Ecological Applications, 18(2) Supplement, 2008, pp. S41–S55

ZOOARCHAEOLOGY AND ARCTIC MARINE MAMMAL BIOGEOGRAPHY, CONSERVATION, AND MANAGEMENT

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Abstract. The Holocene zooarchaeological record of the subarctic and Arctic can be used to aid in the conservation and management of marine mammals. A synthesis of selected zooarchaeological data indicates that there have been significant changes in species ranges, that northern marine ecosystems varied temporally and spatially, and that changes in sea ice extent may be accessible through retrospective research. Despite some limitations, the analysis of faunal collections from regionally appropriate coastal prehistoric and historic-era archaeological sites can be used to provide baseline information on marine systems that is less likely than more recent data to be compromised by intensive and extensive human impacts. The long-term time series data derived through zooarchaeology are particularly relevant to marine conservation and management decision-making in the Arctic where climate change scenarios predict accelerated environmental changes in the coming decades.

Key words: Arctic; climate; marine mammals; zooarchaeology.

INTRODUCTION

Zooarchaeological research offers important insights into the history and evolution of ecosystem structure and function that are necessary in planning for wildlife conservation, management, and mitigation in light of future climate changes (Amorosi et al. 1994, Buckland et al. 1996, Lyman 1996, Grayson 2001, Lyman and Cannon 2004). These issues are particularly pressing in the Arctic, where climate change scenarios predict accelerated environmental changes (ACIA 2004) and where dramatic marine ecosystem change is already documented in some regions (Grebmeier et al. 2006). Most time series used in wildlife conservation and management are restricted to the past 50–100 years. In contrast, zooarchaeological research can significantly lengthen the biogeographic record of some species, perhaps by as much as 10 000–15 000 years. Zooarchaeological data can also be used to provide a baseline for comparison and decision-making that is less likely to be compromised by recent intensive and extensive human impacts of a wide variety (Pauly et al. 1998, Jackson et al. 2001, Springer et al. 2003).

Zooarchaeology is the study of animal remains (archaeofauna) recovered from archaeological deposits. These may include those intentionally or unintentionally deposited by people, the remains of individual animals that subsequently inhabit and die on site, or those that are deposited by other processes such as the accumulations of fauna produced by carnivores, raptors, and pinnipeds (Erlandson and Moss 2001, Lyman 2002, Moss and Erlandson 2002). Archaeofauna can include vertebrate and invertebrate macro- and microfauna, and zooarchaeology is the recovery, identification, and analysis those remains, using a standard set of methods (Binford 1978, Lyman 1994, Reitz and Wing 1999, Dincauze 2000). By its very nature it is interdisciplinary, combining theoretical and methodological approaches from anthropology, archaeology, biology, chemistry, ecology, and geology to explore and explain human–animal–environment interactions and feedbacks.

Zooarchaeological research provides important contextual and population data relevant to current wildlife management and conservation issues. For example, research on North Atlantic cod (*Gadus morhua*) from 11th–18th century archaeological deposits in Iceland demonstrates that the model of a "natural" cod population structure in use in the 1970s was probably "historically unusual" (Amorosi et al. 1996:149). This model suggested that cod stocks consisted mainly of small and young (3–10 years) fish and only a few old (20–30 years) and extremely large fish (1–1.5 m). However, the zooarchaeological information indicates that stocks had previously consisted of many larger, older fish (Amorosi et al. 1994). The use of erroneous data on stock population structure probably contributed to cod fishery mismanagement and, in combination with overfishing and climate change (Hamilton and Haedrich 1999, Hamilton et al. 2003), led to stock collapses in the early 1990s. If the archaeological data had been available, fisheries managers might have recognized that the 20th century stock data "signaled a change in the population" (Amorosi et al. 1996:149). Managers may also have recognized that, even accounting for changes in gear and strategies over the centuries, the exploitation threshold for North Atlantic cod was approaching or

Manuscript received 16 May 2006; revised 8 February 2007; accepted 12 February 2007. Corresponding Editor (ad hoc): A. Berta. For reprints of this Special Issue, see footnote 1, p. S1.

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had already been reached (Amorosi et al. 1994, 1996:149). With such information it is possible that different management decisions could have been made.

Zooarchaeology can also provide data relevant to the conservation and management of Arctic marine mammals, especially with respect to understanding species' responses to climate change, responses to pressures from human activities, and even their recent evolutionary history (see O'Corry-Crowe 2008). Such data can also lead to new insight on long-term trends in regional and local sea ice conditions, information of particular concern for the management of ice-obligate and ice-loving marine mammals.

Limitations and Strengths of Zooarchaeological Data

Making strong paleoecological inferences from zooarchaeological data requires many samples with good spatial and temporal coverage (Lyman and Cannon 2004) and contextual control. Archaeological data are typically recovered at varying spatial scales but the regional scale is most relevant to questions of conservation and management, providing information about biogeography and species distributions. Zooarchaeological data may also provide temporal insight at the seasonal, decadal (more rarely), century, and millennial scales. Depending upon the specific goals, any or all of these data may be relevant, although the longer term (century and millennial) scale is the strength of archaeology; there is often "poor resolution for micro-scale ecological processes" while "macroscale processes are typically apparent" in the record (Lyman and Cannon 2004:12).

A limitation of zooarchaeological data is that archaeofauna are only a sample of what was available at a given point in time in the past. They do not directly reflect ecosystem life assemblages because they are subject to a variety of winnowing processes, both anthropogenic and natural (Grayson 1981). Among many others, these can include human selection of prey, human practices of carcass disposal, post-depositional events that may disrupt deposit integrity, such as freeze–thaw action, and biophysical/biochemical conditions leading to bone deterioration and destruction. In archaeology and paleontology there is a rich literature on methods for recognizing and assessing the impacts of anthropogenic and natural processes on faunal assemblage integrity. Much of this is summarized in Lyman (1994) and Reitz and Wing (1999). Below I highlight a few anthropogenic processes and some natural factors that are germane to the analysis and interpretation of archaeofaunal assemblages and particularly those that contain Arctic marine mammals.

Excavation techniques that may impact archaeofaunal samples include: (1) the failure to screen/sieve archaeological deposits or the use of a large minimum mesh size when screening; this favors recovery of larger animals and larger bone fragments; (2) the failure to collect fauna from all feature types, resulting in unrepresentative samples; (3) the failure to recognize reuse of areas; palimpsest deposits may reflect different activities in the same location (Woollett 1999). Variability in the quantity and quality of data also result from various national histories of archaeological research that encompass different research agendas, traditions of excavation, analysis, and interpretation. Until recently in many areas there was a general neglect of archaeofauna that included the failure to collect it and the analytical prioritization of other classes of archaeological data. Related analytical issues include the failure to adequately and appropriately date assemblages (Mason and Gerlach 1995), a shortage of well-dated stratified deposits (Gerlach and Mason 1992), a scarcity of dateable material, and problems with radiocarbon dating linked to variability in the marine reservoir effect (McGhee and Tuck 1976, Arundale 1981, Dyke et al. 1996, Dumond and Griffin 2002). These factors compound problems with regional comparison and also make difficult the comparison of zooarchaeological trends with paleoclimate trends.

With specific reference to Arctic marine mammals, there are analytical difficulties identifying species from fragmented and even whole bones. Phocid seals are osteologically very similar, and with a few exceptions (skull, mandible, teeth, humeri), their skeletal remains are very difficult to identify as to species (Woollett 1999, Murray 2005*a*). Cetacean bones are often very fragmentary in archaeological deposits because they are heavily processed or modified for tool manufacture or building materials. In such instances identification as to species is not feasible (Huelsbeck 1988), except perhaps using molecular techniques (Yang et al. 2004). Among the Mysticeti (baleen whales) some long bones, scapula, mandibles, maxillae, skulls, and the atlas and axis vertebrae have species-unique morphology (Fiskin 1994), while other elements, such as the ribs and phalanges, do not (Huelsbeck 1988).

On the positive side, zooarchaeology can provide presence/absence information about species in an area at a given point in time (biogeography and paleoenvironmental meaning) (Grayson 1981) and also proxies for species-specific demographic and foraging patterns that are useful for inferring past zoogeographic and migration patterns (Etnier 2004:94–99, Gifford-Gonzales et al. 2005). For example, the archaeological presence of northern fur seals (*Callorhinus ursinus*), Guadalupe fur seals (*Arctocephalus townsendii*), and California sea lions (*Zalophus californiaus*), combined with consideration of their ontogenetic age distributions (determined through the use of thin sections of teeth), the osteometric comparison of their remains to those of modern animals of known age, and the stable isotope characterization of their bones and teeth, provide good proxy measures of past variability in diet, migratory behavior, and breeding colony locations over the past 1500 years in the eastern North Pacific (Etnier 2004). Of significance for conservation, these patterns differ from those described for the recent past with fur seal ranges and possibly also rookeries extending as far south as the Santa Barbara Channel, California, USA, until approximately 1000 years ago (Gifford-Gonzales et al. 2005:34) and northeast to Kodiak Island, USA, in the 18th century (Clark 1986). Archaeological, historical, and osteological data further suggest the possibility of a distinct breeding population, perhaps even an extinct species of fur seal, in the Cape Flattery area of Washington's Olympic Peninsula (Crockford et al. 2002). This kind of information has real implications for decisions "regarding the particular ecosystem conditions or ranges thereof that are legally defensible and biologically desirable" in the context of policy development and restoration (Etnier 2004:102).

The zooarchaeological record also includes proxies of past environmental conditions and, in the north, of changing ice conditions in particular. The presence of ice-obligate or ice-loving species outside their contemporary range(s) and/or changes in the archaeological frequencies of these species over time in a single location may indicate changes in ice extent and/or polynya and ice-edge habitats (Woollett 1999, Woollett et al. 2000, Davis 2001, Henshaw 2003) and provide some clue as to species responses to future environmental changes. For example, changing ice conditions are illustrated by the changing archaeological abundances of three species of *Phoca* from deposits at Hamilton Inlet, Labrador, Canada. There the ratio of ringed (*Phoca hispida*) to harbor seal (*Phoca vitulina*) was roughly neutral in the 17th century, but decreased in the 18th century with harbor seals becoming more common. The ratio then increased in the early/mid 19th century as ringed seals became more common and harp seal (*Pagophilus groenlandica*) abundance declined. These changes are interpreted as reflecting moderate ice in the 18th century more conducive to harbor seals and severe ice in the 19th century more conducive to ringed seals (Woollett 1999:379). Temperature trends derived from tree rings corroborate this, as do glacial geochemical data from the Penney ice cap that suggest decadal and centennial scale variability in sea ice extent, including severe ice in the mid 17th century, moderate conditions through the late 18th century, and rapid onset of severe conditions after the mid 19th century (Woollett 1999:380–381, Woollett et al. 2000).

Osteometric methods applied to archaeofaunal samples can provide information on regional and temporal variation in adult animal size. For example, a suite of standard osteometric measurements of modern *Phoca* seals (Ericson and Storå 1999) was used comparatively to determine that adult harp and ringed seals recovered from archaeological deposits in the Baltic dating to 3300–1800 calibrated years (cal yr) BC (ca. 5300–3800 yr BP) are dwarfed as compared to modern specimens. Other osteometric studies on modern marine mammal specimens have led to the development of methods for estimating sea otter (*Enhydra lutris*) sex from archaeological skeletal material (Lefrancois 2004) and for assessing the length of ancient bowhead whales (*Balaena mysticetus*) (Gerlach et al. 1993).

Just as osteometric analysis informs our understanding of some long-term physiological trends among species, the measurement of heavy metals such as mercury, cadmium, and lead, recovered from the bone collagen or other remains (hair, fur) of archaeofauna, generates important baseline information on preindustrial levels of contaminants and provides retrospective data on animal health and ecosystem conditions (AMAP 2002, Gerlach et al. 2006). Similarly, molecular (DNA) data derived from archaeofauna can be used to evaluate antiquity of stock distinctions (Etnier 2004) and to refine species identifications in questionable cases (Yang et al. 2004).

Archaeological deposits record intentional and unintentional species introductions, including bugs, rats, domesticated animals, and associated pathogens and parasites. Intentional vertebrate (sheep, goats, cattle, and horses) and unintentional invertebrate and parasite introductions (Coleoptra [beetles], human and sheep ectoparasites, and Diptera [true flies]) are demonstrated for both Iceland and Greenland (McGovern et al. 1983, 1988, Buckland et al. 1996). Thus, zooarchaeology is also a powerful tool for identifying invasives and placing these introductions in time and space.

The Archaeological Record of Arctic Marine Mammals: Selected Examples

For discussion purposes I divide the Arctic into six coastal zones that broadly correspond to zones of human–marine system interaction as understood through archaeology and that reflect some coherence in the literature. These are: (1) the Eurasian/Russian Arctic, (2) subarctic and Arctic Alaska, (3) subarctic and Arctic Canada, (4) Greenland, (5) Iceland, and (6) Scandinavia, including the Baltic (Fig. 1). The oldest initial human occupations (terminal Pleistocene) are in the Scandinavian and Eurasian/Russian zones (Pitul'ko and Kasparov 1996, Pitul'ko 1999, Slobodin 1999), and the youngest are in Iceland and date to the 9th century (McGovern et al. 2006). The subarctic regions of Alaska and Canada were first settled early in the Holocene (ca. 9000 yr BP), while the Arctic regions including Greenland were settled in the mid-Holocene (ca. 5000 yr BP) (Maxwell 1985, Dumond 1987). Within each zone information on marine mammals is potentially recorded from the onset of settlement to the recent past. Other evidence of Arctic marine mammal history is recorded in much older paleontological deposits (cf. Harington 1984).

The marine mammals covered below include the polar bear (*Ursus maritimus*) and the pinnipeds, specifically walrus (*Odobenus rosmarus*), ringed and bearded seals (*Erignathus barbatus*), and, where relevant, the ice-associated subarctic harp seal and the harbor seal, which is occasionally ice associated. Some cetaceans are also considered but data are most abundant for the pinnipeds; they are usually the most common marine mammals in these archaeological deposits and consequently they have received the bulk of analytical attention. Summary information for selected examples is presented in Table 1. This is cautiously interpreted given the regional variation in length and quality (preservation) of the archaeological record. Nowhere is it possible to present a complete zooarchaeological history. However, in some places, for some time periods, there is reasonable, local-scale coverage (i.e., within a bay, on a peninsula, a specific island), with potential in a few instances to extrapolate to a wider region. Where such data are available, an effort at synthesis is beneficial for gaining an appreciation of gaps in knowledge and developing research strategies to address such in the future.

Polar bear (Ursus maritimus)

Polar bear remains are rare in archaeological deposits and usually occur as partial fragments of limb bones or individual cranial or extremity elements, in some cases possibly as objects of specialized treatment (Murray 2000). In Alaska reports on fauna from coastal archaeological sites are few and generally lack quantitative information; however, polar bear bones occur in the subarctic area in a Neoglacial-age (4700–4100 yr BP) deposit from Margaret Bay, Unalaska (Davis 2001), and they are reported from Arctic sites such as Hillside (1800 and 1600 yr BP) at Gambell, St. Lawrence Island (Dumond 1998:117), and in more recent deposits (1000 yr BP to historic era) from Barrow (Stanford 1976). A few reported archaeological deposits from the Canadian Arctic archipelago dating to ca. 4000–3500 yr BP, ca. 2500–2000 yr BP, and ca. 1000 yr BP contain some fragments of polar bear bone (McGhee 1979:62, 94, 1984, McCullough 1989), including one with mainly skulls and mandibles (McGhee 1981:55). Some sites of similar age range in west-central Greenland contain polar bear bones (Grønnow and Meldgaard 1991, Moberg 1999); however, many deposits from the earliest periods in both Canada and Greenland contain no polar bear bone at all (see for example McGhee 1979:35, Arnold 1981, Grønnow 1994, LeBlanc 1994, Murray 1996). This may be a function of small sample size (cf. Grayson 1981), of poor preservation associated with older deposits, or of temporal differences in hunting techniques or demand for polar bear. Regardless, the quantity of polar bear in any given deposit from Alaska, Canada, and Greenland is scant compared to other species.

One exception to the "few fragments" trend is the Zhokov Island site in the Laptev Sea, Russian Arctic. Here a sizable collection of polar bear bones ($N = 397$ fragments) represents multiple individuals ($N = 21$). The site dates to the early Holocene (ca. 8000 yr BP) and is interpreted as a place where polar bear exploitation for consumption and trade in hides was the focus of the human occupation (Pitul'ko and Kasparov 1996, Pitul'ko 1999). The deposits also contained a significant amount of reindeer (*Rangifer tarandus*) and bird bone but only a few fragments of pinniped bone (walrus and bearded seal) (Pitul'ko and Kasparov 1996).

One explanation for the rarity of polar bear remains in archaeological contexts may be that it was rarely an important subsistence species for Arctic people. Despite their scarcity however, archaeological polar bear remains are still suitable for molecular, comparative biological, and biochemical research, and paleoenvironmental inferences can be made when polar bear bones co-occur with the remains of other Arctic species in archaeological deposits removed from current ranges.

Walrus (Odobenus rosmarus)

Although ivory is common in many sites across the subarctic and Arctic, it was widely traded. The presence of ivory on a site cannot be taken as evidence for exploitation of a local walrus population unless there is also evidence for on-site processing of carcasses for ivory extraction (cf. LeMoine and Darwent 1998) and/or the post-cranial skeletal remains of individuals of a variety of age classes, including neonates and young of the year.

In subarctic Alaska walrus bone occurs in low frequencies in the Neoglacial deposits from Margaret Bay, Unalaska (Davis 2001), and also in early 20th century deposits from Mink Island, a site on the south coast of the Upper Alaska Peninsula (Murray 2005*b*). In Arctic Alaska walrus occur in high frequencies at sites with occupations spanning the past 1000 years on St. Lawrence Island (Collins 1937), at Cape Nome (Bockstoce 1979), in the Kotzebue area (Giddings and Anderson 1986), and at Barrow (Stanford 1976, Dyke et al. 1999).

In Arctic Canada walrus remains are few in mid-Holocene sites (ca. 4500–2500 yr BP), occurring mainly as fragments of tusk (Murray 1996, 1999, Dyke et al. 1999, Darwent 2004, Murray 2005*a*), but then bones appear in greater quantities in deposits dating from roughly 2000 yr BP forward (McGhee 1981, Murray 1996, 1999, Darwent 2004). In the Foxe Basin the increase in archaeological abundance may be linked to human technological developments in combination with changes in sea level associated with post-glacial rebound and the expansion of benthic habitat (Murray 1996, 1999), while further north among the islands of the archipelago, sea ice expansion may have been a factor (see Harington 2008). In both areas these environmental changes would have facilitated human access by bringing the animals closer to shore and enabling hunting from an expanded and possibly more stable sea ice platform. Interestingly, in these same regions there is a decline in walrus remains in archaeological deposits from ca. 1200 yr BP. This may be due to as yet undetermined ecological, climatological, or anthropo-

FIG. 1. Locations noted in the text (map prepared by C. Strathe).

genic factors, including possible overhunting (Born et al. 1995, Murray 1999), in combination with some degree of human social reorganization (Maxwell 1985). A similar argument for humans as drivers of marine system change has been made for the western Aleutian Islands, where variability in subsistence over the past 2500 years appears to be tied to nearshore ecosystem shifts driven by the overhunting of sea otters (Simenstad at al. 1978).

Walrus bone also occurs in more recent archaeological deposits (ca. 1000 yr BP to present) in the Canadian Arctic. At Southampton Island, Hudson Bay, it is abundant as compared to other species (Collins 1955) and as compared to quantities in sites from the Foxe Basin (Murray 1996, 1999). In the archipelago walrus bones are also present in more recent site deposits, although they are described as relatively rare as compared to the bones of ringed seal (McGhee 1984).

In northern Greenland Darwent (2003:343) and Dyke et al. (1999) note young walrus postcranial material from a site in Jørgan Brønland Fjord (ca. 3900 and 3500 yr BP), as the most northern record of walrus in the eastern Arctic, roughly 400 km north of the current range. Darwent's (2003) data on marine mammals from 10 mid-Holocene era sites in northern Greenland (abstracted and summarized in Table 1) indicates that apart from one incidence, walrus remains are not present, although some other marine species (ringed seal, harp seal) are.

In western Greenland trends in the archaeological abundance of walrus remains are similar to those in Arctic Canada, with a minor increase over time from ca. 4000 yr BP, which probably reflects technological changes more than anything else (Moberg 1999, Gotfredsen 2004). In some western Greenland deposits ca. 4400–2400 yr BP, walrus are indicated only by the presence of a few ivory flakes (Meldgaard 2004), which might simply reflect trade in ivory with people in other regions. Walrus remains have also been documented in small quantities on nearly every medieval Norse archaeological site in Greenland, primarily present as the by-product of tusk and hide processing (McGovern et al. 1993).

TABLE 1. Summary faunal data for examples discussed in the text.

					Pinnipedia						
			Carnivora		Odobenidae	Phocidae					
Location and site name	Years BP†	Total no. fragments‡	Polar bear	Sea otter	Walrus	Bearded	Ringed	Harp	Harbor	Gray	Phoca sp.
Eurasian Russian Artic											
Laptev Sea											
Zhokov Island	8000	895	397	0	4	1	0	0	0	0	0
Bering Strait											
Kaniskak	800–300	NA	P	—	P	P	P	NP	NP	NP	NP
Ninluvak	800–300	NA	—	—	P	P	P	NP	NP	NP	NP
Alaska											
Aleutian Island											
Margaret Bay	4700–4100§	5392	107	91	10	0	593	0	2942	0	0
Kodiak Island											
Craig Point	2000–1000	209	0	4	0	0	0	0	175	0	0
Three Saints	2000–1000	227	0	1	0	0	0	0	167	0	0
Artel	no date	282	0	2	0	0	0	0	172	0	0
Kiavak	500–200	177	0	1	0	0	0	0	92	0	0
Rolling Bay II	500–200	297	0	0	0	0	0	0	58	0	0
St. Lawrence Island											
Hillside	1800–1600	NA	P	NP	P	P	P	NP	P	NP	NP
Hillside	1800–1600	NA	P	NP	P	P	P	NP	P	NP	NP
Miyowagh	Late Holocene	NA	P	NP	P	P	P	NP	P	NP	NP
Iveoghiyoq	Late Holocene	NA	P	NP	P	P	P	NP	P	NP	NP
Seklowaghyaget	Late Holocene	NA	NP	NP	P	NP	P	NP	P	NP	NP
Gambell	Late Holocene	NA	P	NP	P	NP	NP	NP	NP	NP	P
Barrow											
Walakpa¶	1500–1100	9442	15	0	66	140	0	0	0	0	5617
	1100–600	2073	6	0	14	12	0	0	0	0	1264
	600–historic	7008	13	0	19	49	0	0	0	0	2596
Canada											
Mackenzie											
Gupuk	Inuit	11714	1	0	0	5	0	0	0	0	251
Western Arctic											
Crane	2500	39233	NP	NP	NP	P	P	P	NP	NP	P
Banks Island											
Lagoon Site	2338 ± 67	846	0	0	0	1	183	0	0	0	0
Devon Island Port Refuge											
Cold	ca. 4000	1139	0	0	0	49	928	0	0	0	0
Upper Beach	ca. 4000	283	2	0	0	0	10	0	0	0	0
Gull Cliff	ca. 4000–3500	799	3	0	0	31	509	0	0	0	0
Lower Beach	2500	1432	2	0	1	4	1335	0	0	0	0
Snowdrift	1000	NA	P	NP	P	P	P	NP	NP	NP	NP
Cornwallis											
Arvik	1550–780 ± 50§	NA	NP	NP	P	P	NP	NP	NP		P
Bathurst Island											
Brooman Point	900	NA	P	NP	P	P	P	NP	NP	NP	P
Ellesmere Island											
Skraeling	900	15360	357	0	1097	379	10 197	0	0	0	0
Foxe Basin											
NiHf 58	3800#	1263	0	0	15	23	77	0	0	0	418
NiHf 2	3800–3000	291	0	0	11	8	209	0	0	0	0
NiHf 47	2500–1800	308	0	0	78	19	50	0	0	0	0
NiHf 45	1000	2775	0	0	104	45	1225	0	0	0	0
Southampton Island											
T1	1800–1000	NA	P	NP	P	NP	NP	NP	NP	NP	P
T2	19th C	NA	P	NP	P	NP	NP	NP	NP	NP	P

TABLE 1. Extended.

Pinnipedia									
Otaridae		Cetacea			Odontoceti (Porpoise)				
Steller sea lion	Northern fur seal	Beluga	Bowhead	?	Harbor	Dall	Killer whale	?	Reference
0	0	0	0	0	0	0	0	0	Pitul'ko and Kasparov (1996)
NP	NP	NP	NP	NP	NP	NP	NP	NP	Gusev et al. (1999)
NP	NP	NP	NP	NP	NP	NP	NP	NP	
431	323	5	0	48	647	377	5	0	Davis (2001)||
5	2	0	0	0	0	0	0	23	Clark (1986)
4	20	0	0	0	0	0	0	35	
0	98	0	0	0	0	0	0	10	
4	50	0	0	0	0	0	0	30	
6	184	0	0	0	0	0	0	49	
NP	NP	NP	NP	P	NP	NP	NP	NP	Dumond (1998)
NP	NP	P	NP	NP	NP	NP	NP	NP	Collins (1937)
NP	NP	P	P	P	NP	NP	NP	NP	
NP	NP	P	P	P	NP	NP	NP	NP	
NP	NP	NP	NP	P	NP	NP	NP	NP	
NP	NP	NP	NP	P	NP	NP	NP	NP	
0	0	0		14	0	0	0	0	Stanford (1976)
0	0	0		5	0	0	0	0	
0	0	0		22	0	0	0	0	
0	0	0	0	0	0	0	0	0	Friesen and Arnold (1995*b*)
NP	NP	NP	NP	NP	NP	NP	NP	NP	LeBlanc (1994)
0	0	0	0	0	0	0	0	0	Arnold (1981)
0	0	0	0	0	0	0	0	0	McGhee (1979)
0	0	0	0	0	0	0	0	0	
0	0	0	0	0	0	0	0	0	
0	0	0	0	0	0	0	0	0	
NP	NP	NP	NP	NP	NP	NP	NP	NP	McGhee (1981)
NP	NP	NP	NP	NP	NP	NP	NP	NP	LeMoine and Darwent (1998)
NP	NP	NP	NP	P	NP	NP	NP	NP	McGhee (1984)
0	0	0	0	0	0	0	0	0	McCullough (1989)
0	0	0	0	0	0	0	0	0	Murray (2005*a*)
0	0	0	0	0	0	0	0	0	Murray (1996)
0	0	0	0	0	0	0	0	0	
0	0	0	0	0	0	0	0	0	
NP	NP	NP	NP	NP	NP	NP	NP	NP	Collins (1955)
NP	NP	NP	NP	NP	NP	NP	NP	NP	

Table 1. Continued.

			Carnivora		Pinnipedia						
					Odobenidae	Phocidae					
Location and site name	Years BP†	Total no. fragments‡	Polar bear	Sea otter	Walrus	Bearded	Ringed	Harp	Harbor	Gray	Phoca sp.
Labrador											
Eskimo Island 3	AD 1600–1700	2992	0	0	1	0	67	164	79	0	2173
Eskimo Island 1	AD 1700–1800	2826	0	0	0	0	28	78	63	0	2334
Eskimo Island 2	AD 1800–1850	2796	0	0	0	0	45	61	46	0	2382
Snooks Cove	AD 1850–1900	289	0	0	0	0	3	17	16	0	0
Greenland											
North Hall Land											
Solbakken	4000–3500	68	9	0	0	0	4	0	0	0	2
Pearyland											
Adam C. Knuth	4000–3500	846	3	0	1	14	10	1	0	0	10
Bob's Site	4000–3500	98	0	0	0	0	0	0	0	0	1
Pearylandville	4000–3500	1656	2	0	0	0	0	0	0	0	—
Galleriert	4000–3500	35	0	0	0	0	7	0	0	0	18
Hellebæk	2600–2300	53	0	0	0	0	1	0	0	0	37
Vandfaldsnæs	2600–2300	211	0	0	0	0	7	0	0	0	77
Kap Harald Moltke	2600–2300	33	0	0	0	0	2	0	0	0	11
Kap Mylius-Erichsen	2600–2300	158	0	0	0	0	0	0	0	0	17
Kap Ludovika	2600–2300	18	0	0	0	0	2	0	0	0	2
Disko Bay											
Qeqertasussuk	3900–3100	NA	NP	NP	P	P	P	P	P	P	NP
Iceland											
Akurvik 24	11th–13th C AD	8922††	0	0	0	0	0	0	0		26
Akurvik 22	15–16th C AD	99 858††	0	0	0	0	0	0	4		4
Baltic Aland Islands											
Otterbötte	4800	578	0	0	0	0	15	0	0	391	0
Brömsängsbaken	1500–1000	71	0	0	0	0	3	26	0	42	0
Eneborg	1500–1000	73	0	0	0	0	3	30	0	40	0
Kohagen H5	1500–1000	819	0	0	0	0	3	22	0	32	0
Baltic Estonia											
Asva	4800	1812	0	0	0	0	8	44	12	32	0
Ridala	2800–2600	2663	0	0	0	0	6	28	2	22	0
Kaali	2500	141	0	0	0	0	0	2	14	0	0
Asva	1500–1000	1812	0	0	0	0	2	37	4	13	0

Notes: Dashes indicate missing data. Key to abbreviations: C, century; P, present; NP, not present.

† Unless otherwise indicated, all dates are estimates due to inconsistencies in reporting methods, in some cases the use of relative ages rather than radiocarbon ages, and use of dates derived from historic documentation.

‡ Total number of identified bone fragments for the entire reported sample, where available, including fish, terrestrial mammals, and birds. All species data in following columns are reported also as TNF, but only marine mammal fauna are included. Where remains are not quantified presence (P) is noted.

§ Indicates a date in radiocarbon years BP.

|| NISP for species calculated from percent NISP values published in Davis (2001:74).

¶ NISP represent summed values for multiple levels in a single deposit associated with the estimated date.

NISP values reflect summed values for six tent ring features.

†† Samples are dominated by fish remains.

With respect to northwest Greenland it is useful to note that in adjacent regions of Canada (eastern Ellesmere Island), walrus remains are present in many sites dating to the last millennium, and, as in other sites dating to this era, the quantities are small relative to ringed seal. Archaeologists link the walrus and some cetacean remains in these archaeological deposits to the extent and duration of the open-water season, the presence of primary and secondary polynyas, and interplay among wind strength, wind direction, and ice thickness (Schledermann and McCullough 2003). These are all important factors conditioning human predation practices and accessibility to walrus, and they probably fluctuated at scales not necessarily observable in the archaeological record of this region.

The widespread if not always stable or abundant occurrence of walrus in subarctic and Arctic archaeological deposits indicates that ranges and population sizes were subject to periodic fluctuations even before the onset of the commercial ivory trade during the

Table 1. Continued, Extended.

Pinnipedia									
Otaridae		Cetacea			Odontoceti (Porpoise)				
Steller sea lion	Northern fur seal	Beluga	Bowhead	?	Harbor	Dall	Killer whale	?	Reference
0	0	0	0	38	0	0	0	0	Woollett (1999)
0	0	0	0	13	0	0	0	0	
0	0	0	0	5	0	0	0	0	
0	0	0	0	1	0	0	0	0	
0	0	0	0	0	0	0	0	0	Darwent (2003)
0	0	0	0	0	0	0	0	0	
0	0	0	0	0	0	0	0	0	
0	0	0	0	0	0	0	0	0	
0	0	0	0	0	0	0	0	0	
0	0	0	0	0	0	0	0	0	
0	0	0	0	0	0	0	0	0	
0	0	0	0	0	0	0	0	0	
0	0	0	0	0	0	0	0	0	
0	0	0	0	0	0	0	0	0	
NP	NP	NP	NP	P	NP	NP	P	P	Grønnow (1994)
0	0	0		67	0	0	0	0	Amundsen et al. (2005)
0	0	0		1528	0	0	0	0	
0	0	0		0	0	0	0	0	Storå and Lõugas (2002)
0	0	0		0	0	0	0	0	
0	0	0		0	0	0	0	0	
0	0	0		0	0	0	0	0	
0	0	0		0	0	0	0	0	
0	0	0		0	0	0	0	0	
0	0	0		0	0	0	0	0	
0	0	0		0	0	0	0	0	

medieval era. Human activities and changing environmental conditions may both have driven change depending upon the period in question and the location. For example, in some places such as St. Lawrence Island, Alaska, walrus appear to have been proximate for at least the last millennium, regardless of human predation or environmental change. In other locations, such as the more southerly Aleutian Islands, the walrus bone in archaeological deposits is temporally restricted and probably reflects the large climate perturbations associated with the Neoglacial. In areas such as the Foxe Basin, change in the archaeological abundance of walrus remains is likely the result of the combined effects of human hunting efforts and natural-system drivers.

Bearded seal (Erignathus barbatus)

Most ethnographic accounts of Inuit use describe bearded seal as a significant but secondary staple; the skins were particularly important for making lashes, lines, boots, etc. (Boas 1888, Balikci 1970, Smith 1991). Bearded seals are not gregarious like walrus (see Harington 2008), and therefore they are less visible on the sea(ice)-scape. They are comparatively scarce in relation to ringed seals, and Inuit report regular, even annual, fluctuations in their local availability (Smith 1991). Probably reflecting these aspects of their ecology and behavior, bearded seal remains generally do not occur in large quantities in archaeological deposits, although there is widespread pattern of low but consistent representation over time and space. Small quantities of bearded seal bone are reported from sites dating to the last 1000 years in the Barrow area of Alaska (Stanford 1976) and from sites in the Foxe Basin, Arctic Canada, ca. 4500–1000 yr BP (Murray 1996, 1999). A similar pattern is reported for the same time period in Canada's high Arctic (Darwent 2004) and also from southwest Greenland (Gotfredsen 2004). Bearded seal bones are also reported from early Holocene deposits on Zhokov Island in the Laptev Sea and from later Holocene sites along the Russian side of the Bering Sea, as well as from sites on St. Lawrence Island, Alaska, and in the western Canadian Arctic (Table 1).

Ringed seal and other phocidae

The presence and relative abundance of ringed seal and other phocid bones in archaeological deposits fluctuates significantly over time and space. Ringed seals appear in subarctic Alaskan deposits only during specific climate episodes. For example, again at Margaret Bay, Unalaska, we find the remains of ringed seal pups, juveniles, and adults in the Neoglacial deposits (Davis 2001:77). These co-occur with the polar bear and walrus remains discussed above and suggest that conditions were sufficient for the formation of a stable ice platform for breeding, den construction, and haul-out. In contrast to subarctic Alaska, ringed seals are present in site deposits throughout the Holocene in the subarctic and Arctic regions of Labrador (see, for example, Cox and Spiess [1980]). But here it is the ratio of ringed to harbor to harp seals that provides the indicator of climate and sea ice changes (cf. Woollett 1999, Woollett et al. 2000) rather than changes in entire suites of taxa (cf. Grayson 1981).

Moving north we find ringed seal remains in sites dating to the initial human settlement (4500 yr BP) of the coastal areas of Arctic Alaska, Arctic Canada, and Greenland (Maxwell 1985). In fact, across this area ringed seal remains are ubiquitous in archaeological deposits, regardless of cultural affiliation, region, or time period (Collins 1937, 1955, Stanford 1976, McGhee 1979, 1981, 1984, Arnold 1981, Giddings and Anderson 1986, McCullough 1989, Gronnow and Meldgaard 1991, Mason and Gerlach 1995, Murray 1999, 2005*a*, Woollett et al. 2000, Darwent 2003, 2004, Henshaw 2003, Schledermann and McCullough 2003, Gotfredsen 2004, Meldgaard 2004, to note just a few).

In Foxe Basin ringed seal remains dominate early assemblages (ca. 4500 yr BP), are less common in assemblages dating to ca. 2500–1800 yr BP (where walrus is the most abundant marine mammal), and then most common again in assemblages dating ca. 1000 yr BP. Further to the east in Arctic Quebec the frequencies of ringed seal remains are relatively constant, at least during the period ca. 3000–2000 yr BP (Nagy 2001), while data from High Arctic Canada and northwest Greenland indicate a relative increase in ringed seal remains in sites dating from 4500–2000 yr BP. Fluctuations in the abundance of ringed seal remains in Foxe Basin are measured against changes in walrus habitat and human technology (Murray 1996), while in the High Arctic the increased abundance is possibly related to favorable climate changes (Darwent 2004:69).

In some places archaeologists link the appearance and disappearance of sea mammals (including ringed seal) in the archaeological record directly to climate and/or local ecological changes, although these are often not well described. For example, Pitul'ko (1999:421–424) argues that in coastal Fennoscandia, sea mammals separately or in combination with reindeer are the foundation of subsistence from the onset of the Holocene, with exploitation of ringed seal developing first, followed by walrus, then the development of harp sealing, and finally occasional whaling. In parts of Fennoscandia seal hunting ended in the local Early Iron Age (ca. 2000 yr BP), and this appears to be concurrent with a drop in temperatures (Pitul'ko 1999).

Further south in the Baltic the situation appears similarly fluid (Price 1985, Zvelebil and Rowley-Conwy 1986, Anderson 1995, Jaanits 1995, Storå 2002). At ca. 5600 yr BP (middle Holocene), when summers were warmer and winters colder with more severe ice than today (Sub-boreal K Climatic Period), ringed seal is found in archaeological deposits from the Åland region, well outside the current range (Storå 2002). It is also found in small quantities in Åland sites dating between 3800–1000 yr BP (Sub-Atlantic Climate Period), and in sites on Saaremaa Island, Estonia (Storå and Lõugas 2002). However, ringed-seal distributions shrink over time, as indicated by presence/absence data, and gray seal (*Halichoerus grypus*) remains become prevalent (Storå 2002:49–62, Storå and Lõugas 2002). The harp seal, another ice-loving species, is present in many of these same archaeofaunal assemblages, as well as from other middle and later Holocene sites in Gotland, Eastern Middle Sweden, along the Swedish west coast, in Poland, and from Mesolithic (7000–5500 yr BP) sites in Denmark (cf. Storå and Ericson 2004:116–119). Harp seals may even have formed a permanent breeding population in the Baltic during the middle Holocene, as indicated by the occurrence of some very small and very young individuals in the relevant deposits (Storå 2002:51–61). Harp seal bones become less common in deposits over time, and adult size decreases, possibly reflecting changed ecological conditions, including those associated with climate warming, that affect growth and development (Storå 2002:60, Storå and Ericson 2004). The harp seal is not present in the Baltic at all today, with local extinction possibly resulting from climate change and fluctuation, interspecific competition, and/or overhunting (Storå and Ericson 2004:129). Today harbor seals are the most common pinniped species in the southern Baltic, but the archaeological data indicate perhaps total absence throughout the area during the middle Holocene and a more northerly distribution in the later Holocene (Storå and Lõugas 2002).

Across the Tamir/Laptev Sea coastal region of the Russian Arctic, which was initially occupied in the terminal Pleistocene, with widespread occupation by 8000 yr BP (Weber et al. 1993, Pitul'ko 1999) and including interior Lake Baikal in central Siberia, ringed seals occur in archaeological deposits from the middle Holocene onward (Weber et al. 1993). However, fluctuations in the archaeological abundance of ringed seal remains or those of any other Arctic marine mammal in this region and further east along the Russian coasts of the Chukchi and the Bering Seas are difficult to determine because of reporting techniques that generally note only presence or absence of a species or provide incomplete quantification of collections (see, for example, Gusev et al. [1999]) or brief overview of perceived trends (cf. Pitul'ko 1999).

Cetaceans (beluga, narwhal, and bowhead whales)

Cetacean remains are reported from sites across the Arctic and subarctic (see, for example, papers in McCartney [1995]). The record of cetacean exploitation is spatially and temporally spotty, and their remains are sometimes difficult to identify to species (as anything other than "whale") due to morphological similarity or excessive processing beyond recognition. There is also much debate over the cause of some cetacean remains in archaeological deposits. In Iceland there is discussion about whether remains dating prior to the onset of commercial whaling reflect deliberate hunting or exploitation of stranded whales (Amundsen et al. 2005). This mirrors similar debate over the cause of whale remains in prehistoric Alaskan contexts (see, for example, Mason and Gerlach [1995] and Dumond [1995]), and it bears on whether or not archaeological samples can be used to reconstruct stranding patterns and migration routes.

For ecological research and conservation purposes, archaeological deposits that reflect focused human exploitation of cetaceans with preservation of whole or significant portions of individual skeletons of multiple individuals, such as the beluga whale (*Delphinapterus leucas*), drive and kill sites in the Mackenzie Delta, western Canadian Arctic (McGhee 1974, Friesen and Arnold 1995*a*), the bowhead whale kill and processing sites in the central Canadian Arctic (Savelle and McCartney 1994), and similar in Alaska and Chukotka (Mason and Gerlach 1995, Savelle and McCartney 2003), are probably most productive. Such assemblages offer the opportunity to determine the dietary importance of cetaceans to their human predators (Friesen and Arnold 1995*b*), as well as to collect radiometric, osteometric, age, and molecular data on multiple individuals from a single population or a range of individuals within an age class, as in the case of bowhead kill sites (Savelle and McCartney 1994, 1999). Both the beluga drive and the bowhead processing sites date within the last millennia, and the remains from such sites offer important information on recent evolutionary history situated within the context of shorter-term climate change episodes, such as the Medieval Warm Period and the Little Ice Age.

DISCUSSION, POTENTIAL APPLICATIONS, AND RECOMMENDATIONS

This synthesis is by no means complete, and at best it should be considered a first approximation for reasons that are perhaps only partly apparent. The material discussed here is largely limited to research that has taken as its focus the identification of long-term patterns in human–marine mammal interaction on a local scale, although some that provides a qualitative assessment of the character and composition of archaeofaunas is also included. Problem-oriented zooarchaeological research, at least in the North American context, developed only during the past 20 years, a time when funding for archaeology has suffered significant cuts. Northern fieldwork has been curtailed for both financial and political reasons. Many collections made prior to the 1990s do not contain faunal remains because of in-the-field sampling decisions (see, e.g., McGhee 1984) or the collections are severely compromised by field methods. These circumstances are reflected in publication content and focus. There are huge spatial and/or temporal data gaps, and linking local trends to regional or global-scale climate patterns remains difficult in the absence of better coverage and more thorough and more consistent dating.

Nevertheless, when there is an informed understanding of the data limitations, meaningful spatial and temporal comparisons are both feasible and productive (Amorosi et al. 1996). Site types from which samples are selected must be matched appropriately with the research questions being asked (Amorosi et al. 1996:129), and selective use of existing collections may also be warranted, especially in areas where coverage would be severely compromised if they were excluded or in areas where collection of new data is not possible (Amorosi et al. 1996:130). Field methods now generally incorporate techniques designed to improve faunal recovery, and new methods, including the development of molecular approaches to species identification (Butler and Bowers 1998, Etnier 2004, Yang et al. 2004), the identification of species-specific epiphyseal fusion sequences (Storå 2000, 2002), and improvements in older techniques (i.e., thin-section analysis of teeth, stable isotope analysis of bone collagen, osteometrics), offer great potential to contribute to our understanding of biotic responses to ecological and environmental perturbations through study of previously analyzed collections as well those recently recovered.

What can be said based on present data? We have evidence of flexible human response to changes in environmental conditions and access to marine mammals, and we know that water, weather, and ice conditions are important factors conditioning human predation. Along with technology these dictate the nature of human–marine mammal interactions. These variables fluctuate at scales not necessarily observable in the archaeological record (daily, weekly, monthly), and they probably do account for some of the variability in species abundance in archaeological deposits throughout the Holocene, regardless of the specific region. Nevertheless there is clear evidence from some regions of shifts in species' ranges and of the co-occurrence of suites of taxa that do not co-occur today. Thus we have data on past alternate communities, including some instances in which humans are identifiable as drivers of marine community change (cf. Simenstad et al. 1978). The best information on marine mammal response to changing climate conditions comes from subarctic regions such as the Aleutians, Labrador, and the Baltic; in these places there were dramatic shifts in suites of available taxa as typically Arctic species and ice-obligate or ice-loving species extended their ranges southward (or visa versa). For the pinnipeds in particular, presence/absence data, changes in their archaeological abundance, and age profiles suggest shifting ice conditions more or less conducive to local success and even breeding, depending on the species in question.

Where do we go from here? To gain a more complete understanding of the complex relationships among climate, Arctic marine mammal biogeography, and human adaptations, it is perhaps important now to focus on the collection of information from subarctic regions and on historic and prehistoric periods that are identified as anomalously warm or cool. Many more analyses of collections from many more coastal sites, both subarctic and Arctic, are required if we are to move the applied zooarchaeology of the north beyond "documenting the historical dialectic between humans and environments" and then to "use that knowledge to ensure the future of both" (Lyman and Cannon 2004:4). Perhaps of greatest importance is the need to expand coordinated research efforts beyond those well developed in the North Atlantic research community (such as those of the North Atlantic Biocultural Organization), to identify data gaps on a circumpolar scale, and to seek the means to fill those gaps through field and laboratory research. Easily achieved should be the (re)analysis of existing collections (even those with clear sample bias) using new osteometric, chemical, and molecular approaches in an effort to identify pinnipeds and cetaceans to species. It is often less expensive to analyze previously collected materials rather than to excavate to collect new samples, depending upon the research question(s) asked. A systematic study of collections with large numbers of previously indistinguishable samples that can be dated has the potential to reveal new information on species range expansions and contractions in the context of past climate changes, as well as information on human adaptability.

The interest in marine mammal biogeography, conservation, and management issues on the part of archaeologists is situated within a growing emphasis in the historical and social sciences on understanding global change as broadly construed (Crumley 2007). Scholars from a variety of disciplines and from archaeology in particular are now well positioned to heed the call by Amorosi et al. (1996:127) to recognize the "prospect that our common research may be used to inform decisions that may potentially affect a great many living human beings ..." and acknowledge our "obligation to work together to ensure that the interpretive accounts we contribute are the best our discipline can provide." The collection and use of zooarchaeological data in order to fill gaps in our understanding of past ecosystem variability should be an integrated element of interdisciplinary inquiry directed towards understanding future changes, responses to change, and the development of adaptive management strategies. Nowhere is this perhaps more pressing or relevant than in the Arctic.

Acknowledgments

Thanks to Henry Huntington and Sue Moore for inviting me to write this paper and pushing me to complete it. Thanks also to my many colleagues upon whose data and research I have drawn. Cody Strathe deserves credit for the map. S. Craig Gerlach's work on bison in Alaska provoked my interest in "applied" zooarchaeology. The comments of two anonymous reviewers were most constructive for improving both content and argument. Some of the data used here were collected during my doctoral research, which was supported by the Social Sciences and Humanities Research Council of Canada. The U.S. National Park Service, Lake Clark/Katmai National Park, and Jeanne Schaaf provided support for the analysis of the archaeofauna from Mink Island, Shelikof Strait, Alaska. That assemblage contains some of the walrus that is referred to in this paper.

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