

## **Chapter 1: Introduction to the problem**

The issue of over-exploitation and depletion of natural resources by humans has received increasing attention over the past several decades. While the anthropogenic environmental degradation that has occurred over the past century is certainly dramatic, a wide variety of sources indicates that people have had significant impacts on the environments in which they live for thousands, if not tens of thousands of years (Martin 1967; contributions to Martin and Klein 1984; Martin and Steadman 1999; see also Grayson 2001, Jackson *et al.* 2001, for recent reviews). Although many putative cases of over-exploitation appear to be straightforward (Broughton 1994a, 1994b, 1995; Kay 1994; Nagaoka 1998, 2000; Simenstad *et al.* 1978; Steadman 1995; Steadman and Rolett 1996; Szuter and Bayham 1989), many have also proven elusive (Burton *et al.* 2002; Ford 1992; Grayson 1980, 1984, 2001; Hildebrandt and Jones 1992; Mosimann and Martin 1975; Porcasi and Fujita 2000; Porcasi *et al.* 2000; Woodborne 1996).

Using the Pacific Northwest as a test case, my research examines the long-term relationship between humans and a large-bodied prey species, the northern fur seal (*Callorhinus ursinus*, hereafter referred to simply as fur seal) to determine what effects, if any, human hunting has had on the biogeography of fur seals. Scientists have long recognized discrepancies between historically documented patterns of fur seal migration and breeding and the archaeological evidence of such patterns (Burton 2000; Burton and Koch 1999; Burton *et al.* 2001, 2002; Gustafson 1968; Hildebrandt 1984a, 1984b; Hildebrandt and Jones 1992; Lyman 1988, 1989, 1991b, 1995; Lyon 1937; Walker and Craig 1979). These discrepancies apparently indicate major changes in fur seal

biogeography sometime during the late Holocene. However, neither the extent, the timing, nor the cause (or causes) of these apparent behavioral changes has been determined. While commercial Russian fur trade of the 18<sup>th</sup> and 19<sup>th</sup> centuries is likely to have been significant in this regard (Busch 1985; Orr 1972; Stejneger 1896, 1926), prehistoric hunting may have played a role as well.

This dissertation is explicitly designed to determine the cause or causes of those changes. To do this, three competing hypotheses will be evaluated. The null hypothesis is that prehistoric hunting pressure had no effect on fur seal breeding and migration patterns, with all the biogeographic changes a consequence of the commercial Russian fur trade (hereafter, the “historic effects” hypothesis). Under this hypothesis, fur seal behavioral patterns are expected to either (a) remain stable throughout the archaeological sequences examined, or (b) change in such a way that correlates with the onset of commercial sealing. One alternative to the “historic effects” hypothesis is that prehistoric hunting alone can account for the biogeographic changes mentioned above (e.g., the “prehistoric effects” hypothesis). This hypothesis expects the biogeographic changes to predate the onset of commercial sealing. The other alternative hypothesis that will be tested, the “continuous effects” hypothesis, is that both prehistoric and commercial hunting combined to cause fur seals to change their behavioral patterns. This third hypothesis expects to see a continuum of change in fur seal behavioral patterns from the prehistoric into the historic period.

Because climatic events can affect pinniped populations in much the same way as harvest pressure, all three of these hypotheses require simultaneous evaluation of the

effects of climatic change. Although it is possible to measure the effects of climate change on pinniped populations directly via stable isotope analysis (Burton *et al.* 2001, 2002), results of analyses for samples submitted for the research presented here are still pending. Consequently, I will rely on published paleoclimatic records to determine the potential role of climatic events in structuring the archaeological record of pinniped biogeography (see Chapter 7).

I test the three competing hypotheses using data derived from archaeological samples of fur seal skeletal material from throughout the eastern North Pacific (Figure 1.1). The specific variables I utilize to evaluate these hypotheses are demographic profiles and growth rates. These variables, discussed more fully throughout this chapter, are first used to determine to what extent the biogeographic patterns have changed. Based on this information, the trends and timing of any apparent changes are used to identify the most likely causal factor or factors in those changes.

### **Background to the problem**

Due to the economic importance of fur seals, these pinnipeds have figured prominently in both archaeological and contemporary biological studies on the west coast of North America (Burton and Koch 1999; Burton 2000; Burton *et al.* 2001, 2002; Corbett *et al.* 1997; Gustafson 1968; Lippold 1966; Lyon 1937; Scheffer *et al.* 1984; Swan 1870, 1883, 1887). Although paleontological specimens dating to the Holocene are rare (Berta and Deméré 1986; Kohno and Yanagisawa 1997; Reppenning *et al.* 1971; Reppenning *et al.* 1979), archaeological specimens of fur seals have been recovered in sites from Alaska to California, in contexts as old as 4,300 years (Carlson 1979; see

Figure 1.1 and Table 1.1). Despite a long recognition that major changes in fur seal biogeography have occurred within the past 100-300 years (Gustafson 1968; Lyman 1988, 1989, 1991b, 1995) and, indeed, continue to occur (Etnier 2002; Loughlin 1985; Loughlin and Miller 1989; Orr 1972; Peterson *et al.* 1968; Pyle and Long 2001; Sydeman and Allen 1999), fur seal remains recovered in archaeological sites are often interpreted as if fur seal distributions have been stable throughout the late Holocene (Calvert 1980; Carlson 1979; Clark 1974, 1986; Corbett *et al.* 1997; Croes and Hackenberger 1988; Greenspan 1986; Huelsbeck 1994; Minor *et al.* 1987; Yesner 1977, 1988).

The long history of fur seal use on the west coast of North America has contributed, at least in part, to many long-standing assumptions about the nature of their exploitation by humans. Of primary importance is the assumption that throughout some 10,000 years of use, fur seals would have been accessible only during their spring and fall migrations in the open ocean as they traveled to and from the uninhabited breeding grounds in the central Bering Sea (Clark 1974, 1986; Gustafson 1968; Laughlin 1972; Scheffer 1958; Yesner 1988; see Figure 1.2). In fact, archaeological evidence from California and Oregon suggests that the breeding distribution of fur seals was much more extensive in the late Holocene than at European contact (Burton 2000; Burton *et al.* 2001, 2002; Hildebrandt 1984a; Hildebrandt and Jones 1992; Lyman 1988, 1989, 1995; Pyle and Long 2001). Furthermore, beginning in the late 1960s, fur seals have been dramatically expanding their breeding distribution into areas outside their historically documented range (Orr 1972; Loughlin 1985; Peterson *et al.* 1968), adding credence to

the possibility of a more extensive distribution in the past. This, in turn, further calls into question the validity of the assumption that fur seals would have only been accessible for exploitation by coastal communities during their spring and fall migrations.

A closely related assumption is that, if fur seals were only encountered in the open ocean along the continental shelf, human predation would have had little or no impact on their numbers and behavior (Clark 1974, 1986; Gustafson 1968; Laughlin 1972; Yesner 1988, 1992). However, fur seals are relatively large-bodied prey items with low reproductive potential (York and Hartley 1981). As such, they typify the kinds of animals that are highly sensitive to over-exploitation (Fowler 1987; Pimm *et al.* 1988; Scheffer 1955; Winterhalder and Lu 1997). Although the susceptibility to over-exploitation will be a function of the context in which fur seals were hunted (e.g., terrestrial vs. pelagic: Busch 1985; Etnier 1999; Starks 1922), it is fully possible that human exploitation over the past 10,000 years may have affected fur seal populations regardless of what the breeding and migratory distribution may have been (cf. Porcasi *et al.* 2001).

These two assumptions have played a critical role in the interpretation of fur seal exploitation in archaeological subsistence economies in sites from California to western Alaska (Carlson 1979; Corbett *et al.* 1997; Lyon 1937). However, for the coastal areas north of Oregon, neither of these assumptions has been rigorously evaluated. If either, or both, of these assumptions can be demonstrated to be invalid, the role of fur seal remains in interpretations of human impacts on marine mammal populations (Holland 1992; Laughlin 1972; Yesner 1988, 1992), seasonality studies (Calvert 1980; Clark 1974,

1986; Croes and Hackenberger 1988; Huelsbeck 1983), and explanations of human social structure (Ames 1985, 1994; Arnold 1992; Colton and Arnold 1998; Hildebrandt 1984a; Hildebrandt and Jones 1992; Lyman 1988, 1989, 1991b; Minor *et al.* 1987) will need to be reconsidered for the entire Northwest Coast.

### **Previous research**

In spite of the remarkable potential for interdisciplinary research combining archaeology and marine mammalogy in the eastern North Pacific, relatively few studies have done so. Consequently, any discussion of previous work related to the long term effects of human hunting on fur seals must, by necessity, deal with two topics separately: the specifics of fur seal ecology as it is currently understood, with particular reference to recent changes in breeding distribution, and the history of fur seal exploitation as evidenced by the archaeological record. Interpretations of changing patterns in one are meaningless unless viewed in the context of the other.

### **Natural history of northern fur seals**

Northern fur seals belong to the sub-family Arctocephalinae, within the otariid family of pinnipeds (the eared seals; see Wynen *et al.* 2001 for a recent review of Otariid phylogeny). There are eight species of fur seal worldwide, all of which have similar breeding habits (Scheffer 1958; King 1983). The biggest behavioral difference between the northern fur seal (*Callorhinus ursinus*) and the seven species of southern fur seals (*Arctocephalus* spp.) is that northern fur seals are by far the most pelagic species, spending as many as ten months of the year living at sea (Gentry 1998). Consequently, many aspects of their behavior are unique.

Prior to 1968, the behavioral patterns of the northern fur seal were explained based on observations of the Pribilof Islands, AK population (Figure 1.2) made throughout the historic period. This pattern is easily summarized.

After spending a winter in the open oceans off the west coast of North America, northern fur seals congregate on isolated islands in the Bering Sea and eastern North Pacific (Fiscus 1978; Gentry 1998; Lander and Kajimura 1982; Scheffer 1958; see Figure 1.2). Almost without exception, these islands have been, and remain today, uninhabited by humans or other large terrestrial carnivores.

The mature males arrive at these islands in May, followed by mature females in June and July. Fur seals are polygynous, with each adult male maintaining "harems" of 6 to 20 females (Gentry 1998). Immediately after the female decides on a mate, she gives birth to the pup from the previous year's mating. Within hours of parturition, she is ready to mate again. Although the egg is fertilized immediately, the implantation of the embryo is delayed several months. After implantation, the gestation period is approximately nine months, resulting in a full twelve-month cycle between births (Scheffer 1958).

The sub-adult males and females arrive at the islands throughout the summer and into autumn (Bigg 1986). The mature males begin to depart in August, while all other age and sex classes typically remain on the islands until November (Figure 1.3). Apart from time spent on these isolated islands during the breeding season, fur seals are almost wholly pelagic during the rest of the year (Baker *et al.* 1963).

Two distinct types of aggregations form during the breeding season. First, sub-adult and senescent males congregate in large groups at "haul-outs," a general term used

to indicate places where seals come ashore for non-reproductive purposes. Second, breeding males and females with their newborn pups form rookeries. It is not known where sub-adult females spend most of their time prior to reaching reproductive age, but it is known that they do not often come ashore (Kajimura 1980; Gentry 1998).

After the breeding season is over, all of the seals leave the islands (Figure 1.3). Adult males leave first, but tend to stay in the Bering Sea and Gulf of Alaska throughout the winter (Loughlin *et al.* 1999). Adult females leave next, followed by non-breeding males and females, migrating south along the continental shelf as far as Baja California (Fiscus 1978; Gentry 1998; Scheffer 1958; see Figure 1.2). Typically the last seals to leave the islands are the newly-weaned pups, at an age of 4 to 6 months (Gentry 1998; Ragen *et al.* 1995). The reasons for these differences in migration are not fully understood, but they probably relate to the differences in water temperature of the Alaska and the California currents, the relationship between heat loss energetics and body size of fur seals, and availability of different prey species (Loughlin *et al.* 1999).

Until relatively recently, there was no reason to suspect that this pattern had been different at any time since stabilization of sea levels during the late Holocene (Bloom 1983a, 1983b; Fladmark 1979, 1983; Repenning *et al.* 1979; Starks 1922). In the late 1960s, however, biologists made a remarkable discovery on San Miguel Island, off the coast of southern California (Figures 1.1, 1.2). For the first time in recorded history, northern fur seals were found breeding in the eastern Pacific south of the Aleutian chain. What made this so remarkable is that the locality of the newly established rookery was thousands of miles south of the known breeding range (Orr 1972; Peterson *et al.* 1968).

Based on the presence of tagged adult females, the San Miguel population appears to have been founded by individuals from the Pribilof Islands in the eastern North Pacific as well as the Commander Islands in the western North Pacific (Peterson *et al.* 1968; Peterson and LeBoeuf 1968). Because the adult males typically do not migrate south of the Gulf of Alaska (Loughlin *et al.* 1999), it is not known from which stock or stocks they originated.

In addition to uncertainties regarding the origin of the breeding males at San Miguel, it is still not known how the migration patterns of the San Miguel population differ from the Pribilof population. One opinion holds that the San Miguel population is essentially non-migratory, remaining at mid-latitude throughout most or all of the year (Gentry 1998; Lander 1979). In contrast, another opinion holds that fur seals breeding at mid-latitude would follow the same general migration pattern of other mid-latitude pinnipeds (DeLong *pers. com.*), wherein adult females and sub-adults of both sexes remain at mid-latitude throughout the year, while adult males head north for fall and winter. It is important to note, however, that there are virtually no data to support either of these opinions.

Since the establishment of the San Miguel rookery, scientists have been struggling to explain similar changes in the breeding distribution and migration patterns of other marine mammal species in the North Pacific (for sea otters, see Bodkin *et al.* 1994, Kenyon 1969, Kuzin *et al.* 1984 and Simenstad *et al.* 1978; for Guadalupe fur seals, see Etnier 2002, Hanni *et al.* 1997, Hubbs 1979, Hubbs and Norris 1971, Lyon 1937, and Pyle and Long 2001; for northern elephant seals, see LeBoeuf *et al.* 1974, LeBoeuf and

Mate 1978, Pyle and Long 2001, and Radford *et al.* 1965; for Steller's sea lions, see Bigg 1985, Kuzin *et al.* 1977, and Kuzin *et al.* 1984). While the majority of these distributional changes can be attributed to population rebounds following cessation of the commercial fur and oil harvests in the early 1900s (Busch 1985; King 1983; Orr 1972), the case of the northern fur seal is not so clear-cut. Despite the fact that their breeding distribution has been expanding over the past several decades (Chugunkov 1971; Lloyd *et al.* 1981; Peterson *et al.* 1968, Voronov 1974), the fur seal population has decreased over 50% since the 1950s (Antonelis *et al.* 1990; Gentry 1998; contributions to Sinclair 1993; Trites 1992a; see Figure 1.4). Furthermore, many of the new breeding colonies are outside of the historically-documented breeding distribution (Peterson *et al.* 1968; Sydeman and Allen 1999). Consequently, an alternative explanation for the recent changes in the distribution of fur seals seems necessary. Archaeological analyses of fur seal remains hold the potential to address this issue.

Indeed, a possible explanation for the discrepancies between the newly-established and the historically-documented breeding distributions derives from the archaeological analysis of historic sealing camps from the Farallon Islands, just off-shore from San Francisco (Pyle and Long 2001). Historic accounts and shipping logs indicate that fur seals were harvested there by the thousands in the early decades of the 19<sup>th</sup> century (Bancroft 1885; Elliott 1887), but do not indicate the particular species of fur seal involved. Due to the fact that most of these seals were taken in the summer months, when most northern fur seals would be in the central Bering Sea, it was long assumed that the fur seals harvested in the Farallons represented *Arctocephalus townsendi*, the

Guadalupe fur seal (Fleischer 1978; Starks 1922). Pyle and Long's (2001) analysis of archaeological fur seal remains resolves the issue for the case of the Farallon Islands: virtually all of the pinniped remains recovered in the excavations are northern fur seals. Furthermore, the bones of newborn pups were abundant, clearly indicating that northern fur seals were breeding at the Farallon Islands, presumably until the population was eradicated in the 1830s (Pyle and Long 2001; Starks 1922).

Pyle and Long's results are likely to have profound implications for archaeofaunal analyses involving fur seals on the west coast of North America. The presence of a breeding colony of northern fur seals at the Farallon Islands until the early 1800s provides simultaneous explanations for the presence of adult males at low latitudes (Gustafson 1968) as well as pups younger than 4 to 6 months old along the coast of California and Oregon (Burton 2000; Burton *et al.* 2001, 2002; Calvert 1980; Lyman 1988, 1989, 1991b, 1992, 1995). Nevertheless, archaeological sites with an abundance of northern fur seals need to be evaluated on a case-by-case basis to evaluate the degree to which their breeding distributions have changed, as well as the timing and likely cause or causes of those changes.

### **Culture history of fur seal exploitation**

As alluded to above, the archaeological presence of fur seal remains on the west coast has been, with few exceptions, interpreted in terms of the migration and breeding patterns of the Alaska fur seal populations. It is often argued, for instance, that because fur seals would have only been encountered pelagically, human predation would have had little or no direct effect on fur seal populations (Clark 1974, 1986; Gustafson 1968;

Laughlin 1972; Yesner 1988, 1992). For this reason, Yesner (1992) argues that changes in the abundance of fur seals in Aleutian Island archaeological sites are best explained by a change in an unidentified environmental parameter.

The assumption that fur seal breeding and migratory behavior have been stable also pervades archaeological seasonality studies (Calvert 1980; Croes and Hackenberger 1988). Croes and Hackenberger (1988:42), for instance, interpreted the presence of fur seals at the Ozette Village site (45 CA 24; Olympic Peninsula, Washington), as indicative of a spring occupation. Of course, if the migratory and/or breeding behavior of northern fur seals were different during the Ozette occupation than now, this interpretation might well be wrong.

Finally, it has been argued that because fur seals today are primarily pelagic in waters south of the Aleutian archipelago, the archaeological presence of fur seals would indicate the use of ocean-going canoes (Greenspan 1986; Minor *et al.* 1987). The maintenance of ocean-going canoes, the argument continues, would require an extensive social and political infrastructure. Indeed, marine mammal exploitation has played a central role in models attempting to explain the development of cultural complexity in Northwest Coast societies (Ames 1985, 1994; Arnold 1992; Minor *et al.* 1987; Porcasi and Fujita 2000; Porcasi *et al.* 2000). However, as Lyman (1988, 1989, 1991b, 1995) has argued extensively, exploitation of fur seals in California and Oregon would not necessarily require sea-worthy vessels, or an extensive social and political infrastructure. Indeed, efficient exploitation of fur seals in terrestrial contexts could have been

accomplished with technology little more sophisticated than clubs and spears (Sauer 1802; Starks 1922; Swan 1870, 1887).

There are good reasons for the heavy reliance that archaeologists have placed on assumptions about the antiquity of fur seal behavioral patterns, especially breeding distribution. In many cases, the archaeological analyses predate the discovery of the San Miguel rookery (Gustafson 1968; Lyon 1937), thus eliminating any basis for suspecting late Holocene changes in breeding distribution. Gustafson noted the presence of adult male fur seals in the Ozette assemblage, but attributed this to recent changes in migratory, rather than breeding, behavior (Gustafson 1968:49). More recent analysts have lacked access to extensive comparative collections, particularly those that have juvenile fur seals well-represented (Calvert 1980; Huelsbeck 1983). For this reason Calvert (1980) interpreted the presence of foetal/newborn fur seal remains in Vancouver Island archaeological sites as indicative of spring/early summer exploitation of migrating seals, though she acknowledged that the presence of developmentally young fur seals might possibly represent a breeding rookery, suggesting instead summer or fall exploitation patterns (Calvert 1980:223).

Apart from these few studies, the majority of the archaeologists studying fur seal material from sites in Washington, British Columbia, and Alaska have relied, either implicitly or explicitly, on the assumption that modern fur seal breeding distribution (Clark 1986), migration patterns (Carlson 1979) or both (Yesner 1988, 1992) have been relatively stable over the past several thousand years.

Fur seal research in Oregon and California stands in stark contrast to research conducted in other areas of the eastern North Pacific. Specifically, Hildebrandt (1981, 1984a, 1984b), Hildebrandt and Jones (1992), Lyman (1988, 1989, 1995), and Burton and colleagues (Burton 2000; Burton and Koch 1999; Burton *et al.* 2001, 2002) have used archaeological data from California and Oregon to challenge the assumption that fur seal behavioral patterns have been static. Hildebrandt (1984a), for instance, demonstrated that the migratory patterns of adult male northern fur seals have changed at some point over the past 1000 years. Although Gustafson (1968) came to the same conclusion based on evidence from Ozette, Hildebrandt uses this information, along with ethnographic data, to conclude that fur seals were breeding at selected mainland and offshore rookeries along the coast of California in the recent past (Hildebrandt 1984a).

Lyman (1988, 1989, 1995), and more recently, Burton and colleagues (Burton 2000; Burton and Koch 1999; Burton *et al.* 2002) have used a much more direct approach to identify areas along the Oregon coast with prehistoric fur seal rookeries. Using extensive comparative skeletal material, they were able to assign archaeological specimens to age and sex categories more precisely than either Gustafson (1968) or Calvert (1980; see also Smith [1979, 1985] for an identical analytical approach for New Zealand fur seal, *Arctocephalus forsteri*, distributions). The Oregon archaeofaunas examined by Lyman showed evidence of adult and sub-adult female, adult and sub-adult male, and newborn (e.g., less than 4 months old) fur seals in archaeological deposits dating between 3000 and 200 years ago. Likewise, the middle- to late-Holocene archaeofaunas from central and northern California analyzed by Burton and colleagues

showed clear evidence of adult females and newborn fur seal pups (Burton 2000; Burton and Koch 1999; Burton *et al.* 2002). If the pattern of fur seal behavior were the same then as it is now, there should have been few, if any, adult males and there should have been no juveniles younger than 6 to 7 months of age (Fiscus 1978; Gentry 1998; Scheffer 1950d, 1958; see Figures 1.2, 1.3). Based on this information, the obvious conclusions are that fur seals were breeding on the Oregon and California coasts in the recent past, that people were utilizing fur seals from these rookeries, and that these breeding populations were extirpated prior to documentation by European naturalists.

One of the limitations of the recent biogeographical research that has been conducted on the Oregon and California coasts is that, while it has been demonstrated that both the migration and breeding distributions of fur seals have changed in the recent past, it has been impossible to determine *why* these changes may have occurred. This has been due to a pair of related problems. The first is that very little information is available concerning the degree to which migration and breeding distributions have changed or, for that matter, when those changes may have occurred. The second problem, which in large part sets the stage for the first, is that despite ca. 200 years of biological research on fur seals (Scheffer *et al.* 1984), little effort has been made to develop variables relevant to monitoring and explaining changes in fur seal distributions on ecological time scales. With an increasing recognition that variables utilized in ethological studies (e.g. direct population censuses, reproductive rates, growth rates, scat and stomach content analyses) are inapplicable to archaeological data, archaeologists are left with little choice but to develop relevant variables themselves. By way of example, the comparative skeletal

research collections housed at the National Marine Mammal Laboratory (NMML) in Seattle contain over 300 known-age fur seal skulls of both sexes (see Appendix A). This series of crania has been crucial to documenting variability in morphology (Scheffer and Wilke 1953; Wilke 1951) and growth (Scheffer 1950a, 1950b, 1950c, 1955; Scheffer and Kraus 1964). Thus, in terms of ethological studies, biologists have been able to accomplish all of their research goals through the analysis of cranial material. In contrast, at the start of this project in 1998 the post-cranial holdings in the NMML collections consisted of only four known-age skeletons, with similar discrepancies in cranial vs. post-cranial holdings observed in the other major fur seal research collections throughout the country (e.g., California Academy of Sciences, Smithsonian Institution). The end result is that it has been difficult or impossible for archaeologists to adequately characterize fur seal remains from archaeological sites. For instance, if Calvert (1980) had had access to more complete comparative collections, she may have been able to make more precise age determinations, and more secure seasonality determinations.

A significant portion of this dissertation develops variables from reference skeletal material that can be applied directly to archaeological analyses. Until we have a means for characterizing the nature, extent, and timing of the changes in fur seal biogeography in the late Holocene, there is little or no hope of determining what caused those changes. I will utilize two different variables to accomplish this: demographic profiles and growth rates. The rationale for choosing these variables and the specific expectations under the competing hypotheses will each be discussed in turn.

### **Demographic profiles**

Analysis of the demographic composition, or harvest profiles, of archaeological fur seal remains is perhaps the most intuitively straightforward means of delimiting their breeding distribution (Calvert 1980; Lyman 1988, 1989, 1991b, 1995; Porcasi *et al.* 2000; Smith 1985; Woodborne 1996). Although it is impossible to control for sampling biases that can be introduced through cultural preferences of the *hunters* on the one hand and sex-specific escape behavioral patterns of the *hunted* on the other (Lyman 1988, 1989), harvest profiles based on skeletal remains can nevertheless provide valuable information regarding the local availability of different age- and sex-classes. As with any archaeological measure based primarily on presence/absence data, interpretations regarding demographic profiles are asymmetric: the archaeological presence of a particular age class indicates they were locally available; the archaeological absence of that age class is ambiguous (Ervynck 1999; Grayson 1981).

The analysis of harvest profiles will serve two primary functions. The first is to help identify the presence of possible rookery sites. The presence of adults is certainly necessary for breeding colonies. Thus, maximum ages of both sexes will be examined on a site-by-site basis. However, the only truly conclusive evidence of rookery sites is the consistent presence of pre-weaned pups (Lyman 1988, 1989, 1991b, 1995). Due to the difficulty in identifying nursing status based on skeletal remains, however, the approach used here will be to estimate age-at-death from the skeletal remains. The minimum ages will then be compared to the available data on average age of weaning (DeLong 1982; Gentry 1998) to determine the likelihood that a nearby rookery was being exploited at a

particular archaeological site (*a la* Burton 2000; Burton and Koch 1999; Burton *et al.* 2001, 2002; Parkington 1972; Smith 1985; Woodborne 1996).

Under the null hypothesis of “historic effects,” any significant changes in the maximum and minimum ages of fur seals represented in the archaeofaunas are expected to post-date the onset of the commercial fur trade in the eastern North Pacific (Busch 1985; Clark 1986). As noted before, this approach assumes no significant changes in cultural hunting preferences or in escape behavior patterns of the fur seals. In contrast, if prehistoric hunting had a significant effect on fur seal migration and breeding distributions, any changes in maximum and minimum ages are expected to either occur prior to the onset of commercial sealing (the “prehistoric effects” hypothesis) or represent a continuum of change that culminates with the onset of commercial sealing (the “continuous effects” hypothesis).

In addition to maximum and minimum ages of the fur seals being exploited, the harvest profiles also provide valuable information on the presence of trends in the central tendency of the age and size of fur seals being exploited (generically referred to as “average,” with arithmetic mean and median distinguished, as appropriate). A wide range of theoretical and empirical studies of resource exploitation indicates that as harvest intensity increases, the average age and size of individuals in the exploited population will decrease (Beverton and Holt 1957; Caughley 1966, 1977; Swadling 1976). Thus, under the “historic effects” hypothesis, average age and size are not expected to decrease significantly until commercial sealing begins.

## **Growth rates**

In addition to predictable changes in the age- and size-composition of a population with increasing levels of harvest intensity, individual fur seals are also expected to show variability in growth *rates* as a function of population density. If carrying capacity (K) is stable, growth rates should scale with population size. Specifically, individual fur seals living in populations maintained at or near K are expected to grow more slowly than individual fur seals living in exploited populations (Caughley 1966, 1977; Fowler 1990; Scheffer 1955). Individual growth rates are expected on theoretical grounds to be maximized at harvest levels anywhere between K and K/2 (Caughley 1966, 1977), a fact that limits the resolution with which variability in population size can be detected. Nevertheless, variability in growth rate represents one of the only tools available to archaeologists for measuring relative population levels of an economically important taxon.

As with the expected patterns in demographic profiles, growth rate is expected to be stable under the “historic effects” hypothesis until the onset of commercial sealing. Once commercial sealing starts in the eastern North Pacific, growth rates are expected to increase significantly due to the extremely high harvest rates documented historically (Bancroft 1885; Busch 1985; Elliott 1887; Stejneger 1896, 1926). However, if the fur seal population(s) were already maintained at levels below K through prehistoric harvest pressure, the relative effects of the commercial harvest on growth rates are expected to be minimal. This will be true for either the “prehistoric effects” or the “continuous effects” hypotheses.

The measurement of growth rate will be accomplished through comparison of growth curves developed from mandibular measurements of known-age individuals (see Chapter 3). For the modern reference sample, age-determinations derive from tagging and growth studies from throughout the 20<sup>th</sup> century (Osgood *et al.* 1915; Scheffer *et al.* 1984). In contrast, all of the age-determinations for the archaeological samples will be accomplished via examination of sectioned canine teeth (following Scheffer 1950b).

### **Summary**

The idea that archaeofaunal remains can be utilized to examine long-term patterns of resource exploitation is not new. Even with the specific case of northern fur seals, zooarchaeologists have recognized the potential contribution of this approach for 65 years (Lyon 1937). However, it has only been relatively recently that comparative collections and analytical methods have developed to the point where we can hope to explain changing patterns of fur seal exploitation.

The specific approach adopted here will be to examine a suite of widely-held assumptions regarding the stability of fur seal behavioral patterns in the eastern North Pacific. This will require the development of two inter-related variables from modern reference collections (Chapters 2 and 3). Once this is accomplished, the question of what might have caused the apparently major changes in fur seal migration and breeding patterns in the late Holocene can be addressed through the analysis of archaeological fur seal remains (Chapters 5 and 6). As discussed above, the Russian commercial fur trade of the 18<sup>th</sup> century is often implicated in these changes (Busch 1985; Lyman 1988, 1989, 1991b). However, the capacity for hunter-gatherer economies to negatively impact the

surrounding environment has been demonstrated in numerous different settings (Broughton 1994a, 1994b; Grayson 2001; Jackson *et al.* 2001; Nagaoka ; Smith 1985). Thus, the possibility that prehistoric human hunting affected the northern fur seal population(s) negatively needs to be explored. This would be the case particularly if local rookeries were being exploited (Etnier 1999; Jones and Hildebrandt 1995; Hildebrandt and Jones 1992; Porcasi *et al.* 2000). It is important to note, however, that migrating populations of fur seals could have been subjected to predation pressure by humans along most or all of the migration route along the coast of western North America. Consequently, it is possible that the cumulative effects of prehistoric hunting may have played a role in structuring the fur seal behavioral patterns documented in historic times (Porcasi *et al.* 2000).

The results of my research hold significance for archaeologists and zoologists alike. For archaeologists, my results will add to a growing body of data regarding the variability in fur seal exploitation patterns across space and through time. Furthermore, they will serve to underscore the necessity of evaluating exploitation patterns on a site-by-site basis, while at the same time emphasizing the need to consider patterns that are only evident at a much larger scale. The benefits to the zoological community will hinge on the ability to identify the causal mechanism(s) behind the changes in fur seal distributions in the late Holocene. If this is accomplished, resource managers will be in a much better position to manage current populations of pinnipeds in the eastern North Pacific in the face of increasing interactions between a burgeoning human population, global climate change, and the various species of pinniped affected by these changes

(Anderson 2001; DeMaster *et al.* 2001; Gerber and VanBlaricom 2001; Gerber *et al.* 1999; Harwood 2001; Hofman 1995; Trillmich and Ono 1991).