powder from the slide. Allow the slide to be in the ultrasonic cleaner for approximately 10-15 seconds, as this ensures that the shell cross-section has been cleaned of the abrasive micropolish. Wipe off and dry the slide with the cross section with a paper towel.

2) Polishing the cross section immediately after cutting, evaluating whether the annuli are readable and all are present, and then mounting the polished cross section onto a slide.

a) Initial examination of each cross section

i) after each cross section was cut, it was gently polished via using my finger tip to rub the cross section on 400 grade and then nylon finishing paper.

ii) the cross section was cleaned in three liquids in three small bowls: first a 0.5% solution of chlorine, then a dechlorine solution of 0.7% $Na_2S_2O_2$, and finally tap water. Note that for the first two solutions, I needed only about 20 ml each in the glass bowls, while with the water I generally used about 200 ml to provide ample water to wash off the previous solutions.

iii) the cross section was placed on a microscope slide, and placed on the stage of the microscope.

iv) the cross section was then evaluated for readability and completeness of the annuli.

b) The initial age estimation was made for cross sections that were deemed clear enough to read and had the all the annuli present. Generally, at least 3 cross sections were taken: center of umbo, half way to the thickest part of the hinge, and at the thickest part of the hinge.

c) Cross sectioned were stored in Corning plastic trays, as described in the first method

d) When time was available, such as while cutting a new cross section, the readable cross sections were mounted on the slide and labeled as described above in the first method.

e) There was no need to polish the cross section at this point, as they were polished initially.

The two methods of cutting/mounting/aging are reviewed below:

1) Evaluation of the cross section

The second method allowed instant evaluation of the cross sections, allowing me to decide whether the cross section provided a complete annuli record that was easily readable or if I needed to cut another cross section. This alleviated the major draw back of the first method, where you didn't know how readable and complete the cross sections were until you had mounted and polished the cross sections.

2) Polishing effort precision and time requirements

The second method provided a more precise method of polishing the cross sections. By gently pressing the cross section down on the polishing paper, I could be assured of the surface planes I was polishing. In contrast, once the cross section is mounted in the resin on the slide, it is far more difficult to evenly polish the surface due to the cross section in the resin not always laying parallel with the slide surface. Additionally, the polishing time required by the second method was smaller due to the less handling time required in the handling and cleaning stages.

G. Analysis of the cross section

The cross sections are thin enough to allow transmitted light to pass through the shell piece and highlight the annuli. It is helpful to use the lowest power objective (e.g., 1.6/0.5) to get an overall view of the cross section and determine which area of the cross section has the clearest annuli present. Each cross section will probably have a unique "best" path to follow from the first annuli to the outer annuli.

After determining the best axis to follow, the next step is to go to a higher magnification, such as an objective of 4 power. The higher power will allow you to better distinguish the annuli in the outer area of the hinge. In general, the first 20 annuli are widely spaced and easily counted, while the remaining annuli become tightly packed together and are difficult to differentiate. The cleaning of the cross section is critical to whether or not the outer annuli are easily counted, and thus a second polishing attempt may be necessary for difficult-to-read cross sections.

The fact that these geoducks reach ages up to 100+ years (Breen and Shields 1983, Sloan and Robinson 1984) require an accurate count of the tightly packed, outer annuli. The use of an ocular micrometer in one of the eye pieces is useful for counting the annuli. The ends of the micrometer scale (either 0 or 10) can be used as a pointer, so that you do not have to mentally keep track of which annuli you are currently on in your count.

It was decided to take the three readings of each cross section, a process also recommended by Sloan and Robinson (1984). This will allow one to triple check the annuli reading of each specimen. Any obvious errors in aging that has occurred with any of the three readings will become apparent, e.g., if two of the estimated ages are 70, and the third is 50 years. If the three age readings only varied by up to 2 years, then the average of the three readings was used to estimate the age. The preferred method for this process is to make three separate reading "passes" through the entire set of samples, thereby removing the chance of biasing your age estimate via remembering any given specimen's age. Remember to cover up your previous age estimates on the data sheet as you do the second and third reading "passes' through the samples.

IV. DISCUSSION

The full "view" of the annuli may not be present in the cross section through the center of the umbo. In many cases, only the first 20 to 30 annuli are present in this center cross section. The thickest part of the hinge, up to 2 cm way from the center of the umbo, will usually have the complete annuli record. The first annuli is present in the cross section up to 5 mm from the center of the umbo. While the first annuli may not be present in a cross section taken between 5 and 20 mm away from the center of the umbo, the loss of the first annuli is offset by the presence of all the remaining annuli.

It is recommended to take several cross sections (center of umbo, section half way to thick part of hinge, and a section from the beginning of the thick hinge area) to ensure that an accurate age estimation is possible. In order to obtain the 3 cross sections mentioned, you will need to make 6 cuts which should require approximately 18 minutes (3 minutes per cut).

The multiple thin cross sectioning of a geoduck hinge area is believed to improve the chances of determining the correct age. While the acetate peel method was not performed and evaluated in this study, the fact that the peel method relies on only one "view" of the hinge area is intuitively prone to produce errors in age determination. Although the processing time increases due to the need to make more cuts per individual shell, the ability to examine the growth rings from several areas of the hinge piece improves the chances of estimating the correct age. While examining the multiple cross sections from each geoduck specimen, at least 25% of the cross sections were unacceptable due to either obviously missing annuli or difficulty in distinguishing annuli. The ability to select an "acceptable" cross section to determine the age of the individual geoduck is a definite positive aspect of the thin cross sectioning method.

TABLE B1. Measurements and estimated ages of the geoducks sampled from the Kah Shakes harvest of October 5, 1994.

Sample	Wet Weight (grams)	Field Measured Length (mm)	Laboratory Measurements Length (mm)	Laboratory Measurements Width (mm)	Laboratory Measurements Height (mm)	Estimated age (years) of geoduck 1st read	2nd read	3rd read	Average Age
1	678	122	123	76	27.1	12	12	12	12
2	1006	130	130	88	25.7	44	40		42.0
3	860	132	132	80	25.7	34	33		33.5
4	754	127	130	84	27.6	32	30		31.0
5	1009	147	140	87	29.1	47	49		48.0
6	1135	124	126	89	27.4	45	45		45.0
7	1053	140	137	89	27.9	21	23		22.0
8	1094	129	122	88	26.7	50	52	54	52.0
9	461	115	114	79	26.2	42	39		40.5
10	815	139	140	83	24.9	19	19	19	19
11	834	128	127	96	27.5	29	30	32	30.3
12	1368	136	135	90	22.2	44	44		44.0
13	1030	138	137	85	28	38	39	38	38.3
14	906	134	134	79	27.4	11	11	11	11.0
15	587	135	130	82	23.8	36	38	37	37.0
16	1309	144	140	81	28.1	36	31	36	34.3
17	1392	149	152	91	28.1	39	38	41	39.3
18	966	133	131	85	27.7				
19	1226	137	132	86	25.6	42	44		43.0
20	964	145	146	88	27.7	34	38		36.0
21	1042	135	135	89	28.8	46	55		50.5
22	1497	145	142	91	29.4	39	41		40.0
23	1045	139	140	81	25.8	48	48	50	48.7
24	918	148	146	81	26.2	40	39	40	39.7
25	964	137	139	87	26.8	38	41		39.5
26	987	141	142	88	27.4	33	30	27	30.0
27	984	123	127	85	27.5	38	41	41	40.0
28	1261	142	145	95	30.8	49	42		45.5
29	1071	126	130	88	30.3	33	31	32	32.0
30	1262	143	137	97	29.7	41	41		41.0
Mean	1015.93	135.43	134.70	86.27	27.24	36.55	36.69	33.57	36.73
STD Dev	233.26	8.53	8.20	5.11	1.83	10.14	10.59	12.74	10.35
Maximum	1497	149	152	97	30.8	50	55	54	52
Minimum	461	115	114	76	22.2	11	11	11	11

TABLE B2. Measurements and estimated ages of the geoducks sampled from the Little Steamboat Bay harvest of January 9-10, 1995.

Sample	Wet Weight (grams)	Field Measured Length (mm)	Laboratory Measurements Length (mm)	Width (mm)	Height (mm)	Estimated age (years) of geoduck 1st read	2nd read	3rd read	Average Age
1	1017	126.1	126.5	93	34	48	48	46	47.3
2	907	127	130	81.9	33	46			46.0
3	1168	133.1	135	95.1	31.7	44	45	43	44.0
4	1180	140	137	95	30.2	35	38	35	36.0
5	1340	153.3	145.5	91	32.2	51	53		52.0
6	651	125.5	125	82	26	11	11	11	11.0
7	1074	130	127	89.3	32.1	48			48.0
8	825	135	132	88.5	32	42			42.0
9	1376	155.3	152	95	34.4	48	47		47.5
10	1234	149.6	147	96.6	30.3	48			48.0
11	1920	178.7	169.5	118.5	37.1	84	85	84	84.3
12	881	150	147.5	88	30.5	56	50		53.0
13	1320	172.2	166	111.5	35.5	60	60		60.0
14	1274	147.2	144.5	97.5	32	47	47	47	47.0
15	900	134	133.5	79.5	26.6	50	50	50	50.0
16	1522	168	168	105.7	31.3	80	82	84	82.0
17	1634	160.5							
18	901	142.2	136	91	34.2	50	52	51	51.0
19	1069	139.1	137	90.5	35.4	42			42.0
20	1101	131.1	135	91	28.5	45	45		45.0
21	977	123.7	130.5	85	30.5	48	49		48.5
22	950	137	129	85.2	28.2	43	43		43.0
23	1190	137	134	90.4	31.2	48	47	47	47.3
24	1435	160	161	99.2	33.6	74	75		74.5
25	1254	151.7	145	91	34.5	43	42	43	42.7
Mean	1164.0	144.3	141.4	93.0	31.9	49.6	51.0	49.2	49.7
STD	281.88	15.30	13.45	9.03	2.78	14.52	16.38	20.45	14.71
Maximum	1920	178.7	169.5	118.5	37.1	84	85	84	84.33
Minimum	651	123.7	125	79.5	26	11	11	11	11.0

TABLE B3. Measurements and estimated ages of the geoducks sampled from the Ulitka harvest of October 7, 1994. Note that only 27 of the 50 specimens sent to the lab were measured and aged.

Sample	Wet Weight (grams)	Field Measured Length (mm)	Laboratory Measurements Length (mm)	Width (mm)	Height (mm)	Estimated age (years) of geoduck 1st read	2nd read	3rd read	Average Age
1	1371	151							
2	1506	153	162	108	35.4	88	88	90	88.7
3	1384	145							
4	1465	150	155	103	32.1	46	48	47	47.0
5	1613	159							
6	1472	154							
7	1397	158							
8	1384	153							
9	1106	160	161	102	30	48	47	47	47.3
10	716	127	123	84	29.5	19	18	18	18.3
11	1324	147	148	94	32.9	25	25	25	25.0
12	1481	157	155	100	34.5	51	50	50	50.3
13	1034	150	148	91	30.3	51	50	49	50.0
14	1215	159							
15	1024	132	137	97	34.8	43	43	44	43.3
16	1385	150	151	102	34.3	56	57	57	56.7
17	1370	153	152	97	29.6	50	49	51	50.0
18	1644	158	157	104	30.8	59	58	59	58.7
19	1241	152	150	100	32	61	60	59	60.0
20	1528	139							
21	899	143	140	95	29.3	44	42	44	43.3
22	1241	162							
23	1499	157							
24	1234	174	176	111	34.8	42	44	45	43.7
25	1107	149	149	92	30	40	40	40	40.0
26	1034	145							
27	1353	154							
28	1012	153	156	98	32.6	48	46	46	46.7
29	962	129	137	88	30.6	31	34	33	32.7
30	1253	154							
31	1343	152							
32	1076	162							
33	1132	147							
34	1378	166	165	110	35	46	48	47	47.0
35	1269	159	159	105	33.8	49	47	48	48.0
36	838	136	140	101	28.1	56	58	55	56.3
37	1213	159							
38	1010	148	145	90	30.3	42	40	39	40.3
39	1375	147	157	103	35	44	43	42	43.0
40	1372	161							

TABLE B3. Measurements and estimated ages of the geoducks sampled from the Ulitka harvest of October 7, 1994. (continued)

Sample	Wet Weight (grams)	Field Measured Length (mm)	Laboratory Measurements Length (mm)	Width (mm)	Height (mm)	Estimated age (years) of geoduck 1st read	2nd read	3rd read	Average Age
41	996	144							
42	893	140	140	85	28.8	47	48	47	47.3
43	1456	155							
44	1204	158	150	91	32	49	51	48	49.3
45	1119	149	150	100	30	46	45	47	46.0
46	990	143							
47	1219	155							
48	737	142							
49	1557	160	155	97	32.2	64	65	63	64.0
50	1356	143	145	100	34	45	46	45	45.3
Mean	1235.74	151.06	150.48	98.07	31.95	47.78	47.78	47.59	47.72
STD Dev	226.16	9.24	10.53	7.06	2.25	12.67	12.72	12.81	12.70
Maximum	1644	174	176	111	35.4	88	88	90	88.67
Minimum	716	127	123	84	28.1	19	18	18	18.33

TABLE B4. Measurements and estimated ages of the geoducks sampled from the West Gravina harvest of October 4, 1994.

Sample	Wet Weight (grams)	Field Measured Length (mm)	Laboratory Measurements Length (mm)	Width (mm)	Height (mm)	Estimated age (years) of geoduck 1st read	2nd read	3rd read	Average Age
1	777	134	130	78	NA	35	35	35	35.0
2	913	127	130	81	NA	40	40	40	40.0
3	873	140	140	82	NA	34	33		33.5
4	746	140	145	80	NA	33	33	32	32.7
5	737	133			NA	33			33.0
6	1119	143	142	94	NA	71	77	75	74.3
7	776	126	128	79	NA	31	33	33	32.3
8	1223	156	150	88	NA	81	80	87	82.7
9	1366	142	139	92	NA	32	33	33	32.7
10	824	132	131	85	NA	35	35	35	35.0
11	887	137			NA	33	33		33.0
12	1328	170	175	100	NA	66	69	64	66.3
13	1263	140	141	90	NA	34	35	34	34.3
14	1556	160	160	100	NA	87	85	88	86.7
15	1290	160	160	88	NA	86			86.0
16	1069	131		87	NA	32	33		32.5
17	908	141	145	89	NA	32	32		32.0
18	796	122	121	79	NA	32	30		31.0
19	878	125	126	89	NA	32	32	33	32.3
20	732	119	119	82	NA	32	33		32.5
21	694	122	124	82	NA	31	34		32.5
22	780	124	125	86	NA	32	32	32	32.0
23	1007	130	130	90	NA	33	33	32	32.7
24	1033	153	148	88	NA	33			33.0
25	858	125	129	79	NA	31	32		31.5
26	860	137	137	90	NA	40	39	40	39.7
27	998	126	130	93	NA	33	33	33	33.0
28	915	133	130	83	NA	34	32		33.0
29	780	121	120	82	NA	31	32	33	32.0
30	801	124	124	83	NA	33	35	34	34.0
31	881	122	122	84	NA	33	32		32.5
32	848	123	125	94	NA	35	33	33	33.7
33	832	120	123	82	NA	34	33	33	33.3
34	645	118	108	72	NA	36	36	36	36.0
35	738	114	113	81	NA	33	32		32.5
36	1106	136	135	82	NA	34	33	33	33.3
37	730	127	125	82	NA	36	35	34	35.0
38	786	127	125	75	NA	36	38	38	37.3
39	834	119	119	85	NA	32			32.0
40	712	124	126	77	NA	32	32		32.0

TABLE B4. Measurements and estimated ages of the geoducks sampled from the West Gravina harvest of October 4, 1994. (continued)

Sample	Wet Weight (grams)	Field Measured Length (mm)	Laboratory Measurements Length (mm)	Width (mm)	Height (mm)	Estimated age (years) of geoduck 1st read	2nd read	3rd read	Average Age
Mean	922.48	132.58	132.43	85.08		39.08	38.53	41.67	39.22
STD Dev	211.76	12.94	13.76	6.33		15.40	14.35	17.46	15.67
Maximum	1556	170	175	100		87	85	88	86.67
Minimum	645	114	108	72		31	30	32	31.00