



# Defining and identifying sustainable harvests of resources: Archaeological examples of pinniped harvests in the eastern North Pacific

Michael A. Etnier<sup>a,b,\*</sup>

<sup>a</sup>Applied Osteology, Bellingham, WA 98227-0092, USA

<sup>b</sup>Department of Anthropology, Box 353100, University of Washington, Seattle, WA 98195-3100, USA

Received 22 January 2007; accepted 28 April 2007

## KEYWORDS

*Callorhinus ursinus*;  
Harvest profiles;  
*Phoca vitulina*;  
Pinnipeds;  
Resource depression;  
Sustainability;  
Zooarchaeology

## Summary

Archaeologists and resource managers are starting to recognize the value of studying ancient cultures for examples of how resources have, and have not, been sustainably utilized in the past as a way of understanding current trends in environmental degradation. These studies do not provide sweeping generalizations about aboriginal resource use but, rather, identify the range of conditions under which sustainable harvests may be possible. The hypothesis of sustainable harvests must be tested using variables that can be measured equally well in ancient (e.g., archaeological) and modern contexts.

These factors are carefully considered in this analysis of pinniped (seal and sea lion) remains from two archaeological sites on the eastern North Pacific (ENP) coast, where pinnipeds have been hunted for millennia. Reconstruction of the age composition, or harvest profile, of *Callorhinus ursinus* at the Ozette Village Site, Washington, shows that males and females of all ages were harvested, and supports the hypothesis that it was done so sustainably for over 500 years. After this period of apparent stability, *C. ursinus* abandoned local breeding colonies in the early historic period. In contrast, harvests of this species at the Moss Landing Hill Site, California, primarily targeted young of the year, and sub-adult and adult females. While this harvest is also inferred to have targeted a local breeding colony, *C. ursinus* appear to have been extirpated nearly 2000 years earlier at Moss Landing than at Ozette.

The causes of these extirpations are not known, but the timing does not correspond well with known climatic changes, suggesting that subsistence, and perhaps commercial, hunting may have played a role. These examples underscore the need to recognize that patterns of resource use are highly variable – different cultures

\*Corresponding author at: Department of Anthropology, Box 353100, University of Washington, Seattle, WA 98195-3100, USA.  
E-mail address: [metnier@u.washington.edu](mailto:metnier@u.washington.edu).

have had varying levels of effects on economically important species, and these effects have varied temporally, spatially, and taxonomically.

© 2007 Elsevier GmbH. All rights reserved.

## Introduction

As environmental degradation and the clear need for sustainable resource use in modern times emerges (Callicott & Mumford, 1997; Fowler & Hobbs, 2003; Goodland, 1995), more and more researchers are turning to the past for evidence of historical precedents, both among hunter gatherers (Grayson, 2001) and horticulturalists (Briggs et al., 2006). Analyses of historical time periods often indicate that unsustainable use of resources is the norm in market economies (Busch, 1985; Jackson et al., 2001; Krech, 1984). Anthropological and archaeological analyses of subsistence economies show much more varied results: some point to long-term sustainability (Butler & Campbell, 2004), while others argue that over harvest of resources is the norm in subsistence, as well as market, economies (Alvard, 1998; Broughton, 1994a, 1994b; Grayson, 2001; Kay, 1994; Martin, 1967; Mosimann & Martin, 1975; Nagaoka, 2005, 2006; Porcasi, Jones, & Raab, 2000). Still others suggest that evidence for or against sustainability of subsistence economies hinges on the spatial scale examined (Butler & Campbell, 2004; Lyman, 2003). Here, I present harvest data of pinnipeds (seals and sea lions) spanning the last 2500 years from the eastern North Pacific (ENP). These data show that, rather than conforming to broad generalizations, cultural patterns of resource use are, in fact, highly variable – different cultures have had varying levels of effects on economically important species and these effects have varied temporally, spatially, and taxonomically. Determining the patterning to this variation can inform modern resource management issues.

As Butler & Campbell (2004) have noted, archaeological examinations of resource use have suffered from the inconsistent use of terminology. In this analysis, two key terms will be used as follows:

*Resource Depression:* A decline in the encounter rate of a prey species caused by the activities of the predator (Charnov, Orians, & Hyatt, 1976);

*Sustainability:* The use of a resource in such a way that allows stable harvest rates into perpetuity.

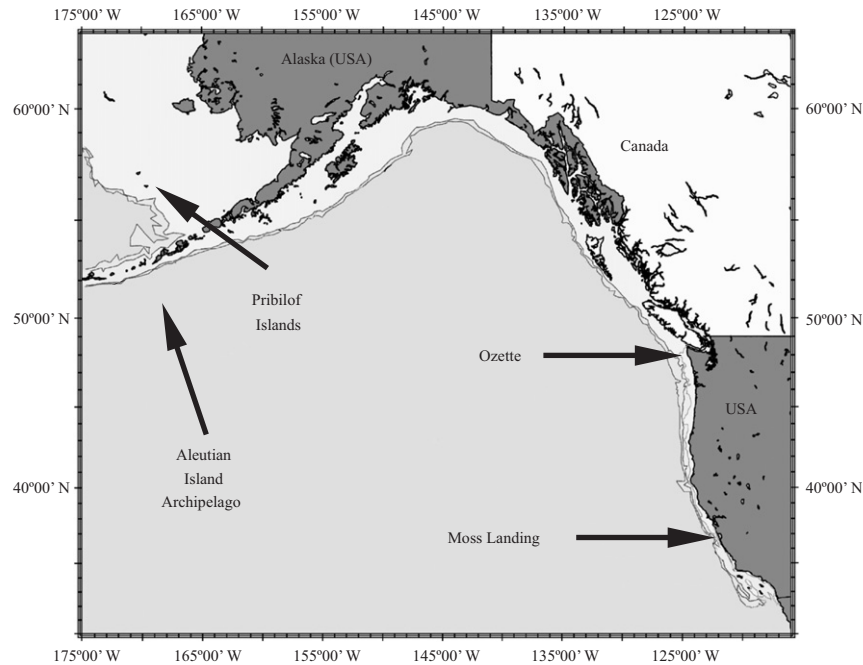
As the search for precedents of sustainable resource use expands to include more analyses of archaeological remains, the problem of how to

measure these phenomena looms large. The challenge lies in trying to evaluate the degree to which harvests of a particular resource were or were not sustainable. Several archaeological measures have been proposed, but the use of relative abundance indices is perhaps the most common (Bayham, 1979; Broughton, 1994a, 1994b; Butler & Campbell, 2004; Cannon, 2000; Nagaoka, 2005, 2006). These indices are used to infer whether or not resource depression, or a decline in encounter rates, has occurred for high-ranked prey items, and either implicitly or explicitly equate resource depression with unsustainable harvest intensity.

A more direct measure of harvest intensity is the age composition of the prey species being targeted (Koike & Ohtaishi, 1987; Lyman, 1987). Theoretical and empirical studies in wildlife management indicate that a general increase in harvest intensity will lead to a decrease in the average age and size of individuals in the exploited population (Beverton & Holt, 1957; Caughley, 1977). If, however, a specific sex or age class is differentially targeted, the outcome may differ from this generalized pattern. For instance, if local breeding is disrupted, recruitment into the population will be restrained and the average age may actually increase (see below). Thus, the hypothesis that a particular population or sub-set of a population was being over harvested can be tested if the age composition of the harvest can be quantified using archaeofaunal remains. Tests of the over-harvesting hypothesis are particularly powerful if temporal trends in age data can be generated for a single archaeological site, but data representing a single point in time are also useful for regional comparisons.

## Methods

Pinniped bones were examined from two archaeological sites from the Pacific Coast of the United States: the Ozette Village Site (45-CA-24), located on the northwest tip of the Olympic Peninsula, Washington, and the Moss Landing Hill Site (CA-MNT-234), located approximately at the centre of Monterey Bay, California (Figure 1). While it cannot be determined if the animals represented by the bones were actively hunted or scavenged (Gifford-Gonzalez et al., 2005), the contexts from



**Figure 1.** Map of eastern North Pacific, showing locations of place names mentioned in text. Isobaths indicate continental shelf.

**Table 1.** Pinniped species commonly encountered in the eastern North Pacific south of the Aleutian Islands. Taxonomy follows Wilson and Reeder (1993). See text for discussion of migration/dispersal patterns and period of pup dependency for each species

Species	Period of pup dependency	Migratory?
<i>Phoca vitulina</i> (Linnaeus, 1758)	1 month	No
<i>Mirounga angustirostris</i> (Gill, 1866)	1 month	Semiannual
<i>Callorhinus ursinus</i> (Linnaeus, 1758)		
modern	4 months	Alaska: yes; California: unknown
ancient	6–9 months?	Alaska: yes; Washington/Oregon/California: no
<i>Arctocephalus townsendi</i> (Merriam, 1897)	9–12 months	No
<i>Eumetopias jubatus</i> (Schreber, 1776)	12–24 months	No
<i>Zalophus californianus</i> (Lesson, 1828)	12–24 months	No

which the bones were recovered, plus the systematic distributions of cut marks on the bones, strongly suggest that most, or all, of the pinniped bones are the remains of past human meals (Huelsbeck, 1994; Milliken, Nelson, Hildebrandt, & Mikkelsen, 1999). For this analysis, I assume that the relative abundance of different species, sexes, and age classes of pinnipeds are represented in the archaeological collections in proportion to their past availability. I further assume that relative predation on the species, sexes, and age classes involved did not change over the time period studied. Finally, I assume that the bones recovered from the archaeological sites represent animals har-

vested within tens of kilometres from the sites, and do not represent the long-distance transport of carcasses from other areas.

Six pinniped species are commonly encountered in the ENP south of the Aleutian Island Archipelago (Table 1). Today, the geographic ranges of these six species overlap in central and southern California (Angliss & Outlaw, 2007; Carretta et al., 2007). In the past, the ranges overlapped in Oregon and Washington as well (Etnier, 2002a). Note that only two of these species are migratory – northern elephant seals, *Mirounga angustirostris* (Gill, 1866), and the Alaska population of northern fur seals, *Callorhinus ursinus* (Linnaeus, 1758). This

characterization contrasts strongly with that presented in the leading debate on pinniped exploitation in the ENP (Hildebrandt & Jones, 1992; Jones & Hildebrandt, 1995; Lyman, 1995), wherein all fur seals and sea lions are regarded as migratory, and *M. angustirostris* is not considered at all. As indicated in the Hildebrandt, Jones, and Lyman debate, human exploitation is likely to affect non-migratory, locally breeding pinniped populations much more strongly than species encountered only as migrants. However, data that post-date their debate demonstrate that *C. ursinus* once maintained mid-latitude breeding colonies (Burton et al., 2001; Crockford, Frederick, & Wigen, 2002), and isotopic evidence suggests that this population was non-migratory (Burton et al., 2001; Newsome et al., 2007).

The other pinniped species in the ENP are not migratory, but exhibit sex-specific and age-specific seasonal dispersals, with females and their pups moving tens of kilometres and males moving tens to hundreds of kilometres from the respective breeding colony at the end of the breeding season (Angliss & Outlaw, 2007; Carretta et al., 2007). These dispersal patterns, coupled with nursing periods of up to 24 months (Newsome, Etnier, Aurioles-Gamboa, & Koch, 2006; Trites et al., 2006), suggest that these species would have been present in the near-shore waters of the ENP throughout the entire year, albeit in locally and seasonally variable numbers (Table 1).

Species-level identifications of the pinniped bones were made with reference to published characters (Lyman, 1991; Lyon, 1937) and comparative skeletal specimens housed at the National Marine Mammal Laboratory and the Burke Museum of Natural History and Culture, both in Seattle, Washington, USA. Sex of individual *C. ursinus* bones was identified based on dental characters (Huber, 1994) and size and relative ontogenetic development of different skeletal elements (Etnier, 2002b). Dental characters can be used to distinguish newborn and older *C. ursinus* (Huber, 1994; Scheffer & Kraus, 1964), but it is not always possible to identify sex-based on the post-cranial bones of immature individuals (Etnier, 2002b).

Age-at-death of the archaeological *C. ursinus* specimens was estimated using non-linear growth curves for 15 skeletal elements generated from a large series of known-age *C. ursinus* comparative specimens (mandibles: female  $n = 392$ , male  $n = 404$ ; post-cranial skeletons: female  $n = 43$ , male  $n = 51$ ; for details see Etnier, 2002b; Newsome et al., 2007). Sex-specific growth curves were used to estimate age-at-death for all mandibles and those post-cranial elements for which sex could be

determined. Age-at-death of post-cranial bones for which sex could not be determined was estimated using growth curves that aggregate data for both males and females (Etnier, 2002b). Numeric age estimates of post-cranial skeletal elements cannot be determined for specimens with fully fused epiphyseal growth plates since growth and, by extension, correlation between age and bone length, stops at this stage (females, ~4–9 years; males, ~10–14 years); hence, these specimens can only be categorized as “adult.”

Accuracy of age estimates using this approach varies between skeletal elements, and decreases with increasing age. Standard deviation (SD) of age estimates based on mandibles from young-of-the-year (YOY) ranges from 1 to 2 months, while the SD of age estimates based on post-cranial bones from YOY ranges from 1 to 5 months (Newsome et al., 2007). For individuals >1-year old, age estimates based on mandibles systematically underestimate age-at-death and artificially truncate the upper end of the age distribution. An analysis of annual growth rings in sectioned canine teeth ( $n = 230$ ) shows that male mandibles from Ozette are consistently smaller than male mandibles of similar age in the comparative reference collection ( $n = 405$ ), which derives from the Alaska population in the 20th century. This implies that body size of males at Ozette was significantly smaller than their Alaskan conspecifics. Because of this, the regression-based age estimates for mandibles average 0.5–1.5 years lower than the true age for juvenile males 1–4 years old, with the underestimation of age increasing to an average of 3.0 years for adult males (Etnier, 2002b). The accuracy of age estimates for individuals >1 year based on post-cranial skeletal elements has not been calculated, but it is assumed to differ in similar fashion to the accuracy of age estimates for YOY. That is, regressions for post-cranial skeletal elements will consistently underestimate age, and the magnitude of the error for age estimates will be slightly larger than those based on the mandible.

Pinniped bones are quantified as number of identified specimens (NISP; Grayson, 1984). Age-at-death data are quantified using a modified version of NISP called “ageable NISP” (Lyman, 1987). This approach uses all measured skeletal elements to generate age estimates unless two or more elements are demonstrably from the same individual (e.g., articulated specimens). The age-at-death data were used to generate age–frequency histograms, or harvest profiles, for different temporal units from the archaeological sites. Median age is used to identify trends in the central tendency of the harvest profiles, as this allows the inclusion of both numerical and categorical age determinations.

## Results

Excavations in three different portions of the Ozette Village Site yielded over 134,000 mammal bones (exclusive of cetaceans), >90% of which were identified as pinnipeds (Friedman, 1976; Gustafson, 1968; Huelsbeck, 1994). The majority of the collections ( $n = \sim 80,000$ ) derive from a trench excavation referred to as area A (Gustafson, 1968), but were unavailable for analysis. A much smaller sample ( $n = \sim 1000$ ) derives from Area A75 and was located approximately in the middle of the large midden deposit at Ozette (Friedman, 1976). The remaining  $\sim 53,000$  bones derive from excavations in Area B70, which unearthed five intact house structures and their associated midden deposits (Samuels, 1991). Only the pinniped mandibles from area B70 were analyzed for this study ( $n = 1476$ ; see Table 2) because this element provides the most accurate species-level identifications as well as the most accurate age estimates (either through inverse regression or through counts of dental annuli).

Although Ozette was occupied for at least 2000 years (Gustafson, 1968), the oldest dates from excavations in area B70 are AD 1037–1298 (Samuels, 1991; radiocarbon age of charcoal samples with calibrated two sigma range based on Stuiver & Reimer, 1993; Stuiver et al., 1998). The first European contact at Ozette was in 1788 (Colson, 1953), and the village was occupied into the early 20th century (Table 2; Samuels, 1991). Thus, this pinniped sample represents roughly 700 years of harvest data.

All six pinniped species extant in the ENP are represented at Ozette, though in drastically different proportions (Table 2). Based on the presence of bones morphometrically and isotopically inferred to be from unweaned individuals (pups,  $\leq 4$  months old), *C. ursinus* were breeding at or somewhere near Ozette (Etnier, 2002b; Newsome et al., 2007; see also Crockford et al., 2002). Guadalupe fur seals, (*Arctocephalus townsendi* Merriam, 1897), are the second most abundant pinniped species in the Ozette collections (Table 2), but dental annuli indicate that all of those individuals were YOY  $\sim 4$ –12 months old, and do not represent a locally breeding population (Etnier, 2002a). The presence of bones morphometrically inferred to be from pups of harbour seals, *Phoca vitulina* (Linnaeus, 1758), and Steller sea lions, *Eumetopias jubatus* (Schreber, 1776), suggests that these species were breeding locally (Etnier, unpublished data). *P. vitulina* is the only pinniped species that currently breeds on the Washington coast (Jeffries, Huber, Calambokidis, & Laake, 2003).

Adult female, and juvenile male and female *C. ursinus* from the modern Pribilof Islands, Alaska

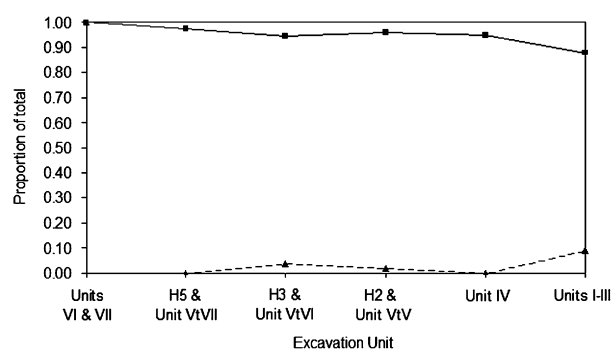
**Table 2.** Frequency and relative abundance of pinniped species in different excavation units from Ozette. Frequency based on number of identified specimens (NISP) of mandibles in each excavation unit; relative abundance based on NISP divided by the total for all pinnipeds in each excavation unit. Dates of occupation from Samuels (1991) listed as calendar year

Excavation unit	Approximate dates	<i>P. vitulina</i>		<i>M. angustirostris</i>		<i>C. ursinus</i>		<i>A. townsendi</i>		<i>E. jubatus</i>		<i>Z. californianus</i>		Excavation unit total		
		NISP	NISP/total	NISP	NISP/total	NISP	NISP/total	NISP	NISP/total	NISP	NISP/total	NISP	NISP/total	NISP	NISP/total	Total
I and III	late 1800s to 1910	5	0.088	0	0.000	50	0.877	0	0.000	2	0.035	0	0.000	0	0.000	57
IV	after 1719	0	0.000	0	0.000	144	0.947	7	0.046	1	0.007	0	0.000	0	0.000	152
House 2 and Unit VtV	1650 to 1700	4	0.019	0	0.000	207	0.958	3	0.014	2	0.009	0	0.000	0	0.000	216
House 3 and Unit VtVI	n.a.	7	0.036	0	0.000	184	0.944	2	0.010	2	0.010	0	0.000	0	0.000	195
House 5 and Unit VtVII	$\sim 1500$ to $\sim 1520$	0	0.000	2	0.010	187	0.974	1	0.005	2	0.010	0	0.000	0	0.000	192
House 1 and Unit VXM	$\sim 1500$ to $\sim 1700$	7	0.011	0	0.000	610	0.953	21	0.033	1	0.002	1	0.002	0	0.000	640
VI and VII	1037 to 1298	0	0.000	0	0.000	24	1.000	0	0.000	0	0.000	0	0.000	0	0.000	24
Site total		23	0.016	2	0.001	1406	0.953	34	0.023	10	0.007	1	0.001	1	0.001	1476
Proportion of site total		1.595		0.139		95.284		2.358		0.693		0.069				

population migrate along the west coast of North America as far south as California between late fall and early spring. Thus, an unknown proportion of the *C. ursinus* bones at Ozette may have come from the Alaska population. Preliminary attempts to use DNA to distinguish local and non-local *C. ursinus* from archaeological samples from the ENP have thus far been unsuccessful due to high levels of genetic variability in *Callorhinus* (Moss et al., 2006; Newsome et al., 2007). The low frequencies of *M. angustirostris*, *A. townsendi*, and California sea lion, *Zalophus californianus* (Lesson, 1828), suggest that these species only occasionally dispersed into the vicinity of Ozette from the south (Table 2).

One of the most striking aspects of the Ozette sample is the overwhelming dominance of *C. ursinus*, both in relative (88–100% of identified pinnipeds per excavation unit) and absolute ( $n = 1406$ ) terms (Table 2). When the abundance of *C. ursinus* relative to that of all pinnipeds combined is plotted through time, it is clear that this dominance continues throughout the entire chronological sequence, decreasing only slightly in the early historic period (Figure 2). In addition, male and female *C. ursinus* of all ages were harvested at Ozette (Figure 3), including adults, YOY, and small individuals inferred to be pups. Pups are present in excavation units dating up to the late prehistoric period (Figure 4), while Units IV and I–III (the historic units) each have a single individual estimated to be between 4 and 5 months old that may or may not represent unweaned pups (Newsome et al., 2007).

The only pinniped species with both ancient and modern breeding populations at Ozette, *P. vitulina*, shows a low, but steady, trend in relative abundance through most of the chronological sequence



**Figure 2.** Temporal trends in relative abundance of *Callorhinus ursinus* (squares) and *Phoca vitulina* (triangles) at Ozette. Note that excavation Units I and III have been combined because of the small sample sizes, as have Units VI and VII. Data from House 1/Unit VXM not plotted. See Table 2 for raw data and chronology of excavation units.

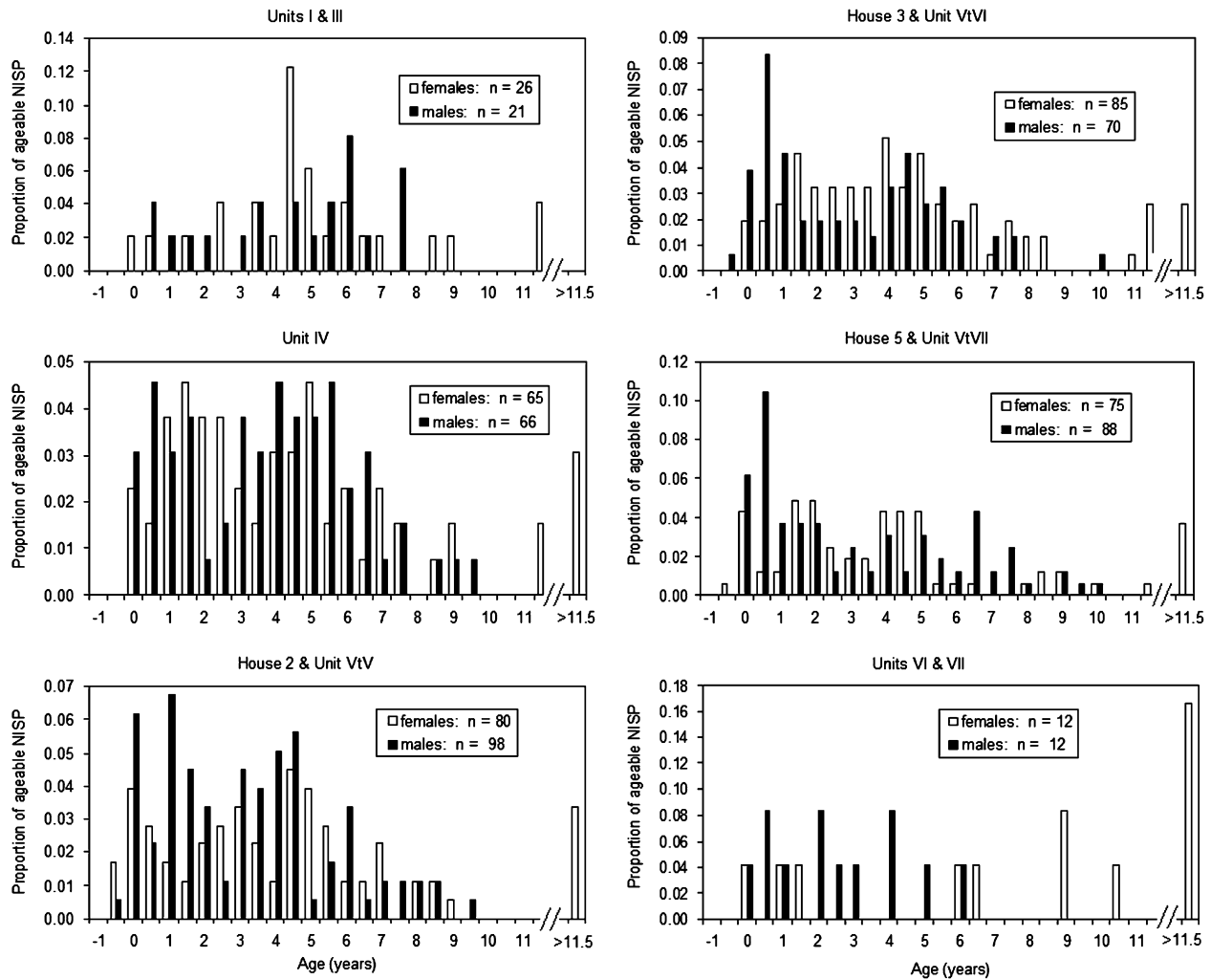
at Ozette – a pattern complementary to that exhibited by *C. ursinus* (Figure 2). With the decrease in the overall reliance on *C. ursinus* in the early historic period, the relative abundance of *P. vitulina* increases correspondingly, although slightly.

To evaluate the hypothesis that changes in harvest intensity caused *C. ursinus* to decline in the early historic period, temporal trends in median age of male and female *C. ursinus* were calculated for the sample period (Figure 5). As discussed above, a net increase in harvest intensity is expected to result in a decrease in median age of the harvested population – as long as reproduction and recruitment are not disrupted (Caughley, 1977; Koike & Ohtaishi, 1987; Lyman, 1987). However, an alternate possibility is that disruption of the local breeding colony, or colonies, could be signaled initially by an increase in median age as recruitment of local juveniles decreases, a hypothesis that can be tested with these data since *C. ursinus* appears to have been breeding in the vicinity of Ozette.

Cochran's test of linear trends among proportions (Cannon, 2001; Etnier, 2004; Zar, 1996) allows a statistical evaluation of temporal data that are unevenly spaced. In this particular case, the proportion of animals estimated to be YOY is compared to the proportion of animals >1 year old for each excavation unit. This approach is used because the proportion of YOY is expected to be positively correlated with proximity to breeding colonies. Thus, a decline in the proportion of YOY in general, and pups in particular, would signal reduced reproductive output or the local extermination or abandonment of those colonies. Likewise, the trend in animals >1 year old is expected to scale inversely with harvest intensity: higher levels of harvest intensity should lead to an overall reduction in the median age of *C. ursinus*.

The temporal trend in median age of *C. ursinus* at Ozette shows an initial drop for females (Figure 5). Median age of both sexes then increases gradually over time; there are upward inflections: for males ~1650–1700 (House 2/Unit VtV); and for females after 1719 (Unit IV). The cause of the initial drop in median age of females is not clear, but may be an artifact of small sample size (Figure 3).

The overall trend of increasing median age is driven by a significant decrease in the proportion of YOY relative to the overall age distribution ( $\chi^2_{\text{trend}} = 8.040$ ; degrees of freedom = 1;  $p = 0.005$ ). Examination of the harvest profiles for each excavation unit indicates that the increase in median age in the early historic period is caused by the loss of YOY (Figure 4). Specifically, 2–4-month-old pups are not encountered after ~1650–1700 (House 2/Unit VtV).



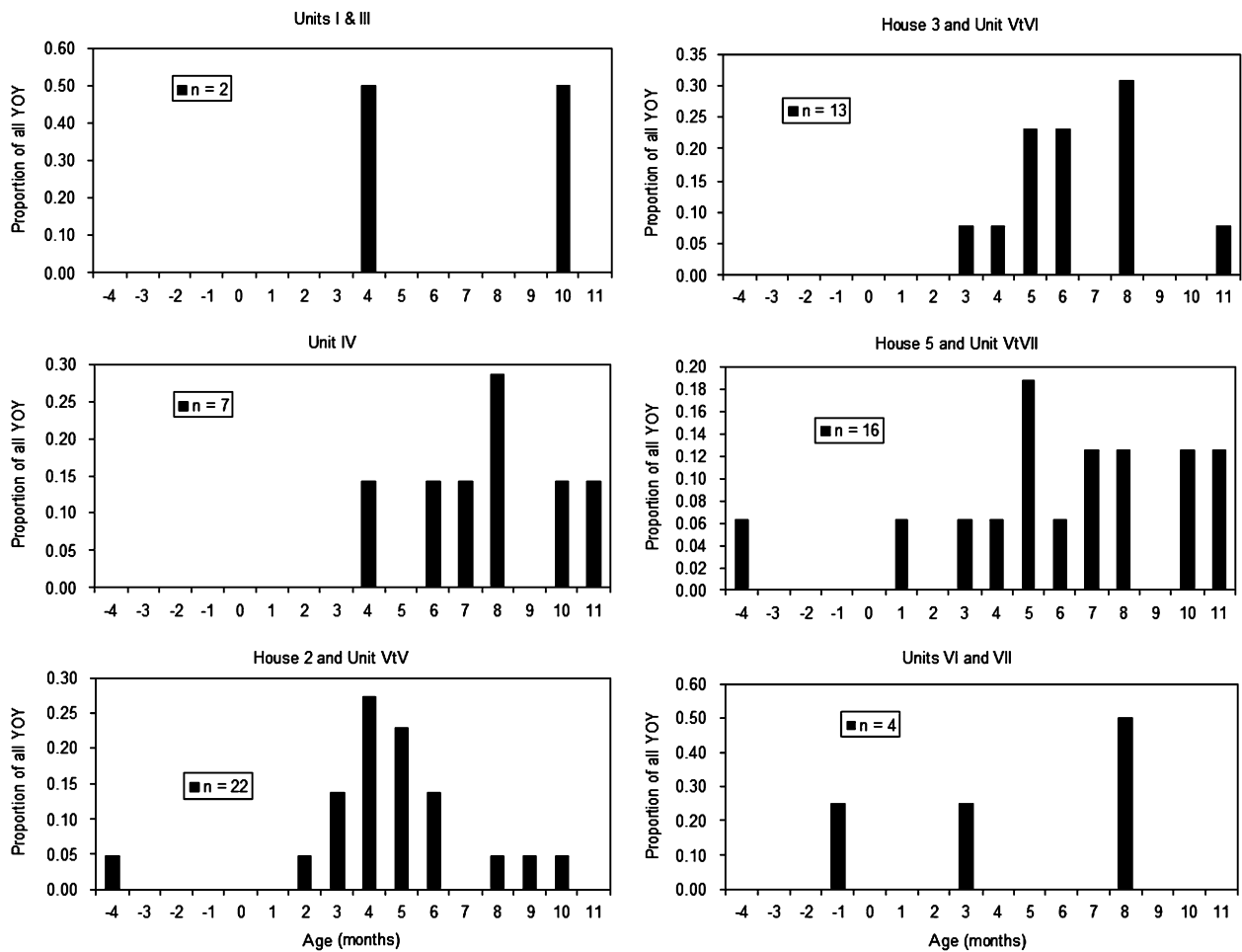
**Figure 3.** Distribution of age estimates for *Callorhinus ursinus* mandibles from Ozette for successive excavation units (see Table 2 for chronology). Data from House 1/Unit VXM not plotted. Sample sizes indicated for each histogram represent ageable NISP by sex. Ages estimated via non-linear regression, which artificially truncates the upper end of the estimated age distribution (Etnier, 2002b; Newsome et al., 2007). Negative ages are inferred to be fetuses.

As with the initial drop in median age of females, the absence of pups in the early historic period may be an artifact of low sample size. It is important to note, however, that no *C. ursinus* breeding colonies were documented by the first European explorers and naturalists to visit the area, nor did local informants report any (Swan, 1870; but see Crockford et al., 2002). Thus, after withstanding ~500 years of harvest pressure, the *C. ursinus* colony or colonies in the vicinity of Ozette were evidently abandoned sometime before 1788.

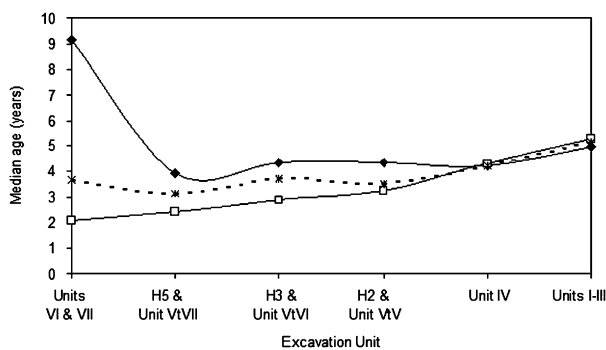
The pattern of *C. ursinus* exploitation at the Moss Landing Site (Figure 1), which was occupied from ~6550 BC until ~AD 1800 (Milliken et al., 1999), provides an intriguing contrast to that at Ozette. Despite the fact that there are significant temporal, cultural, and environmental differences between Ozette and Moss Landing, the two sites have

one feature in common – an apparently heavy reliance, at least at times, on *C. ursinus*. The majority of the *C. ursinus* bones from Moss Landing were recovered from a single temporal unit in the “primary midden” portion of the site with dates ranging from ~300 BC to AD 350 (Newsome et al., 2007; radiocarbon age of *C. ursinus* bones with two sigma range, with marine reservoir correction), roughly coeval with the earliest evidence for *C. ursinus* exploitation at Ozette (Gustafson, 1968). Although analyses of the Moss Landing pinniped remains are still in progress, *C. ursinus* comprises 68% of the identified pinniped bones from the primary midden ( $n = 2,086$ ), while *P. vitulina* represents less than 1% (Gifford-Gonzalez, unpublished data; Newsome et al., 2007).

A sub-sample of *C. ursinus* post-cranial skeletal elements and mandibles ( $n = 84$ ) was measured to



**Figure 4.** Distribution of age estimates  $\leq 1$  year for *Callorhinus ursinus* mandibles from Ozette for successive excavation units (see Table 2 for chronology). Data from House 1/Unit VXM not plotted. Sample sizes indicated for each histogram represent ageable NISP for males and females combined. Ages estimated via non-linear regression. Negative ages are inferred to be fetuses.



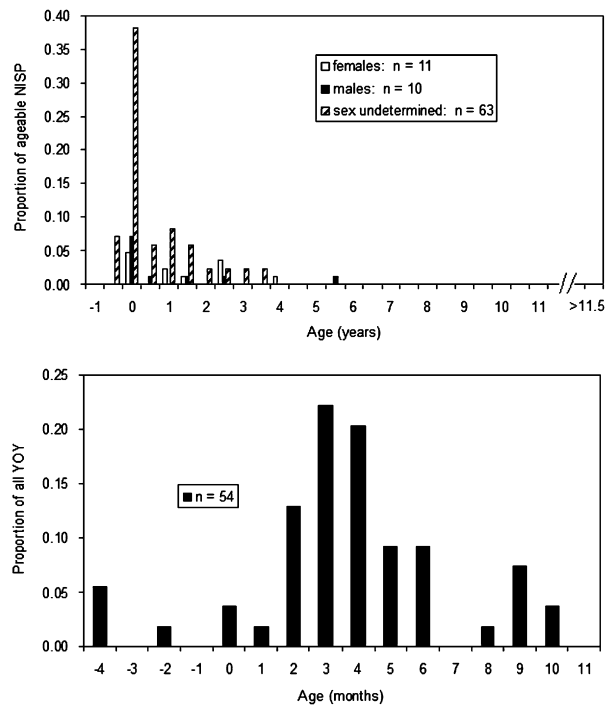
**Figure 5.** Temporal trend in median ages of *Callorhinus ursinus* (females, solid diamonds; males, open squares; both combined, asterisks) at Ozette. Data from House 1/Unit VXM not plotted. Sample sizes as in Figure 3. See Table 2 for chronology of excavation units.

generate the harvest profile. An additional 22 *C. ursinus* bones were identified as adult females based on morphology and the fusion of epiphyses.

Despite the evidence for exploitation of a breeding colony, bones of adult males were not encountered in this sample. Even taking into account the fact that the age estimates from post-cranial remains are less accurate than those from mandibles, the harvest profile at Moss Landing (Figure 6) differs significantly from that of Ozette (Figure 3), with an emphasis on YOY of both sexes, including pups (see also Burton et al., 2001), and, to a lesser extent, sub-adult (1 to 3 years old) and adult females. The median age of *C. ursinus* from Moss Landing ( $n = 106$ ) is  $\sim 9$  months, which is significantly lower than at Ozette (Figure 5).

To summarize, the results from the Ozette analysis show that *C. ursinus* were a dominant part of the pinniped assemblage throughout the entire excavation sequence. Males and females of all ages were harvested. Despite a gradual increase in median age (Figure 5), there were no dramatic changes in the age structure of the population for





**Figure 6.** Distribution of Age estimates for *Callorhinus ursinus* harvested at Moss Landing. Upper panel represents all ageable NISP ( $n = 84$ ), lower panel represents age estimates  $\leq 1$  year ( $n = 54$ ). Females and males not distinguished. Negative ages are inferred to be fetuses.

nearly 500 years (Figure 3; Table 2). *P. vitulina* was a minor component of the Ozette sample, both in a relative and an absolute sense. But the patterns of relative abundance in the Ozette sequence indicate that the harvests of both *C. ursinus* and *P. vitulina* were sustained for nearly 500 years. The Moss Landing data contrast strongly with those from Ozette. While data from both sites suggest that *C. ursinus* were being exploited from nearby breeding colonies (Burton et al., 2001; Newsome et al., 2007), and that both breeding colonies eventually collapsed, *C. ursinus* disappear from Moss Landing some 2000 years earlier than at Ozette.

## Discussion

There are many factors that could explain the disruption of the putative *C. ursinus* breeding colony in the vicinity of Ozette. One possibility is that, after nearly 500 years of harvests that only minimally affected median age and the presence of biologically relevant age/sex classes, harvest pressure at Ozette increased significantly at the end of the occupation sequence, resulting in the extirpation of local breeding colonies. However, this would have required an increase in age-specific harvest

pressure, since the trend in median age is the opposite of that predicted under a general increase in overall harvest pressure.

A second possibility is that climatic conditions changed in such a way that was unfavourable to *C. ursinus* populations. For example, the “Little Ice Age” (LIA) that lasted from  $\sim$ AD 1350 to 1900 (Mann, Crowell, Hamilton, & Finney, 1998) roughly corresponds to the period of change in the *C. ursinus* breeding distribution documented here. However, mid-latitude pinniped populations in the ENP respond positively to cooling, rather than negatively (Trillmich et al., 1991).

Two other major events roughly correspond to the same time period that *C. ursinus* disappeared from the vicinity of Ozette. The first is the Cascadia Fault subduction earthquake (Cole, Atwater, McCutcheon, Stein, & Hemphill-Haley, 1996). In addition to potentially causing the mudslides that buried portions of Ozette Village (Samuels, 1991), this earthquake may have resulted in a dramatic change in the configuration of the coastline. The attendant loss of seal breeding habitat could explain the disruption of the *C. ursinus* breeding colony or colonies along the Washington coast.

The second major event is the expansion of the Russian fur trade into the North Pacific (detailed in Busch, 1985). Though there is no record that the Russian fur traders worked along the Washington coast prior to the early 19th Century, the early days of the commercial fur trade were characterized by rapid depletion of fur seal populations (*C. ursinus* and *Arctocephalus* spp.) through shore-based harvests on breeding colonies throughout the world. Written accounts of these exploits are relatively rare, but the accounts that were recorded were often falsified to minimize the chances of competition with other sealing captains (Busch, 1985).

In contrast to Ozette, the disappearance of *C. ursinus* from Moss Landing appears to be straightforward. The disappearance is several hundred years prior to the “Medieval Warm Period” (MWP), which lasted from  $\sim$ AD 900 to 1350 (Hughes & Diaz, 1994), and does not correspond with any other major changes in the paleoclimatic record (for full discussion see Newsome et al., 2007), suggesting that human exploitation may have been causal. Furthermore, wildlife studies show that selective culls of adult females can cause severe declines in large mammal populations (Caughley, 1977; York & Hartley, 1981). However, if the exploitation of adult females is what caused *C. ursinus* to abandon Moss Landing, it is not clear why predation on adult females at Ozette did not have similar consequences. In the absence of data on the harvest rate (relative to overall population

size), hypotheses regarding the effects of sex-specific selectivity are difficult to test.

I have argued that, despite differences in temporal, cultural, and environmental settings, pinniped harvest data from Ozette and Moss Landing can be meaningfully compared. Perhaps, the biggest challenge to this argument is that the analysis is based on drastically different sample sizes. Ozette has several hundred individual pinnipeds represented, while the Moss Landing data analyzed here represent not more than tens of individuals. Nevertheless, the Moss Landing data are sufficient to characterize the age composition of the harvest (Lyman, 1987), and show clear evidence that a *C. ursinus* rookery was being exploited.

Previous archaeological studies on pinniped exploitation have relied heavily on relative abundance data as an index of resource depression, or decreasing encounter rates of pinniped species. While these studies provide valuable insights on resource use, many modern natural resource management schemes, including that used for *C. ursinus* until the 1980s, intentionally reduce population levels to 40–60% of the original population in order to maximize productivity (Beverton & Holt, 1957; Lander & Kajimura, 1982). Thus, declines in relative abundance cannot be assumed to equate with unsustainable harvests; nor for that matter, can stable patterns of relative abundance be assumed to equate with sustainable use. Rather, the hypothesis of sustainable resource use should be further evaluated with trend data on the age composition of the harvest. This is particularly important for understanding changing patterns of pinniped use since many species exhibit age- and sex-specific migrations, dispersals, and escape/avoidance behaviours (Lyman, 2003). In cases where relative abundance and harvest profile data both suggest the possibility of unsustainable resource use, this hypothesis must be further evaluated in reference to changes in climatic or oceanographic conditions, human population density, and hunting technology in use in a particular locale. Finally, ancient DNA analyses may help determine the degree to which local populations of prey species were being maintained by immigration from “source” populations (Etnier, 2004; Grayson, 2001; Lyman, 2003; Moss et al., 2006; Newsome et al., 2007).

The patterns of pinniped exploitation at Ozette and Moss Landing fit into a larger discussion of archaeological evidence for and against the sustainability of pinniped harvests on the Pacific Coast of North America (Hildebrandt & Jones, 1992; Jones & Hildebrandt, 1995; Lyman, 1995; Porcasi et al.,

2000) and elsewhere (Nagaoka, 2006; Smith, 1979; Woodborne, Hart, & Parkington, 1995). This study has shown that, while the harvests of *C. ursinus* at Moss Landing may have resulted in the extirpation of that species, the Ozette data show that unsustainable use of pinniped populations is not a universal pattern (see also Lyman, 2003). At Ozette, *C. ursinus* were harvested for ~500 years before a dramatic shift in harvest intensity and/or environmental factors caused the disruption of the local breeding population. Although it is still unclear why the patterns at Moss Landing and Ozette differ so strongly, future research aimed at identifying the specific characteristics of pinniped exploitation that have, and have not, been sustainable in the past may lead to a better understanding of how to best manage these resources in modern times.

## Acknowledgements

An earlier version of this paper was presented at the 2006 International Council of Archaeozoologists conference in Mexico City, Mexico. Thanks are due to Dr. Jack Frazier for the invitations to participate in the special session on sustainability, and to contribute to this edited volume. The manuscript has benefited greatly from comments from Dr. Frazier and three anonymous reviewers. Thanks to the Makah Cultural and Research Center for their continued support of and interest in my research. Finally, special thanks to Stephanie Jolivette for agreeing to present this paper at the 2006 ICAZ conference in my absence. Portions of this research were funded by the US EPA STAR Research Program (Fellowship # U 915384-01-1).

## References

- Alvard, M. (1998). Indigenous hunting in the Neotropics: Conservation or optimal foraging. In T. Caro (Ed.), *Behavioral ecology and conservation biology* (pp. 474–500). Oxford: Oxford University Press.
- Angliss, R. P., & Outlaw, R. B. (2007). *Alaska marine mammal stock assessments, 2006*. NOAA technical memorandum, NMFS-AFSC-168.
- Bayham, F. E. (1979). Factors influencing the archaic pattern of animal utilization. *Kiva*, 44, 219–235.
- Beverton, R. J. H., & Holt, S. J. (1957). On the dynamics of exploited fish populations. *Ministry of agriculture, fisheries and food: Fishery investigations, Series II*, Vol. 19. H. M. Stationary Office: London.
- Briggs, J. M., Spielmann, K. A., Schaafsma, H., Kintigh, K. W., Kruse, M., Morehouse, K., et al. (2006). Why ecology needs archaeologists and archaeology needs

- ecologists? *Frontiers in Ecology and the Environment*, 4, 180–188.
- Broughton, J. M. (1994a). Declines in mammalian foraging efficiency during the late Holocene, San Francisco Bay, California. *Journal of Anthropological Archaeology*, 13, 371–401.
- Broughton, J. M. (1994b). Late Holocene resource intensification in the Sacramento Valley, California: The vertebrate evidence. *Journal of Archaeological Science*, 21, 501–514.
- Burton, R. K., Snodgrass, J. J., Gifford-Gonzalez, D., Guilderson, T., Brown, T., & Koch, P. L. (2001). Holocene changes in the ecology of northern fur seals: insights from stable isotopes and archaeofauna. *Oecologia*, 128, 107–115.
- Busch, B. C. (1985). *The war against the seals: A history of the North American seal fishery*. McGill-Queens University Press: Kingston, Ontario.
- Butler, V. L., & Campbell, S. K. (2004). Resource intensification and resource depression in the Pacific Northwest of North America: A zooarchaeological review. *Journal of World Prehistory*, 18, 327–405.
- Callicott, J. B., & Mumford, K. (1997). Ecological sustainability as a conservation concept. *Conservation Biology*, 11, 32–40.
- Cannon, M. D. (2000). Large mammal relative abundance in Pithouse and Pueblo Period archaeofaunas from Southwestern New Mexico: Resource depression among the Mimbres–Mogollon. *Journal of Anthropological Archaeology*, 19, 317–347.
- Cannon, M. D. (2001). Archaeofaunal relative abundance, sample size, and statistical methods. *Journal of Archaeological Science*, 28, 185–195.
- Carretta, J. V., Forney, K. A., Muto, M. M., Barlow, J., Baker, J., Hanson, B., et al. (2007). *US Pacific marine mammal stock assessments: 2006*. NOAA technical memorandum, NMFS-SWFSC-398.
- Caughley, G. (1977). *Analysis of vertebrate populations*. New York: Wiley.
- Charnov, E. L., Orians, G. H., & Hyatt, K. (1976). Ecological implications of resource depression. *American Naturalist*, 110, 247–259.
- Cole, S. C., Atwater, B. F., McCutcheon, P. T., Stein, J. K., & Hemphill-Haley, E. (1996). Earthquake-induced burial of archaeological sites along the southern Washington coast about A.D. 1700. *Geoarchaeology*, 11, 165–177.
- Colson, E. (1953). *The Makah Indians: A study of an Indian tribe in modern American society*. University of Minnesota Press: Minneapolis.
- Crockford, S. J., Frederick, S. G., & Wigen, R. J. (2002). The Cape flattery fur seal: An extinct species of *Callorhinus* in the eastern North Pacific? *Canadian Journal of Archaeology*, 26, 152–174.
- Etnier, M. A. (2002a). Occurrences of Guadalupe fur seals (*Arctocephalus townsendi*) on the Washington coast over the past 500 years. *Marine Mammal Science*, 18, 551–557.
- Etnier, M. A. (2002b). *The effects of human hunting on northern fur seal (Callorhinus ursinus) migration and breeding distributions in the Late Holocene*. Unpublished Ph.D. thesis, University of Washington, Seattle. Available at <<http://www.pinniped.net/etnier/dissertation/>>.
- Etnier, M. A. (2004). The potential of archaeological data to guide pinniped management decisions in the eastern North Pacific. In R. L. Lyman, & K. P. Cannon (Eds.), *Zooarchaeology and conservation biology* (pp. 88–102). Salt Lake City: University of Utah Press.
- Fowler, C. W., & Hobbs, L. (2003). Is humanity sustainable? *Proceedings of the Royal Society of London, Series B*, 270, 2579–2583.
- Friedman, E. (1976). *An archaeological survey of Makah Territory: A study of resource utilization*. Unpublished Ph.D. thesis, Washington State University, Pullman.
- Gifford-Gonzalez, D. P., Newsome, S. D., Koch, P. L., Guilderson, T. P., Snodgrass, J. J., & Burton, R. K. (2005). Archaeofaunal insights on pinniped-human interactions in the northeastern Pacific. In G. Monks (Ed.), *The exploitation and cultural importance of marine mammals* (pp. 19–38). Oxford: Oxbow Books.
- Goodland, R. (1995). The concept of environmental sustainability. *Annual Review of Ecology and Systematics*, 26, 1–24.
- Grayson, D. K. (1984). *Quantitative zooarchaeology: Topics in the analysis of archaeological faunas*. New York: Academic Press.
- Grayson, D. K. (2001). The archaeological record of human impacts on animal populations. *Journal of World Prehistory*, 15, 1–68.
- Gustafson, C. E. (1968). Prehistoric use of fur seals: Evidence from the Olympic Coast of Washington. *Science*, 161, 49–51.
- Hildebrandt, W. R., & Jones, T. L. (1992). Evolution of marine mammal hunting: A view from the California and Oregon Coasts. *Journal of Anthropological Archaeology*, 11, 360–401.
- Huber, H. R. (1994). A technique for determining sex of northern fur seal pup carcasses. *Wildlife Society Bulletin*, 22, 479–483.
- Huelsbeck, D. R. (1994). Mammals and fish in the subsistence economy of Ozette. In S. R. Samuels (Ed.), *Ozette archaeological project research reports*. (pp. 17–91). Vol. 2. Department of Anthropology, Washington State University, Pullman, and National Park Service, Pacific Northwest Regional Office, Seattle.
- Hughes, M. K., & Diaz, H. F. (1994). Was there a 'Medieval Warm Period,' and if so, where and when? *Climatic Change*, 26, 109–142.
- Jackson, J. B. C., Kirby, M. X., Berger, W. H., Bjorndal, K. A., Botsford, L. W., Bourque, B. J., et al. (2001). Historical overfishing and the recent collapse of coastal ecosystems. *Science*, 293, 629–637.
- Jeffries, S., Huber, H., Calambokidis, J., & Laake, J. (2003). Trends and status of harbor seals in Washington State: 1978–1999. *Journal of Wildlife Management*, 67, 207–218.
- Jones, T. L., & Hildebrandt, W. R. (1995). Reasserting a prehistoric tragedy of the commons: Reply to Lyman. *Journal of Anthropological Archaeology*, 14, 78–98.

- Kay, C. E. (1994). Aboriginal overkill: The role of native Americans in structuring western ecosystems. *Human Nature*, 5, 359–398.
- Koike, H., & Ohtashi, N. (1987). Estimation of prehistoric hunting rates based on the age composition of Sika deer (*Cervus nippon*). *Journal of Archaeological Science*, 14, 251–269.
- Krech, S. I. (1984). *The Subarctic fur trade: Native social and economic adaptations*. Vancouver: University of British Columbia Press.
- Lander, R. H., & Kajimura, H. (1982). Status of northern fur seals. *Mammals in the Seas, FAO Fisheries Series, IV*, 319–345.
- Lyman, R. L. (1987). On the analysis of vertebrate mortality profiles: Sample size, mortality type, and hunting pressure. *American Antiquity*, 52, 125–142.
- Lyman, R. L. (1991). Notes on identification of pinniped remains. In R. L. Lyman (Ed.), *Prehistory of the Oregon coast: The effects of excavation strategies and assemblage size on archaeological inquiry* (pp. 344–348). San Diego: Academic Press.
- Lyman, R. L. (1995). On the evolution of marine mammal hunting on the west coast of North America. *Journal of Anthropological Archaeology*, 14, 45–77.
- Lyman, R. L. (2003). Pinniped behavior, foraging theory, and the depression of metapopulations and nondepression of local population on the southern Northwest Coast of North America. *Journal of Anthropological Archaeology*, 22, 376–388.
- Lyon, G. M. (1937). Pinnipeds and a sea otter from the Point Mugu shell mound of California. *University of California Publications in Biological Sciences*, 1, 133–168.
- Mann, D. H., Crowell, A. L., Hamilton, T. D., & Finney, B. P. (1998). Holocene geologic and climatic history around the Gulf of Alaska. *Arctic Anthropology*, 35, 112–131.
- Martin, P. S. (1967). Pleistocene Overkill. *Natural History*, 76, 32–38.
- Milliken, R., Nelson, J., Hildebrandt, W., & Mikkelsen, P. (1999). *Volume 1: The Moss Landing Hill Site*. A technical report on archaeological studies at CA-MNT-234. Far Western Archaeological Research Group, Inc., Davis, CA. Submitted to the California State University.
- Mosimann, J. E., & Martin, P. S. (1975). Simulating overkill by Paleoindians. *American Scientist*, 63, 304–313.
- Moss, M. L., Yang, D. Y., Newsome, S. D., Speller, C. F., McKechnie, I., McMillan, A. D., et al. (2006). Historical ecology and biogeography of North Pacific pinnipeds: Isotopes and ancient DNA from three archaeological assemblages. *Journal of Island and Coastal Archaeology*, 1, 165–190.
- Nagaoka, L. (2005). Declining foraging efficiency and moa carcass exploitation in southern New Zealand. *Journal of Archaeological Science*, 32, 1328–1338.
- Nagaoka, L. (2006). Prehistoric seal carcass exploitation at the Shag Mouth site, New Zealand. *Journal of Archaeological Science*, 33, 1474–1481.
- Newsome, S. D., Etnier, M. A., Aurioules-Gamboa, D., & Koch, P. L. (2006). Using carbon and nitrogen isotope values to investigate maternal strategies in northeast Pacific otariids. *Marine Mammal Science*, 22, 556–572.
- Newsome, S. D., Etnier, M. A., Gifford-Gonzalez, D., Phillips, D. P., van Tuinen, M., Hadley, E. A., et al. (2007). The shifting baseline of northern fur seal ecology in the Northeast Pacific Ocean. *Proceedings of the National Academy of Sciences*, 104, 9709–9714.
- Porcasi, J. F., Jones, T. L., & Raab, L. M. (2000). Trans-Holocene marine mammal exploitation on San Clemente Island, California: A tragedy of the Commons Revisited. *Journal of Anthropological Archaeology*, 19, 200–220.
- Samuels, S. R., (Ed.) (1991). *Ozette Archaeological Project Research Reports. Volume 1. House structure and floor midden, reports of investigations* (Vol. 63). Department of Anthropology, Washington State University, Pullman, and National Park Service, Pacific Northwest Regional Office, Seattle.
- Scheffer, V. B., & Kraus, B. S. (1964). Dentition of the northern fur seal. *Fishery Bulletin*, 63, 293–342.
- Smith, I. W. G. (1979). Prehistoric sea mammal hunting in Paliser Bay. *Prehistoric man in Palliser Bay. National Museum Bulletin*, 21, 215–224.
- Stuiver, M., & Reimer, P. J. (1993). Extended <sup>14</sup>C database and revised CALIB radiocarbon calibration program. *Radiocarbon*, 35, 215–230.
- Stuiver, M., Reimer, P. J., Bard, E., Beck, J. W., Burr, G. S., Hughen, K. A., et al. (1998). INTCAL98 radiocarbon age calibration 24,000–0 cal BP. *Radiocarbon*, 40, 1041–1083.
- Swan, J. G. (1870). The Indians of Cape Flattery, at the entrance of the Strait of Fuca, Washington Territory. *Smithsonian Institution Contributions to Knowledge*, 220(Article 8), 1–105.
- Trillmich, F., Ono, K. A., Costa, D. P., DeLong, R. L., Feldkamp, S. D., Francis, J. M., et al. (1991). The effects of El Niño on pinniped populations in the eastern Pacific. In F. Trillmich, & K. A. Ono (Eds.), *Pinnipeds and El Niño: Responses to environmental stress* (pp. 247–270). Berlin: Springer.
- Trites, A. W., Porter, B. P., Deecke, V. B., Coombs, A. P., Marcotte, M. L., & Rosen, D. A. S. (2006). Insights into the timing of weaning and the attendance patterns of lactating Steller sea lions (*Eumetopias jubatus*) in Alaska during winter, spring, and summer. *Aquatic Mammals*, 32, 85–97.
- Wilson, D. E., & Reeder, D. M. (Eds.) (1993). *Mammal species of the world*. Washington, D.C: Smithsonian Institution Press.
- Woodborne, S., Hart, K., & Parkington, J. (1995). Seal bones as indicators of the timing and duration of hunter-gatherer coastal visits. *Journal of Archaeological Science*, 22, 727–740.
- York, A. E., & Hartley, J. R. (1981). Pup production following harvest of female northern fur seals. *Canadian Journal of Fisheries and Aquatic Science*, 38, 84–90.
- Zar, J. H. (1996). *Biostatistical analysis* (3rd ed.). Upper Saddle River, NJ: Prentice-Hall.