

Chapter 5: Application of bone growth models to archaeological assemblages

Chapters 1 and 2 detailed the rationale behind using demographic data to test the three competing hypotheses (historic effects, prehistoric effects, and continuous effects) regarding the impacts of human hunting on northern fur seal migration and breeding distributions. To summarize, demographic data from archaeological sites will first be utilized to evaluate the degree to which the prehistoric biogeography of fur seals, specifically their breeding distribution, differs from the biogeographic distribution documented historically. Once this is accomplished, demographic data will be used to identify geographic and temporal trends in the composition of archaeological samples of fur seals to determine which of the three hypotheses is supported.

In this chapter, I use several characteristics of demographic data derived from archaeological fur seal remains: general shape of the demographic profile (e.g., relative abundance and distribution across age classes); maximum and minimum ages of both sexes; and the central tendency of age of both sexes (generically referred to as “average” age). The shape of the demographic profile will provide a measure of long-term trends in harvest practices (Gustafson 1968; Klein *et al.* 1981; Lyman 1987; McCartney 1995; McCartney and Savelle 1993; Savelle and McCartney 1991). The maximum and minimum ages will provide an indication of whether or not fur seals may have been breeding locally (Burton *et al.* 2002; Lyman 1988, 1989, 1991b, 1995; Lyon 1937; Parkington 1972; Smith 1985; Woodborne 1996). The key age classes used for documenting breeding distribution include adults, whose presence would suggest the *possibility* of the presence of breeding colonies, and pre-weaned pups, whose presence

would suggest the strong likelihood of close proximity to a breeding colony. Finally, trends in average age (measured by arithmetic mean and median) of animals harvested will provide a basis for inferring levels of harvest intensity (cf. Beverton and Holt 1957; Caughley 1966, 1977; Klein and Cruz-Uribe 1983; Klein *et al.* 1999; Koike and Ohtaishi 1985, 1987; Swadling 1976; York and Hartley 1981).

Skeletal measurements utilized

The von Bertalanffy (VB) growth curve data in Chapter 2 and Appendix D provide the empirical basis for the age estimations of the unknown (i.e., archaeological) samples of fur seal bone. They do not, however, provide any guidance regarding how best to apply the VB growth curve data for age estimations. For instance, it was pointed out in Chapter 2 that the growth patterns of fur seal skeletal elements show remarkable redundancy, with virtually all of the skeletal measurements correlating in a strong positive direction with age. In fact, the relationship between bone dimensions and age has a coefficient of determination (r^2) of 0.70 or higher for 163 of the 173 measurements listed in Table 2.3 and Appendix D. Thus, analysts are faced with the decision of which measurement or combination of measurements to use to construct the demographic profiles.

The redundancy of measurements within a single skeletal element suggests that it would be inappropriate to combine such measurements in a multiple regression. Indeed, Figure 5.1 makes it clear that combinations of linear measurements within a single skeletal element cannot be used in multiple regressions because of the high degree of dependence between predictor variables (Zar 1996; Neter *et al.* 1996). Consequently, in

cases where the landmarks for multiple measurements were preserved on a given specimen, I have used only the measurement with the highest r^2 value.

As indicated in Chapter 2, bone growth essentially stops with epiphyseal fusion. Consequently, linear measurements taken on fully fused elements have little or no relationship with age. Thus, elements were only measured if they were unfused and if all the necessary landmarks for a particular measurement (e.g., metaphyseal surfaces) were preserved. Any fused portions of elements were assigned to minimum age categories (e.g., = 4 years) based on the patterns of fusion documented for that particular element in Chapter 2.

Once the linear measurement was obtained for a particular element, age was calculated using the algebraic rearrangement of Equation 2.3 as follows:

$$\text{(Equation. 5.1)} \quad \text{age} = -\frac{1}{a} * \ln \left[1 - \frac{\text{length}^b - Y_1^b}{Y_2^b - Y_1^b} * (1 - e^{-a(T_2 - T_1)}) \right] + T_1,$$

with parameters keyed as in Equation. 2.2, using the appropriate parameter values from Table 2.3 and Appendix D (see Konigsberg and Frankenberg 1992; Konigsberg *et al.* 1997). Note that I have substituted age and length for t and $Y(t)$, respectively.

As discussed in Chapters 2 and 3, the use of reference VB growth curves to estimate age of unknown samples assumes that the relationship between size and age has remained constant through time and across space. Although it has not been possible to evaluate the spatial component of this assumption, the results of Chapter 3 make it clear that fur seals exhibit significant variability in growth rates across relatively short time spans. The effect this variability has on the accuracy of age-estimates for unknown

samples based on calibration with the reference VB growth curve was evaluated for mandibles. For that element, the bias in age-estimation was shown to be a function of relative population level and age (see Table 3.3). Of particular importance to this study is the demonstration that the bias in age-estimation for animals younger than one year was slightly positive for both cohorts, but averaged less than one month. In any case, evaluation of the accuracy of age-estimates for unknown samples requires an independent estimate of age. I will return to this issue in Chapter 6.

Quantification methodology

To quantify the age estimates, I use a modified version of number of identified specimens (NISP), which has been termed “ageable NISP” by Lyman (1987). This approach uses all of the measurable skeletal elements to generate age distributions unless two or more elements are demonstrably from the same individual (e.g., articulated specimens). The age estimations for the Chaluka and Ozette assemblages provide an exception to this approach in that only mandibles were used (as discussed in Chapter 4).

The relative merits of NISP and minimum number of individuals (MNI) have been discussed at length elsewhere (Grayson 1979, 1984; see Lyman 1994 for a detailed review) and will not be elaborated upon here. For the purposes of this analysis, I will simply point out that two of the four demographic variables I am using (minimum age and maximum age) should, by definition, be interpreted on an ordinal scale. A third variable—the demographic profile—consists of a histogram of the relative abundance of age classes. These histograms are also best interpreted at an ordinal scale. As such, the use of a derivative of NISP is appropriate in these cases (Grayson 1984). The fourth

variable—central tendency of age—is arguably best calculated from MNI data. However, this is not a feasible approach in most of the assemblages due to sample sizes available for analysis. Related to the sample size issue, effective presentation of the data often requires combining and splitting of stratigraphic units—a process that has been shown to dramatically affect MNI, but one that leaves NISP unaffected (Grayson 1984; Lyman 1987). For these reasons, all of the demographic variables utilized in this chapter have been calculated based on “ageable NISP.”

Using this process, demographic data have been derived for a total of 24 distinct stratigraphic units from nine sites in the eastern North Pacific (detailed in Chapter 4). Histograms were generated in two different ways. For the overall age distribution, histograms were generated for each sex separately using half-year intervals. For individuals less than a year old, histograms were generated using one-month intervals, with data for males and females combined. Specimens that were assigned to minimum age categories based on epiphyseal fusion were included in the relative abundance calculations for the histograms but were not plotted. For instance, although individuals categorized as “= 4 years” contributed to the overall sample size, the categorical ages could not be plotted efficiently with the numeric age determinations.

The use of categorical age determinations differentially affects the two measurements of average age used here (arithmetic mean and median). Only the numeric age determinations could be used for the calculations of mean age. In contrast, calculations of median age, which are based on a rank-ordered list of age determinations, can combine ratio-scale data with ordinal-scale data (Zar 1996). The only time this

combination is problematic is when the median age either falls between a categorical and numeric age, or when the median age falls completely within a categorical age range (discussed under “Temporal Trends in Demographic Profiles” below).

The demographic data will be presented in a number of different ways. First, sites will be presented in the same order as in Chapter 4. That is, they will be presented from Umnak Island, Alaska clockwise to Cape Alava, Washington. When multiple sites occur in close proximity to each other the sites will be presented in chronological order from oldest to youngest. To simplify comparison between sites, each aspect of the demographic data will be presented separately for the entire series of sites. For instance, the overall demographic profile will be presented for Oglodax’, Chaluka, the Kodiak Island sites, and so on, south to Ozette. After that, the next aspect of the demographic data will be presented in the same order until all of the relevant data have been covered. Finally, data will also be presented by stratigraphic unit where appropriate, in chronological order from oldest to youngest.

Demographic profiles

Before the demographic profiles can be discussed, two important characteristics of the histograms need to be clarified. First, the proportion of specimens for which sex could be determined is highly variable between sites. The proportion of a sample for which sex can be determined will be a function of the age and sex composition of that sample, as well as of the skeletal elements analyzed. For instance, the Umnak assemblages are dominated by very young individuals. In the case of the Oglodax’ assemblage, the full range of skeletal elements (post-cranial and cranial) was analyzed.

Thus, a high proportion of the Oglodax' assemblage was identified as "sex indeterminate." In contrast, only mandibles were available for the Chaluka assemblage. Mandibles are much more sexually dimorphic, regardless of age (Huber 1994; Lowry and Folk 1990; Scheffer and Kraus 1964). Consequently, the majority of the age estimations for these assemblages use sex-specific VB growth curve data from Table 2.3 and Appendix D.

The second characteristic that is important to note is that a low proportion of negative ages have been plotted in the histograms. These correspond to what are inferred to be fetal individuals.

Umnak Island, Alaska, Sites: Despite the differences in portions of assemblages analyzed, the demographic profiles from Oglodax' and Chaluka are quite similar. As documented by Yesner (1977, 1988), one of the most striking characteristics of the demographic data from the Umnak Island sites is the dominance of young-of-the-year age class (YOYs). Indeed, 76% of the ageable NISP from Oglodax' falls between zero and twelve months (Tables 5.1, 5.2; Figures 5.2, 5.3). Likewise, YOYs from Chaluka comprise 73% of the ageable NISP (Tables 5.3, 5.4; Figures 5.4, 5.5).

Shifting focus to the maximum ages represented, the demographic data from the Umnak Island sites indicate that breeding-age individuals (females = 3 years; males = 7 years) comprise a very low proportion of animals harvested. Yesner's (1977) analysis indicated that 10.8% of fur seals in assemblages from this region were "adult or mature." Indeed, the demographic data presented here correspond closely to that value (Tables 5.1, 5.3).

When the age distribution of YOYs is examined with higher resolution (Tables 5.2, 5.4; Figures 5.3, 5.5) the nature of the harvest profile becomes even more clear. At the youngest end of the age spectrum, the presence of fetuses is easily explained by their coincidental take with pregnant adult females in the late spring or early summer. More generally, both Umnak Island assemblages indicate that the bulk of the YOYs were harvested between their fourth and sixth months. According to studies on the modern fur seal population in the Pribilof Islands, this is the age that most pups begin their southward migration through the Aleutian passes (Gentry 1998; Ragen *et al.* 1995). As such, their presence in archaeological assemblages from sites located on those passes is easily explained. The presence, in low proportions, of fur seal pups in the zero to three-month-old age range is more difficult to explain. This will be discussed at length after data from the other assemblages have been presented.

Kodiak Island, Alaska, sites: In contrast to the Umnak Island sites, the Kodiak Island sites show a much more even distribution of ages (Tables 5.5, 5.6; Figures 5.6, 5.7). A much higher proportion of the post-cranial specimens was from adult females and large sub-adult males. Therefore, sex could be determined for a much higher proportion of the Kodiak Island assemblages than for the Oglodax' assemblage. The specimens of unknown sex span a much broader age-range in the Kodiak Island assemblages than in the Umnak Island assemblages. However, it is still possible to characterize these assemblages as being dominated by adult females and sub-adult males.

Young-of-the-year are not well represented in the Kodiak assemblages, with ageable NISPs of four (Three Saints Bay) and nine (Rolling Bay and Kiavak combined).

When the distribution of ages is examined at one-month intervals (Figures 5.8, 5.9), it is broadly similar to that of the Umnak Island sites. However, the small samples make interpretation of these distributions tenuous at best.

Cape Flattery, Washington, sites: Unlike all of the other sites reported here, no demographic data have been published on the fur seals from sites distributed on and around Cape Flattery. Due to their close proximity to the migratory route of the Pribilof fur seal population, it might be expected that the assemblages would consist primarily of adult females and sub-adults of both sexes (see Chapter 1). On the other hand, Gustafson's reports (1968) of the demographic composition of Ozette would lead to the expectation that adult males and females might be abundant. Neither pattern appears to obtain. Rather, as with the Umnak Island sites, the demographic profiles are strongly positively skewed, with YOYs being the modal age class at Neah Bay (Table 5.7; Figure 5.10), and one-year olds the modal age class at Tatoosh (Table 5.7; Figure 5.11). The Sooes age distribution is also positively skewed (Table 5.7; Figure 5.12). However, this distribution is bimodal, with a mode between zero and 18 months, and a second mode for sub-adult males between 5 and 6 years.

Closer examination of the YOY age distributions from the Cape Flattery sites (Table 5.8) does not indicate any consistent pattern. Neah Bay, for instance, is reminiscent of the pattern observed in the Umnak Island samples— a mode at 4 months, with low proportions of fetuses and animals in the one- to two-month range (Figure 5.13). Tatoosh, on the other hand, has low proportions of fetuses and animals in the one- to two-month range, but also has modes at four and nine months (Figure 5.14). Finally, Sooes

has modes at one month, five months, and eight months (Figure 5.15). Despite the lack of a consistent pattern, the distributions of YOYs documented in the Cape Flattery sites are dramatically different than would be expected from the historically-documented behavioral patterns of fur seals, as I will discuss below.

Ozette, Washington: Due to the degree of preservation at Ozette, coupled with the remarkably large sample sizes, this assemblage holds the greatest potential to elucidate regional patterns in fur seal behavior. Even taking differences in sample size into consideration, the Ozette assemblage is unique among those examined here. Specifically, the Ozette age distribution (Table 5.9; Figure 5.16) is the only one that approximates the age structure of a stable population. That is, successively older age classes are represented by fewer and fewer individuals, as would be the case in a stable population. The presence of adult males and females has been reported previously (Gustafson 1968). However, as discussed in Chapter 1, the age categories used by Gustafson, while accurate, mask a great deal of variability within those age categories.

Turning again to the younger age classes, the age distribution of YOYs from Ozette (Table 5.10; Figure 5.17) generally fits the pattern documented for the Umnak Island sites and Neah Bay. That is, the modal age class is in the four- to six-month age range. Fetuses are present in low proportions, as are one- and two-month olds. Two primary differences observable in the age distribution of Ozette YOYs include a reasonably high proportion of three-month olds and a distinct mode for 8 month males.

Interpreting the demographic profiles

As discussed in Chapter 1, demographic profiles have been generated to evaluate the degree to which the archaeological evidence of the breeding and migration patterns of fur seals differ from the patterns that were documented historically. Interpretation of the oldest age-classes is relatively straightforward: females older than three years and males older than seven could, potentially, have entered their reproductive years (though average age of first reproduction is much older—see discussion in Chapter 1). The low frequency of adults in sites where adults would have presumably been readily available on a seasonal basis (e.g., Oglodax' and Chaluka) gives an indication of the degree to which archaeological deposits may be biased. Thus, while their presence is certainly meaningful, their absence may not be.

Interpretation of the youngest age classes, specifically the distribution of ages within the first year of growth, is problematic as well. The traditional approach is to use four months as the threshold for identifying pre-weaned pups and, by extension, the presence of a local rookery (Lyman 1988; Burton *et al.* 2002). This threshold is based on age data for pups encountered historically along the Washington and Oregon coasts (Kenyon and Wilke 1953; Fiscus 1978; Scheffer 1950d), as well as data on the average age of weaning and departure from the rookeries (Gentry 1998; Lander and Kajimura 1982; Ragen *et al.* 1995). If this threshold were used for the demographic assemblages presented here, the interpretation would be that all of the archaeological sites included in this analysis were located in the immediate vicinity of fur seal rookeries. There are,

however, significant problems associated with using four months of age as a threshold for inferring direct exploitation of fur seal rookeries.

The first problem stems from the fact that the age of pups encountered historically along the Oregon coast is based, at least in part, on surveys that pre-date the founding of the San Miguel Island rookery (e.g., Kenyon and Wilke 1953). The presence of mid-latitude rookeries that persisted into the early historic period, such as the one recently identified in the Farallon Islands (Pyle and Long 2001), would be expected to dramatically affect the earliest age at which pups might be encountered along the mainland coast.

The second problem relates to the use of *average* ages of weaning and departure from rookeries as a threshold for identifying possible rookery sites. Even if the timing of these phenomena is not normally distributed, we would still expect that some individuals will fall on either side of that average. Furthermore, these studies appear to implicitly include in their studies only those pups that survive the weaning process. Obviously, pups that do not survive weaning and strand on mainland beaches would have been easily accessible to hunter-gatherers living along the coast.

Finally, the birth of fur seal pups well outside of the main breeding grounds, even on the mainland coast, has been documented (Stein *et al.* 1986; Swan 1883). Although this is a notably rare occurrence, it nevertheless happens occasionally. Thus, even indisputable pre-weaned pups recovered from archaeological contexts must be interpreted in relation to the overall age distribution of YOYs.

To evaluate the possible effects that these issues might have on the interpretation of archaeological fur seal remains, I have analyzed fur seal stranding data for the California coast compiled by the Marine Mammal Stranding Network (U.S. Department of Commerce n.d.). The data consist of information on date, location, and approximate age of 196 fur seal strandings for the time period 1981-2000. Of these 196 strandings, 133 were identified as pups. Age-at-stranding was calculated using the same algorithm presented in Chapter 2, substituting the average birth date determined for the San Miguel Island population (24 June; DeLong 1982). When the age distribution of stranded pups is plotted as a histogram in one-month intervals (Figure 5.18) the hazards of using a threshold of four months for identifying the local presence of a rookery are immediately apparent. Although the modal stranding age is, indeed, four months, low frequencies of fur seals are stranding on the mainland California coast between the ages of zero and two months. These strandings are occurring a minimum of 45 km from San Miguel Island (Table 5.11), the only active rookery identified in the area prior to 1996¹.

To get a better idea of the distribution of strandings along the coast, age distributions of stranded YOYs are also plotted by county (Figure 5.19). Interestingly, Santa Barbara County, the closest to San Miguel, has neither the highest frequency nor the earliest records of pup strandings (Table 5.11). Rather, the majority of strandings, as well as some of the earliest strandings, are reported in the next county to the north, San

¹ Small numbers of pups have been born on the South Farallon Islands since 1996 (Pyle and Long 2001). Of the 39 pup strandings that post-date 1996, only seven were recorded in counties adjacent to the South Farallon Islands, with inferred stranding ages of three to six months.

Luis Opisbo County (Table 5.11). This pattern is almost undoubtedly a consequence of the typical trends in surface water currents in the southern California Bight during autumn months (CALCOFI 2001; see Figure 5.20).

The stranding data from the California coast provide a revised basis for interpreting the age distributions of YOYs identified from archaeological assemblages. Specifically, pups between zero and one month of age can be expected to show up in very low frequencies quite far from centralized rookeries. These could represent either females unsuccessfully giving birth some distance away from the rookery (Stein *et al.* 1986) or the stranding of newborn pups within 50 to 100 km of the rookery (depending on strength and direction of surface water currents). Likewise, two- and three-month olds appear to be able to travel somewhere on the order of 100 to 300 km from where they were born, generally following (or, more likely, being carried by) the main flow of surface waters. Although this does not appear to represent the behavior of normal, healthy individuals, the fact remains that they nevertheless would have been accessible to hunter-gatherers living along the coast (encountered either as weakly-swimming individuals in the open ocean or as strandings).

Keeping this in mind, the Umnak Island age distribution is more reliably interpreted. The passes through the Aleutian Island chain are approximately 400 km from the Pribilof Islands (Figure 1.1). With reference to Figures 5.3 and 5.5, it seems extremely unlikely that pups would be able to cover this distance within their first one to two months. If this supposition were true, it would seem to indicate that these individuals were coming from a fur seal rookery located somewhere other than the

Pribilof Islands. However, as I noted before, these age classes are quite rare in the Oglodax' and Chaluka assemblages, suggesting that Umnak Island was not the site of a fur seal rookery. Rather, a rookery may have existed somewhere along the Aleutian chain, perhaps as close as 100 km away.

Interpretation of the age distributions from the Kodiak Island sites is hampered by the small sample sizes. However, if Figures 5.8 and 5.9 provide an accurate reflection of the age distribution of YOY fur seals that were in the area, then it seems likely that there was also a rookery within a few hundred kilometers of the south end of Kodiak Island. It does not seem very likely that pups could have traveled all the way from the Pribilof Islands to the south end of Kodiak in their second and third months. When the Umnak Island sites are taken into consideration, the data strongly suggest that at least one rookery existed somewhere along the Aleutian Island chain or along the Alaska Peninsula until relatively late in prehistory.

When the age distributions of YOYs from the Cape Flattery sites and Ozette are examined with the California stranding data in mind, they also do not suggest immediate proximity to a rookery. But, in contrast to the Alaska sites that showed an abrupt increase in the frequency of animals between three and four months (e.g., Figure 5.5), the Cape Flattery and Ozette distributions show an abrupt increase between two and three months (e.g., Figure 5.17). This suggests that a rookery may have been much closer, possibly within 50-100 km. Furthermore, fur seals were apparently available on a year-round basis.

Given the close proximity to the continental shelf and open ocean to the west, determining the location of this rookery along the coastline should be a relatively simple task. As discussed in Chapter 1, extremely young fur seals were identified from archaeological deposits in Hesquiat Harbor on the west coast of Vancouver Island (Calvert 1980). Likewise, Lyman (1988, 1989, 1991b, 1995) argues for rookeries to the south of Ozette, at Seal Rock and Umpqua/Eden, Oregon. Unfortunately, Calvert's report does not provide any skeletal measurements of fur seal material, and the Hesquiat Harbor assemblages were not accessible for inclusion in my analysis. Both of these factors obviate an evaluation of the Hesquiat Harbor area as the possible location of an extinct fur seal rookery. In contrast, Lyman (1991b) presents long-bone measurements (total length) for specimens from Seal Rock, occupied 400-100 BP ($n = 30$) and Umpqua/Eden, occupied 3000-50 BP ($n = 8$). When ages are calculated from these measurements using Equation 5.1 and the appropriate VB growth curve data, and these ages are plotted as histograms, the modal ages are late-term fetuses and one-month old pups (Figures 5.21, 5.22). These results provide strong support for Lyman's interpretation of the existence of a fur seal rookery in the immediate vicinity of Seal Rock and Umpqua/Eden.

Despite the strong empirical support for the presence of a fur seal rookery in close proximity to Ozette and the other Cape Flattery sites, it is still not clear whether fur seal pups would have been more likely to move/drift northwards or southwards. Figures 5.23 and 5.24 show why this is the case. The patterns of surface currents off the coast of Washington are extremely variable, both on a monthly (Figure 5.23) and annual (Figure

5.24) basis (Ingraham and Hastings 1976; Schwarzlose 1963). Generally speaking, surface waters flow south off the Washington coast in summer and shift back to the north during the fall. However, depending on the timing of when the direction of flow reverses, either Vancouver Island or the Oregon coast could be a likely source for young pups. It is possible that both areas, or another unidentified location, acted as a source for fur seal pups along the Washington coast.

Documenting temporal trends in demographic profiles

Although it has not been possible to identify their exact locations, the evidence from archaeological sites distributed along the eastern North Pacific coastline indicates that fur seal rookeries were, at one time, much more widely distributed than today. Because the timing of the distributional changes will be a critical piece of evidence for evaluating the cause/s of those changes, I next present stratigraphic and temporal data for the demographic data derived from the archaeological assemblages. As with the overall demographic profiles, temporal trends will be presented clockwise along the coastline, starting with the Umnak Island sites. Within sites, age distributions will be presented by stratum (see Chapter 4 for stratigraphic details).

I will test the relative stability of the age distributions of fur seals through the archaeological sequences using Cochran's test of linear trends among proportions (Cannon 2000, 2001; Zar 1996). This test takes into account the natural relative ordering of the archaeological strata regardless of their absolute (e.g., calendric) dates. To do this, the age data are reduced to an $R \times 2$ contingency table, with each of the two

columns representing the frequencies of two mutually exclusive age classes and the rows representing successive archaeological strata.

Cochran's test of linear trends is a special form of chi-square analysis that partitions the total chi-square into two components (Zar 1996): the component that is explained by the linear (e.g., temporal) trend, and the component that is independent of the linear trend (referred to as the "departure from the linear trend"). It is important to note that by incorporating the relative ordering of the sequence, Cochran's test of linear trends is more powerful than a standard chi-square. Thus, the null hypothesis of "no trend among proportions" may be rejected even when the overall chi-square fails to reject the null hypothesis of "no significant difference among proportions" (Zar 1996:564).

For each stratigraphic sequence consisting of three or more strata, I will use Cochran's test of linear trends for the overall age distribution and the age distribution of YOYs. For the overall age distribution, the two age classes I use are: 1) all animals younger than one year (YOYs), and, 2) all animals one year and older (Table 5.12). This approach is used because the proportion of YOYs is expected to be positively correlated with proximity to rookeries. Thus, a decline in the proportion of YOYs would signal the local extermination of rookeries. Furthermore, because many of the age distributions are skewed, combining all animals one year and older results in a higher proportion of the contingency table cells with expected values > 5.0 , a commonly-used minimum threshold to avoid biased results. Failure to do so can result in over-estimates of the χ^2 value, which leads to a rejection of the null hypothesis with a probability greater than the stated alpha-level (Zar 1996).

In addition to examining trends in the overall age distribution, I also analyze trends within the YOY age class separately. Young-of-the-year are divided into two categories: 1) YOYs that are four months and younger, and, 2) all other YOYs less than 12 months. As discussed above, pups disperse from rookeries in low frequencies prior to the average weaning age of four months. While using this age threshold an indicator of *immediate* proximity to a rookery may be misleading, it is nevertheless clear that virtually all animals older than four months are capable of wide dispersal on a regional level (Ragen *et al.* 1995; U.S. Department of Commerce n.d.). Thus, examination of trends in the proportion of animals = 4 months will provide a general indication of if/when rookeries diminish within a large region.

Temporal trends in the archaeological sequences

Examination of the time series of overall age distributions of Oglodax' (Figure 5.25) and Chaluka (Figure 5.26) show little variability through time: the strong positive skew identified for each of the full assemblages is consistent throughout the stratigraphic sequences.

The general stability of these distributions can also be seen in the plots of central tendency of age by stratum. Although both the arithmetic mean and the median have been calculated (Tables 5.1-5.4), I primarily use median age to identify trends in the central tendency of age. The use of median age has two main advantages over the mean (Zar 1996). The first is that the sample median is a "resistant" statistic in that it is only slightly affected by the presence of extreme values. This is particularly important when dealing with skewed distributions, as in the case of the Umnak Island fur seal age

distributions. The second advantage of using the sample median to examine temporal trends in the central tendency of fur seal ages is that both ratio- and ordinal-scale data can be incorporated into the statistic. Thus, while the mean may be biased by the omission of individuals assigned to minimum age categories, the sample median will provide a more accurate measure of central tendency because it is based on the full range of ageable NISP. However, as I will discuss below, neither of these measures of central tendency performs well with small samples.

To illustrate these points, mean and median age for the Oglodax' fur seals have been plotted by stratum in Figure 5.27 (with data from Table 5.1, oldest stratum at the left). In 5.27a, all animals (males, females, sex indeterminate) have been combined to show the composite pattern. The composite mean age shows dramatic fluctuations between Levels 6 and 3, with a generally declining trend through the rest of the sequence. In contrast, the composite median age is relatively stable across this same sequence, fluctuating between 0.52 and 0.68 years.

Examination of Table 5.1 shows why these measures differ so much through the Oglodax' sequence: sample sizes in general are quite small within individual stratigraphic units, and the sex-specific numeric age determinations are biased towards older individuals. Because the age distribution is strongly positively skewed (Figures 5.2 and 5.25), the presence of a few old individuals in Level 5 exerts a stronger influence on calculations of mean age than on calculations of median age. For example, with the omission of the two adult males in Level 5, mean age shifts from 1.915 to 1.357 years, a

decrease of 29%. In contrast, median age shifts from 0.518 to 0.507 years when those same individuals are omitted from the calculations, a decrease of only 2%.

The second point illustrated by the trends in average age at Oglodax' is that calculations of the median can often, but not always, incorporate ratio- and ordinal-scale data. For instance, the composite median age for Level 5 is 0.518 years, regardless of the exact age of the male categorized as "≤ 7 years" (Table 5.1). However, if we focus on the age distribution of a specific sex within any given stratum, the samples for most of the Oglodax' sequence are so small that no measure of central tendency is likely to be very meaningful.

Because the sex-specific and stratum-specific samples are so small for the Oglodax' assemblage, the only additional plot presented here is median age of all YOYs (sex not distinguished: see Figure 5.27b). As with the overall median age, the median age of YOYs is relatively stable throughout the sequence—ranging from 5.3 to 6.7 months.

The results of the Cochran's test for linear trends support the interpretation of a stable age distribution throughout the Oglodax' sequence (Tables 5.12 and 5.13). This is true for the proportion of YOYs relative to the overall distribution ($\chi^2_{trend} = 0.228$; $p = 0.633$) as well as for the proportion of pups relative to all other YOYs ($\chi^2_{trend} = 2.223$; $p = 0.136$). Because expected cell frequencies were less than five for many of the Oglodax' strata, Cochran's test for linear trends was also calculated using combined totals for pairs of adjacent strata (Tables 5.12 and 5.13). The results are not

significant for the overall distribution ($\chi^2_{trend} = 2.179$; $p = 0.140$) or for the distribution of YOYs ($\chi^2_{trend} = 0.137$; $p = 0.711$).

As with the Oglodax' faunas, small samples for individual strata within the Chaluka assemblage hampers interpretation. Levels 2 and 3 show the same strong positive skew to the age distribution (Figure 5.26, Table 5.3). The age distribution of Level 1 is suggestive of a positive skew, but with an ageable NISP of only four, nothing conclusive can be said. In spite of the small sample sizes within strata, median age appears to be stable throughout the entire sequence, both in terms of overall median age (Table 5.3, Figures 5.26, 5.28A) and median age of YOYs (Table 5.4, Figures 5.28b, 5.30).

The other similarity between the Oglodax' and Chaluka assemblages is that Cochran's test of linear trends does not reject the null hypothesis of "no trend among proportions" (Tables 6.12, 6.13). This is true for the proportion of YOYs relative to the overall distribution ($\chi^2_{trend} = 0.002$; $p = 0.964$) as well as for the proportion of pups relative to all other YOYs ($\chi^2_{trend} = 0.469$; $p = 0.493$). Despite the fact that expected cell frequencies are less than five in several cells of the contingency tables, over-estimation of χ^2 does not appear to be a problem in this case, suggesting that there is, indeed, no trend to the age distributions in the Chaluka assemblage.

The Kodiak Island sites are all single-component sites, negating the ability to examine temporal trends. However, as discussed in Chapter 4, Rolling Bay and Kiavak appear to have been occupied until shortly before the onset of the commercial fur trade

(Clark 1974, 1986). Thus, the overall demographic characteristics discussed above were in place at least that late in time.

Little can be said regarding temporal trends in the Cape Flattery sites due to small sample sizes per stratigraphic unit. Tatoosh is the only Cape Flattery site for which sample sizes are adequate to suggest any trends. For the overall age distributions (Table 5.7, Figure 5.31), there appears to be a reduction in average age between the prehistoric and historic components that is driven primarily by the distribution of individuals in the one- to three-year age range.

Within the YOY age class at Tatoosh, median age changes little between the prehistoric and historic strata (Table 5.8). However, examination of Figure 5.32 suggests that the bimodal age distribution discussed above (with modes at four and nine months; see Figure 5.14) does not persist into the historic occupation of the site. Rather, the age distribution in the historic deposits is limited primarily to individuals seven months old and older. This apparent shift will be discussed more fully after the Ozette sequence has been presented.

The value of the large sample sizes from Ozette is particularly evident when analyzing temporal trends for the assemblage. In contrast to the other Washington coast sites, Ozette has sufficient sample sizes, particularly for strata dating to the historic period, to determine when the major changes in fur seal biogeography documented in the first half of this chapter were likely to have occurred.

Examination of the overall age distributions (Figure 5.33) suggests that the main changes post-date AD 1780 (Units I and III), with a dramatic reduction in the frequency

of individuals in the zero to four year age range. However, when the trends in median age are examined (Table 5.9; Figure 5.34A) it appears that the increase in median age associated with the reduction in these age classes actually begins in Unit IV, sometime between AD 1719 and 1780.

The temporal trends in the age distribution of YOYs at Ozette suggests why this might be the case. As discussed before, the age distribution of YOYs for the entire assemblage (Figure 5.17) suggests that there was a fur seal rookery within 50-100 km of Ozette. Examined by stratigraphic unit, it appears that two- and three-month old pups are not encountered after AD 1719 (Unit IV). Specifically, the age distribution of YOYs from Units I-IV (combined in Figure 5.35) suggests that the youngest fur seal pups encountered in the historic strata were four months or older.

In point of fact, the lack of YOYs in the zero-to-four month age range is not statistically significant ($\chi^2_{trend} = 0.632$; $p = 0.427$; see Table 6.13). Even when adjacent strata are combined in order to increase the expected frequencies of pups, Cochran's test of linear trends is not significant for the proportion of pups relative to all other YOYs ($\chi^2_{trend} = 1.456$; $p = 0.228$). In contrast, the proportion of YOYs relative to the overall distribution decreases significantly through time in the Ozette sequence ($\chi^2_{trend} = 8.040$; $p = 0.005$). Even when the strata are combined to produce expected cell frequencies greater than five, the trend is still significant ($\chi^2_{trend} = 5.673$; $p = 0.017$). As pointed out above, the decrease in the proportion of YOYs relative to the

overall distribution is reflected in the increase in median age beginning with Unit IV, sometime between AD 1719 and 1780.

In Chapter 4, I pointed out that the Pribilof Island population of fur seals was severely over-harvested between 1796 and 1840. Because many of the sub-adult males encountered in Washington waters are expected to derive from the Pribilofs, it may be the case that the demographic patterns documented at Ozette were influenced by the harvest practices of the Russians far to the north. If this were the case, individuals from the Pribilofs would be expected to exhibit higher growth rates than individuals from mid-latitude populations under lower levels of harvest rates. This possibility will be examined in Chapter 6.

Interpreting trends in demographic profiles

Because the framework for interpreting the overall demographic profiles has already been established, interpretation of the trends in demographic profiles is relatively straightforward. In general, the site-specific demographic profiles tend to be stable throughout the occupation sequences. The majority of these apparently stable sequences span large portions of prehistory and terminate at or near the period of initial European contacts (e.g., Rolling Bay/Kiavak). In the one instance where sample sizes are large enough to support an interpretation of shifts in demographic profiles (e.g., Ozette), those shifts correspond to the post-contact era.

Interpretations regarding trends in median ages are much more complex because of the wide range of possible harvest scenarios. The general interpretive framework discussed in Chapter 1 was developed in harvests that were either (a) indiscriminate as to

size and age classes harvested, as in small-mesh fish netting, or (b) biased towards larger, older individuals, as in large-mesh fish netting or hand-picking of shellfish. Both of these scenarios are expected to lead to an overall reduction in the average age of the harvested population.

Because of the specifics of the life history patterns of fur seals, a much broader range of harvest scenarios, and their subsequent effects on population structure, are possible. As with the theoretical and empirical examples from the fisheries literature, high levels of culling across all fur seal age classes would be expected to lead to a decrease in overall average ages. However, if culling were focused primarily on YOY fur seals, the affects on average ages of YOYs would be expected to show different patterns depending on context. In the scenario that has historically been assumed to obtain, if only migrating YOYs were targeted, it is unlikely that human harvest pressure would have any effects on the age structure. In contrast, if localized rookeries were being utilized to the point of extirpation, the average age of YOYs would actually *increase* as the proportion of newborns declined.

This is exactly what appears to be happening in the Cape Flattery and Ozette assemblages. Individuals in the one- to three-month old age range are present in low frequencies throughout all of the prehistoric components. Although the lack of individuals in the one- to three-month old age range from the historic strata is not significant in the Ozette sequence, the fact remains that no fur seal rookeries were documented historically along the coasts of British Columbia, Washington, or Oregon

(Scammon 1968; Swan 1870, 1883). Furthermore, the significant decrease in the proportion of YOYs after European contact supports the historic effects hypothesis.