Chapter 6: Application of growth rate models to archaeological assemblages

The rationale for examining variability in growth rates of fur seals as a test of the three competing hypotheses forwarded to explain the late Holocene changes in fur seal biogeography has been discussed in detail in Chapters 1 and 3. To summarize, growth rates in fur seals are expected to co-vary with population size relative to carrying capacity (Baker 1991; Baker and Fowler 1990; Fowler 1990; Scheffer 1955; Trites and Bigg 1992). Under the "prehistoric effects" hypothesis, fur seal populations are expected to be maintained at levels substantially lower than carrying capacity through the effects of hunting pressure. The test implications of this hypothesis are that relative to well-documented reference samples, fur seals are expected to exhibit higher growth rates and/or grow to larger overall size throughout most or all of the archaeological sequences. In contrast, the "historic effects" hypothesis predicts that fur seal populations were relatively unaffected until the onset of the commercial fur trade. Under this hypothesis, population levels are expected to be at or near carrying capacity throughout the prehistoric sequence. If such were the case, it follows that fur seals harvested during this time period would be expected to exhibit lower growth rates and/or grow to smaller overall size. Under the "historic effects" hypothesis, this pattern is not expected to change until after the onset of commercial sealing. Finally, the "continuous effects" hypothesis expects to see gradual, rather than abrupt, increases in growth rates and/or body size across the prehistoric-historic transition.

I have stressed throughout this dissertation that these hypotheses are best tested on a site-by-site basis. Nevertheless, only the Ozette assemblage will be included in this growth rate analysis. Because the growth rate analysis will be utilizing the von Bertalanffy (VB) growth curves generated in Chapter 3, this analysis is limited to male mandibles that (a) retain the landmarks for mandibular short length (see Figure 2.8) and (b) have an independent means of estimating age, such as growth structures evident in the canine tooth. As discussed in Chapters 4 and 5, the Ozette assemblage is the only collection included in this study that has sufficiently large samples of mandibles that fit these criteria.

Table 6.1 shows the number of identified fur seal specimens from the major stratigraphic units from Ozette, and the number of specimens included in the growth rate analysis. Many of the 230 specimens selected for analysis still had the canine tooth securely lodged in the mandible. In cases where the mandibular canine had been dislodged, canines were matched with mandibles from the same provenience based on degree of refit, as well as characteristics of staining and sediment accumulation evident on the exterior surfaces of the teeth and mandibles. Although a combination of both right and left mandibles is utilized here, characteristics of size of the mandibles, as well as size, shape, and degree of wear on the canines, were evaluated within each stratigraphic unit to minimize the possibility of sampling the same individual twice.

Removal and preparation of teeth

In order to arrive at an age estimate independent of mandible size, we[2] sectioned mandibular canines and etched them in formic acid to accentuate annular growth layer

---

[2] I was assisted in all aspects of the tooth sectioning by Arden Rowell and Cristie Boone, both students at the University of Washington.

groups, or GLGs (Klevezal 1996; Pierce and Kajimura 1980; Scheffer 1950b). Prior to sectioning, all canines were removed from the mandible and cleaned. For specimens with the canine securely lodged in the mandible, a Dremel rotary tool mounted with a No. 409 emery wheel (0.635 mm thick) was used to cut the buccal margin of the canine alveolus. Speed of the cutting tool was maintained between 5,000-15,000 rotations per minute to minimize heating caused by friction.

Once the teeth were removed from the alveolus they were dry-brushed to remove the majority of the adhering sediment and any soft tissue preserved in the root cavity, all of which was saved. The teeth were then gently washed in deionized, distilled water. Teeth were subsequently allowed to dry slowly to minimize cracking. Clean, dry teeth were weighed to the nearest 0.0001 gram using a Sartorius digital balance to track loss of mass from the sectioning and etching process (Figure 6.1).

Sectioning of teeth followed protocols developed for maxillary canines detailed in Pierce and Kajimura (1980) and Griffith (2000). Those protocols are as follows:

1) teeth were mounted on wooden blocks using a hot glue gun, and
2) teeth were cut on a Tyslide table saw mounted with a diamond-edged blade (1.35 mm thick) and recirculating water cooling system.

Due to constraints on availability, tap water was used in this process rather than deionized, distilled water.

It is no accident that these protocols were originally developed using maxillary canines. The maxillary canines are relatively straight along both the longitudinal and sagittal axes (Figure 6.2A). Consequently, they are easily removed from the maxilla and easy to section such that the entire length of the pulp cavity is exposed (Griffith 2000; Pierce and Kajumura 1980; see Figures 6.2B and 6.2C). Such exposure is a prerequisite to accurate age determinations (Anas 1970; Scheffer 1950b). In contrast, mandibular canines are notably curved along the sagittal axis (Figure 6.3A), which often makes their removal from the mandible difficult. Furthermore, mandibular canines are often curved and/or twisted along the longitudinal axis as well (Figure 6.3B). Although this curvature makes it impossible to expose the pulp cavity in a single cut, it was determined during the course of this research that cutting one or more facets on the lingual aspect of the lower canines results in a uniform exposure along the pulp cavity (Figure 6.3C).

After the pulp cavity was exposed with the saw, the teeth were removed from the wooden blocks by reheating the glue with a heat gun. While the glue was still pliable, as much as possible was removed from the surface of the tooth. It is particularly important that no glue is left adhering to the sectioned surface prior to soaking in the formic acid, as this will result in irregular etching.

The final stage before acid etching was polishing of the sectioned surface. An Ecomet III wet polishing wheel was used with 600-grit sandpaper. This process removes saw marks from the sectioned surface, but also allows for precise exposure of the GLGs along the pulp cavity. As with the Tyslide saw, this equipment uses tap water rather than deionized, distilled water.

Finally, acid etching was performed to increase the resolution of the GLGs evident in the sectioned canines. Teeth were soaked in a 5.5% solution of formic acid for 6-18 hours. After soaking in formic acid, teeth were transferred to an acetone bath for 5 minutes, then soaked in tap water for 24-48 hours. After this time, the teeth were removed from the water bath and dried slowly as before to minimize splitting.

Although optimal etching time varied considerably due to age of the individual and degree of preservation, most teeth were easily read after ~13 hours of soaking. Determining optimal etching time required some trial and error. For this reason, specimens with the least specific provenience (e.g., “exterior midden” and/or “slump wash”) were used first. While Pierce and Kajimura (1980) suggest that teeth can be periodically examined visually to determine the appropriate soaking time, they do not stress the importance of the acetone bath. In point of fact, this step was found to be crucial for resolving GLGs and, by extension, for determining the appropriate soaking time.

Reading the sectioned teeth

The surfaces of the dry, etched teeth were rubbed with a soft graphite pencil to highlight the GLGs. Teeth were then examined under a dissecting microscope at varying levels of magnification under low-angle lighting (which also serves to highlight GLGs). Reading of the teeth was conducted as follows: first, the dentine-enamel interface was identified; second, based on the location of the dentine-enamel interface, the first growth arrest line (GAL) was located to identify the end of the first year’s growth (if present); finally, the number of major GLGs beyond the first growth arrest line was counted to determine age-at-death to the nearest year. Although it is theoretically possible to arrive at fractional age estimations using tooth sections, the age estimations used here were rounded to the nearest year, a process which is termed interval censoring (Holman 2000).

All calculations involving these age determinations utilize the mid-point of each age interval (e.g., an age of 6.5 years would be used for an animal that has started its sixth year of growth).

All teeth were read independently at least once by each of three readers. In cases where age determinations differed by only one year between any of the three readers, that tooth was re-examined once. In contrast, for cases where age determinations differed by more than one year between any of the three readers, that tooth was re-examined by all three readers. Most differences in readings involved interpretation of what constituted a GAL, rather than an inability to discern GLGs. For instance, the tooth in Figure 6.4 has distinctive ridges across the entire surface of the tooth, but each GLG is separated by a distinctly more prominent ridge. These prominent ridges are interpreted as annular GALs. Consequently, the individual in Figure 6.4 was interpreted as being in its fourth year of growth, and was entered into the analysis as 4.5 years old. The individual in Figure 6.5 also shows distinctive ridges across the entire surface. However, few of these ridges appear to be more prominent than any other ridges, complicating the identification of the GALs. The individual in Figure 6.5 was interpreted as being in its third year of growth, and was entered into the analysis as 3.5 years old. In the end, a combination of reference to sectioned teeth from known-age specimens and examination of the appearance of the GLGs on the exterior of the tooth was used to guide interpretation of these problematic tooth sections.

Using the process outlined above, all but one of the tooth sections were resolved through consultation among the three readers. The single tooth that could not be agreed upon was determined to be anywhere between 9 and 14 years of age. This specimen was not included in subsequent analyses.

Comparison of growth curves

Examination of the sectioned fur seal teeth provides an estimate of age-at-death that is typically accurate to within a year or so (Anas 1970; Scheffer 1950b). Because teeth were selected for sectioning only if they could be associated with a complete mandible, length-at-age data were generated that are essentially identical in form to those utilized in Chapter 3. From that, the length-at-age data for the Ozette mandibles were then characterized by non-linear VB growth curves (Equation 2.4; Figure 6.6) using non-linear parameter estimation in SPSS (Norusis 1997). Finally, the estimates of the parameters that describe these curves were statistically compared (Cerrato 1990; Kimura 1980; Schnute 1981) with the parameters estimated for different population levels in Chapter 3. Recall that the different population levels analyzed in Chapter 3 date to the period 1910-1920, when the fur seal population was at its historic low of between 200,000 and 300,000 individuals (Lander 1980; York 1987a); and the period 1940-1955, when the fur seal population had stabilized at its historic high of around 1.5 million (York 1987a). I refer to these two time periods as popmin and popmax, respectively. The results from Chapter 3 showed that although estimates of growth *rates* were statistically indistinguishable for popmax and popmin, overall mandible size was smaller during popmax. This finding supports the hypothesis of density dependent growth in fur seals and provides the possibility of using growth rates and/or overall size as a proxy measure of relative population levels.

For the ease of comparison between the archaeological samples and the reference samples, the starting values for the non-linear parameter estimation are the same here as in Chapter 3. Specifically, $T_1 = 0$ and $T_2 = 8$, with solutions sought for y_1, y_2, a, and b. The estimates of y_1 (e.g., size at $T_1 = 0$) from the Ozette mandibles are of limited utility in this analysis due to the combination of low sample sizes of yearling males available for sectioning and the interval-censoring of this age class as 0.5 years old. Therefore, I will focus primarily on y_2, a, and b, and their relationship to the same parameters estimated for popmax, popmin, and the full reference sample, which consists of 405 mandibles collected primarily from the Alaska population between 1874 and 1998.

Overall Patterns: Examination of the length-at-age data and accompanying VB growth curves in Figure 6.6 suggests that after the first year of growth, the Ozette mandibles tend to be smaller in any given year class than mandibles in the same year class in the full reference sample. Indeed, the 95% confidence intervals for the estimates of y_2, which corresponds to average size at $T_2 = 8$ years, do not overlap (Table 6.2), indicating that the differences in size are significant at the 0.05 alpha-level (based on a *t*-distribution with df = n – 4). Although the opposite is true for estimates of y_1 (size at $T_1 = 0$; see Table 6.2), keep in mind that all of the yearling mandibles from Ozette were interval-censored to 0.5 years of age. Furthermore, in contrast to the full reference sample, the Ozette mandibles analyzed here do not include any foetal individuals. Thus, the VB growth curve is not accurately measuring size at $T_1 = 0$ for the Ozette mandibles.

The estimates of a and b for the full Ozette assemblage are difficult to interpret (Table 6.2). On the one hand, a is significantly higher for the Ozette mandibles than it is in the full reference sample ($0.01 < p < 0.05$). However, *b* is significantly *lower* for the Ozette mandibles than it is for the full reference sample ($0.01 < p < 0.05$). As I will show below, these two parameters are even more difficult to interpret when the Ozette assemblage is examined stratum by stratum, primarily due to high standard errors of the estimates.

Temporal Patterns at Ozette: Temporal trends in the growth curves will follow the same stratigraphic designations used throughout this dissertation, and are presented in both tabular (Tables 6.1 and 6.2) and graphic (Figures 6.7 – 6.10) formats. Note that as with other chapters, the House 1/Unit V values have not been plotted graphically since these deposits span the same amount of time as House 5, House 3, and House 2 combined. In addition, comparisons will now be made directly with popmin and popmax, rather than the values for the full reference sample.

The first characteristic of the temporal patterns in the estimates of the VB growth curve parameters that I will discuss is the estimate of the growth rate parameters, *a* and *b*. Although the same general pattern documented for the Ozette assemblage as a whole still obtains (e.g., *a* is higher and *b* is lower in the archaeological samples than in the reference samples), the standard errors (SEs) of the estimates of both, particularly for House 3 and Units I-III, are quite high relative to the SEs of popmin and popmax (Table 6.2 and Figures 6.7-6.8). As a consequence, the estimates of *a* and *b* for the Ozette mandibles cannot be statistically distinguished from the same parameters calculated for popmin and popmax.

The SEs of the estimates of y_1 and y_2 for the Ozette mandibles are generally more comparable to the SEs of the estimates of y_1 and y_2 for popmin and popmax (Table 6.2; Figures 6.9-6.10). Although Units I-III still has the highest SE, the overall patterns documented for the whole Ozette assemblage generally hold. Specifically, y_1 tends to be higher throughout the Ozette sequence than in the reference sample. As stated above, this is likely to be an artifact of sampling, with yearlings poorly represented in the tooth section data. More germane to tests of my hypotheses is the fact that y_2 is consistently lower in the Ozette mandibles than in the reference sample. Indeed, y_2 is significantly lower ($0.01 < p < 0.05$) than either popmin or popmax in all stratigraphic units except Units I-III (Table 6.2; Figure 6.10). The estimate of y_2 for Units I-III is statistically significantly lower than in popmin ($0.01 < p < 0.05$), but is indistinguishable from that of popmax ($p > 0.5$).

Accuracy of age estimates

A different way to evaluate the tooth section data from the Ozette samples is to examine the relationship between the two independent estimates of age—the calibration based on the VB growth curve derived from the full reference sample (see Chapters 2 and 5) and the reading of the sectioned tooth. There is no reason to think that the accuracy of age estimates based on sectioned teeth will vary through time. Thus, any differences in aspects of growth relative to the full reference sample will be reflected as a deviation from a one-to-one relationship between the two independent estimates of age. As shown in Chapter 3, individuals with relatively fast growth rates and/or larger body size will tend to fall above the y = x line, whereas individuals with relatively slow growth rates and/or smaller body size will tend to fall below the line y = x.

The use of interval censoring complicates this relationship somewhat because it collapses all individuals from the same year class into linear clusters along the x-axis. Nevertheless, if, as I assume, ages within a given year class are normally distributed, equal numbers of individuals will fall above and below the line y = x (Figure 6.11). Thus, even when cases have been interval-censored, the regression line describing the relationship between the two age estimates will still have a slope of one if both approaches are measuring age accurately.

Before this relationship can be used to evaluate the Ozette tooth sections, the details of mandible growth in fur seals need to be reviewed. Specifically, it was shown in Chapters 2 and 5 that mandible growth in male fur seals plateaus around 9 or 10 years (see also Scheffer and Wilke 1953). Based on this information alone, we can predict that age estimates based on calibration of VB growth curves for mandible length will under-estimate individuals older than this.

Overall patterns: Examination of Figure 6.12 makes it clear that, in addition to the anticipated under-estimation of individuals older than 9 or 10 years, the ages of virtually all of the Ozette mandibles were under-estimated via calibration. An important exception to this observation is the yearling age class (see also Figure 6.6). With the exception of yearlings, age estimations based on tooth sections, which are considered here to be the less variable of the two approaches, were consistently older across all other age classes—not just for individuals in which mandible growth had reached a plateau.

This is, of course, just another way of saying that the Ozette mandibles tend to be smaller than mandibles of the same age from the reference collection.

The degree to which the calibration age estimation under-estimates age can be evaluated by examining the slope of the regression line that describes the relationship between the two independent estimates of age (Table 6.3; Figure 6.12). For the Ozette assemblage as a whole, the slope of the line is 0.7032, which is significantly lower than a slope of 1.0 ($0.01 < p < 0.05$), and significantly lower than the slope documented for the under-estimations in popmax ($0.01 < p < 0.05$; see Table 3.4). These results have potential implications for the demographic analysis presented in Chapter 5. I address this issue below.

Temporal Patterns at Ozette: When the relationship between the age estimations based on tooth sections and those derived from calibration based on mandible length is examined stratum by stratum (Table 6.3; Figure 6.13), there is some suggestion of a gradual increase over time in the accuracy of the calibration-based ages. That is, there is an increase in the slope of the line describing the relationship between the two independent estimates of age through time. However, at no point in the Ozette stratigraphic sequence is the slope statistically equivalent to unity. Furthermore, at no point are the different slopes statistically different from each other. Finally, even the highest slope (Units I-III) is significantly lower than the slope documented for popmax ($0.01 < p < 0.05$; see Table 3.4).

Discussion

Analysis of the tooth section data from Ozette has clearly shown that male fur seals tend to be smaller than reference samples collected at two different population levels in the history of the Pribilof Island, AK, population. There is some suggestion that this pattern may have changed in Units I-III, which date to the historic period (Table 6.1). However, the high SEs for parameter estimates from this stratum obviate any firm conclusions in this regard.

At least two explanations can be forwarded for the discrepancies in size between the Ozette mandibles and the reference samples. The first, as posited in the test implications of my three competing hypotheses, is that differences in size reflect density dependent differences in growth patterns. If this were the case, the data presented here would provide strong support for the hypothesis that population levels of the Ozette fur seals were maximized—at a level perhaps even higher (relative to carrying capacity) than the historically documented maximum of the Pribilof Island, Alaska, population. Furthermore, the fact that this pattern persists into the historic period suggests that prehistoric hunting had little or no effect on fur seal population levels.

There is, however, a second possible explanation for the discrepancies in size between the Ozette mandibles and the reference samples. If the fur seals harvested at Ozette derive, at least in part, from a population distinct from the Alaskan population, as suggested by the demographic data presented in Chapter 5, the tooth section data may be measuring latitudinal differences in body size rather than relative population levels.

Considering the fact that the Alaska fur seal population has been studied for over 200 years (Scheffer *et al.* 1984) and the San Miguel fur seal population has now been studied quite closely for over 30 years (DeLong 1982; DeLong *et al.* 1998; Peterson *et al.* 1968), the question that is immediately raised is whether or not there are latitudinal size differences in the two extant populations of fur seals in the eastern North Pacific. Unfortunately, there is currently no means of testing whether or not this is the case. Despite broadly similar research programs over the past couple of decades, fieldwork is conducted at different times of the year in each location. The most complete datasets have been generated for pups (Sinclair and Robson 1999). However, the pups from the Alaska population are weighed at 6 weeks old; in California, pups are weighed at 18 weeks old (Sharon Melin, *pers. com*.).

In terms of archived skeletal reference material, only 69 of the ~800 reference crania available for this study were unambiguously collected from the California population (51 female, 18 male). Of those 69, 38 are under one year of age (20 female, 18 male). Finally, the yearlings collected from the Alaska population range in age from 0-4 months, whereas the yearlings collected from the California population are primarily stranding victims, aged 3-6 months.

Although it is not currently possible to evaluate whether the discrepancies in size between the Ozette mandibles and the reference samples reflect density dependent or latitudinal differences in growth patterns, the implications for testing the three competing hypotheses forwarded to explain the late Holocene changes in fur seal biogeography should be minimal. The fact remains that the general growth patterns at Ozette are stable essentially throughout the entire sequence, suggesting that at no point in prehistory was this population over-harvested.

Implications for Age Estimates and Demographic Profiles:

The problem still remains, however, that age estimates based on calibration of mandible length systematically under-estimate age-at-death for male mandibles from Ozette. This systematic error in age estimation could have profound implications for the interpretation of the demographic data generated in Chapter 5. It is not clear if this problem applies generally to all archaeological samples, or is specific to mid-latitude samples. If this problem is specific to mid-latitude archaeological samples, all of the Cape Flattery sites may be significantly affected.

Because evaluation of the magnitude of the bias in age-estimation requires two independent age estimates from the same specimen, Ozette is the only Cape Flattery assemblage that can be readily evaluated. Inasmuch as the systematic error appears to be consistent throughout the Ozette sequence (Figure 6.13), the error should be consistent for all stratigraphic units. Furthermore, examination of Figures 6.6 and 6.12 suggests that the magnitude of the under-estimation increases with age, with little or no bias in age-estimates for animals younger than one year. This observation regarding the distribution of errors in age estimates corresponds closely with the results presented in Chapter 3.

To evaluate the effects of the bias in age-estimates based on calibration of MSL against the full reference VB growth curve, age-at-death has been recalculated for male mandibles from Ozette using the VB growth curve generated from the series of 230 individuals in the tooth section analysis presented above (see Table 6.2). Although the accuracy of age-estimates for the youngest age classes is critical to interpretations regarding the proximity of fur seal rookeries, nominal yearlings have been excluded from the recalculations for several reasons. First, the results of Chapter 3 suggest that age-estimates based on MSL only slightly over-estimate age for yearlings. Second, Figures 6.6 and 6.12 indicate that most of the divergence between the full reference VB growth curve and the Ozette VB growth curve occurs after the first year of growth. Finally, as discussed above, pups are relatively poorly represented in the sample used to generate the Ozette VB growth curve, and all of these animals have been interval-censored to 0.5 years. Consequently, the Ozette VB growth curve is not accurately describing growth in the lower end of the curve (Figure 6.14). For all of these reasons, I have used an MSL of 50.00 mm as the cut-off for the recalculations of age. Although this will not exclude all animals estimated to be younger than one year based on the Ozette VB growth curve, it provides a convenient cut-off for the analysis.

The improved accuracy in age determinations is immediately apparent in Figure 6.15, which plots the relationship between age estimated from MSL based on the Ozette VB growth curve and age estimated from the tooth sections for the 230 mandibles included in the tooth sectioning analysis. Whether or not the regression is forced through the origin, the slope of the regression line is statistically indistinguishable from unity ($0.01 < p < 0.05$; see Table 6.4), indicating that the corrected age estimates are comparable with the estimates based on sectioned teeth. This suggests that application of the Ozette VB growth curve to the full assemblage is appropriate. Note, however, that the Ozette VB growth curve is only applicable to those individuals whose age has been estimated from MSL (see Appendix E for details).

The differences between the age estimates based on calibration of MSL and the corrected age estimates are evaluated in two ways, both of which follow the format of Chapter 5. Specifically, histograms representing age-at-death are plotted for each stratigraphic unit from Ozette (Figures 6.15 to 6.21), providing a comparison of the age distribution estimated from the full reference VB growth curve and the age distribution estimated from the Ozette VB growth curve. Next, the temporal trends in median age are compared for each of the two VB growth curves (Figure 6.22).

Figures 6.16 to 6.22 demonstrate two important characteristics of the biased age-estimates derived from the full reference VB growth curve. The first is a clear shift upwards in the corrected age distribution. Despite this shift, the general shape of the distribution is retained. For instance, the age distribution of House 2 and Unit VtVI is still bimodal (Figure 6.18): the modes have simply shifted from around 1.0 and 4.5 years to 2.0 and 6.0 years. The second characteristic is a lengthening of the right-hand tail in the distribution. This same general pattern holds regardless of which stratigraphic unit is examined.

In the “Accuracy of Age Estimates” section above, I explained the truncation of the upper end of the age distribution as being a function of male fur seal growth slowing to essentially zero after about age 10. It is not clear if the improved ability of the Ozette VB growth curve in this region is a function of a different growth pattern, or simply the presence of more animals in the asymptotic region of the Ozette VB growth curve.

Finally, as suggested by the histograms plotted in Figures 6.16 to 6.22, the corrected age estimates result in a systematic increase in median ages for all stratigraphic units (Figure 6.23). Despite the systematic increase in median ages, the same general pattern documented in Chapter 5 still obtains. Specifically, the corrected age estimates for mandibles = 50.00 mm indicate an increase in median age beginning in Unit IV, sometime between AD 1719 and 1780. In addition to the increase in Unit IV, the corrected age estimates also indicate a slight increase in median age between House 5/Unit VtVII and House 3/Unit VtVI that was not documented in Chapter 5. Because this increase is present in both the corrected and uncorrected age estimates, the distribution of mandibles smaller than 50.00 mm must have masked this shift in the Chapter 5 analysis.

Conclusions

I have argued that, despite the fact that growth curves generated from modern reference samples systematically under-estimate age for male mandibles from Ozette, the conclusions remain essentially unchanged. This is based on the observation that animals younger than one year old fall on or near the full reference VB growth curve, and that the age distribution for animals older than one year simply shifts upwards. This shift may change the proportion of adults identified in the assemblage. However, the presence of adult males at Ozette has been well-documented previously (Gustafson 1968). Thus, the systematic upward shift in the age distribution is probably insignificant.

Examination of tooth sections from 230 male fur seals from the Ozette archaeological site clearly indicates that the animals being harvested off the coast of WA from ca. 450 BP to ca. AD 1700 were significantly smaller than males collected from the

AK population during the 20th century. Although the specific causal mechanism behind these size differences has not been identified, analysis of the temporal patterns in growth patterns of male fur seals at Ozette indicates that these growth patterns were stable throughout most, if not all, of the Ozette sequence. As such, the tooth section data supports the "historic effects" hypothesis. This hypothesis states that the major changes in fur seal biogeography documented here (e.g., Chapter 5) and elsewhere (Burton 2000; Burton and Koch 1999; Burton *et al.* 2002; Gustafson 1968; Hildebrandt 1984a; Hildebrandt and Jones 1992; Lyman 1988, 1989, 1991b, 1995) are a consequence of the commercial Russian fur trade. The implications of these findings will be discussed at length in the following chapter, which will synthesize the results of both analysis chapters.

The systematic error in age estimates documented here was only identifiable because of the large sample of mandibles and associated canines from the Ozette assemblage. Although I have not been able to determine *why* the animals at Ozette tend to be smaller than animals in the reference sample, the fact remains that the size difference persists throughout most or all of the Ozette sequence.

If the systematic error in age estimates is limited to fur seal material recovered from mid-latitude archaeological sites, it should be possible to increase the accuracy of the age estimates (albeit at the expense of precision) by increasing the sample of reference specimens from the California population. However, if the systematic error applies generally to all archaeological samples, the implication is that age estimates based on bone measurements (of any element) provide neither accurate, nor precise demographic data for fur seals. This view is perhaps overly pessimistic. In any case, the possibility that this is a flawed approach to reconstructing demographic data from archaeological fur seal skeletal samples suggests that additional research is needed in this area.