

**The Paleoenvironment of Humans and Marine Birds of the Aleutian
Islands: Three Millennia of Change.**

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Running title: Aleutian paleoenvironment

Revised

29 November 2004

23 February 2005

ABSTRACT

A unique window into the biological history of the Aleutian Islands is provided by the zooarcheology of early human sites. We focus on the paleoavifauna hunted by early Aleuts who inhabited Amchitka and Buldir islands (central Aleutians), and Shemya Island (western Aleutians) from about 3,500 years ago to the present. Most of the seabird species recovered from these early sites varied widely in distribution and abundance through time and space. Pelagic procellariids such as Short-tailed Albatrosses and Short-tailed Shearwaters were present and abundant at most sites and at most times. During periods of increased temperatures and precipitation (e.g., 650-1100 ybp), nearshore foragers such as cormorants and parakeet auklets increased in abundance, but during periods of cooling (e.g., 1800-2100 ybp), piscivorous birds feeding offshore such as murre and kittiwakes predominated. Over three millennia, we found that marine bird populations were negatively correlated with temperature and positively correlated with precipitation. We detected hunter-related depletions of populations breeding in accessible colonies at small scales of space and time, but we did not observe widespread or long-term effects. We conclude that local oceanography and regional changes in prey bases caused by environmental and climate change in the past had a significant impact on the distribution and abundance of Aleutian marine birds.

Key Words: Paleobiology, zooarchaeology, environmental change, population dynamics, marine birds, Aleutian Islands.

INTRODUCTION

“The natives of Attu inform me that the Cod has not long been an inhabitant of the waters around that island. Its advent was near 1873. Previous to that time individuals had been obtained but rarely and many of the men had not seen a Cod [before]...The Codfish are very numerous at the present day. They attain immense size there. I saw one individual in February, 1881, that weighed just out of the water an even thirty pounds.”

(Turner, 1886)

The first Europeans to the Aleutian Islands (Fig. 1) viewed an environment that differed in many ways from the present. Davydov (1810) and Berkh (1823) noted abundances of marine vertebrate animals in the Aleutians far higher than exist today—even after more than a half-century of exploitation by Russian fur traders. The first scientifically detailed reports were by William Dall, a naturalist associated with the California Academy of Sciences. He observed that Black Brants (*Branta nigricans*) were breeding in the Near Islands, that Ancient Murrelets (*Synthliboramphus antiquus*) occurred in high abundances throughout the Aleutians, and that Parakeet Auklets (*Aethia psittacula*) were restricted to only Amchitka Island in the central Aleutians (Dall, 1874). None of these observations are the case today. The most quantitative reports, however, were by Lucien Turner, who worked as a weather observer and naturalist on Attu Island in 1878 - 1881. He reported that Pacific Cod (*Gadus macrocephalus*) and Atka Mackerel (*Pleurogrammus monopterygius*) were unknown in the Near Islands five years previous to his arrival, but during his time on Attu Island they occurred in prodigious numbers. For example, from June 1 to July 31, 1879, five families

on Attu Island collected 10,000 pounds of Atka Mackerel by hand. Capelin (*Mallotus villosus*) were perhaps even more abundant in the waters around Atka Island: "...dead fish were so thick on the beach that it was impossible to walk without stepping on hundreds of them. They could be gathered with a shovel, they laid so thickly" (Turner 1886: 102). [Capelin are now nearly absent from the region for reasons unknown (Piatt and Anderson, 1995)]. He described birds on Attu Island at that time as common species that are rarely or never seen there today (e.g., Red-legged Kittiwake *Rissa brevirostris*) and, based on eyewitness accounts by native Attuans, reported that Pallas's Cormorants (*Phalacrocorax perspicillatus*)—by then extinct—abounded there only 15 years earlier.

Many of the subsequent changes in the natural environment of the Aleutians and Bering Sea clearly were the direct or indirect effect of European activities. These include the near extirpation of sea otters, *Enhydra lutris* (Doroff *et al.*, 2003); declining fisheries in cod, pollock (*Theragra chalcogramma*), and decapoda (Jackson *et al.*, 2001); and disappearance of Short-tailed Albatross (*Phoebastria [Diomedea] albatrus*) and Aleutian Canada Geese (*Branta canadensis leucopareia*) from most breeding islands (Jones, 1963). Other changes, including the abrupt appearance in the 1880s of Arctic Cod and Atka Mackerel in the Near Islands, and the recent population crashes of sea otters, Steller sea lions (*Eumetopias jubatus*) and Northern fur seals (*Callorhinus ursinus*) (Braham *et al.*, 1980; Trites, 1992; Trites and Donnelly, 2003), are less attributable to anthropogenic effects and may be associated with environmental variability (Francis, 1996) or other yet unknown factors.

Recent evidence indicates that the Beringian and North Pacific regions are undergoing rapid environmental change (Trenbeth and Hurrell, 1994; Mantua *et al.*, 1997),

with consequent cascading effects on the biota (Oedekoven *et al.*, 2001; Jones *et al.*, 2002; Steneck *et al.*, 2002). At the same time, the collapse of virtually every major fishery around the world in recent decades (Amorosi *et al.*, 1996; Lyman, 1996; Jackson *et al.*, 2001; Reitz, 2004) has made it urgent to understand the underlying processes driving change in marine ecosystems. As our knowledge of ecosystem processes increases, it is clear that present-day conditions and records are inadequate to characterize long-term, large-scale ecosystem variability and function. It is valuable, therefore, to place the present conditions in Beringian marine ecosystems into a deep temporal context of historical patterns and to provide a baseline for interpreting local and regional change.

A unique window into the biological history of the Beringian environment is provided by the zooarcheology of early human sites. When Europeans entered Beringia in the mid-18th century, the region was already populated by indigenous peoples for many millennia. At the time of first contact, the early Aleuts had been living in the Aleutian Islands for about 5,000 years (Dumond, 2001). They were superb hunters of the marine environment and had developed a sophisticated material culture capable of exploiting marine vertebrates and invertebrates in pelagic and nearshore environments. The remains of food—bones, invertebrate remains, and other domestic waste—and cultural artifacts formed “kitchen middens” near the dwellings. Lengthy residence led to the compaction and discontinuous development of plant cover and soil, and the gradual accumulation of sand, sandy loam, or loam deposits. Taphonomic processes, such as periodic soaking of the developing layer by atmospheric precipitation, led to its gradual transformation into a “cultural layer”—a stratum of associated horizons of soil enriched with bones, artifacts, and humus. Radiocarbon dating shows that cultural layers can be formed over hundreds and

thousands of years (Dinesman *et al.*, 1999). Careful analysis of these materials, coupled with precision dating of depositional strata, can provide a detailed proxy of the dynamics of the vertebrate community thousands of years ago and up to the present (Klein and Cruz-Uribe, 1984; McCartney, 1984; Lefèvre *et al.*, 1997).

We will use three detailed studies of the early Aleutian environment as means to explore the historical patterns of change in the marine vertebrate community, and to serve as a model how zooarcheology and anthropology may help elucidate complex issues related to environmental correlates of climate change and perturbation. We will explore what relative roles human occupation and environmental change have had on the coastal biota of the central and western Aleutians. We will also indicate what insights paleo-environmental history can provide in interpreting the magnitude and direction of biotic change currently under study.

METHODS

Source Materials

Paleobiotic samples with radiocarbon dates from Beringian regions are increasingly available; most of the material used here was excavated in connection with archeological studies on early human occupation of islands and shores of the Gulf of Alaska, Alaska Peninsula, and Aleutian Islands (Desautels *et al.*, 1971; Corbett *et al.*, 1997; Corbett *et al.*, In Press). The number of excavated archeological sites in the study region is highest in the Gulf of Alaska (e.g., Kachemak Bay, Kodiak I), and decreases with distance west of the Alaska Peninsula (e.g., Rat Islands, Near Islands). Although there has been a long history of archeological excavations in the Aleutian Islands (Dall, 1877; Jochelson, 1925; Eyerdam, 1934; Friedmann, 1934, 1935b, a; Eyerdam, 1936; Friedmann, 1937; Hrdlicka, 1945; Spaulding, 1962; Lippold, 1966, 1972), there are only a few that used quantified sampling methodologies, that have zooarcheological material identified to species, and that have the material directly associated with radiocarbon dates (Table 1). Only three of them (Amchitka Island; Buldir Island; Shemya Island) have sufficient radiocarbon-dated time depth in identified material for comparisons. We have focused on birds in this study because of the high diversity of bony material and large sample sizes of identified material.

Zooarcheological specimens are dated by their contextual matrix rather than by radiocarbon dating of individual objects, and we use published dates as ^{14}C years before present (^{14}C y BP) \pm error (Table 2). All dates are uncalibrated, since there have been few calibration studies from the Aleutian Island, and there seems to be great variability in the marine reservoir effect throughout the Bering Sea basin (Dumond and Griffin, 2002; Savinetsky and Khassanov, 2004). Identifications were made by comparison with reference

material of recent species of birds known from the Beringian region, including the Gulf of Alaska, Bering Sea, Alaska, Siberia and the Russian Far East, and regional seas of the Arctic Ocean.

Climatic reconstruction

To estimate the change in climatic conditions of the Aleutian Islands, we used evidence from published studies on Bering Island and Kodiak Island, located on the extreme western and eastern boundaries of the archipelago (Finney *et al.* 2000, Razjigaeva *et al.* 2004). These studies and several others are based on standard analysis of diatom presence and abundance in buried soils (Mann *et al.*, 1998; Sawada *et al.*, 1999; Finney *et al.*, 2000; Calkin *et al.*, 2001; Tunnicliffe *et al.*, 2001; Gorbarenko *et al.*, 2002; Gorbarenko *et al.*, 2004; Razjigaeva *et al.*, 2004). The reconstruction of past temperatures and precipitation on Shemya Island, however, derived from analysis of layer-by-layer changes in ash content of peat and the degree of its decomposition sampled from deposits (Savinetsky *et al.*, 2004) adjacent to the midden sites. In cases of good drainage, these changes in peat are determined by the temporal dynamics of warming and the saturation of the deposits (Dinesman *et al.*, 1999). To determine the degree of change in precipitation over the time of formation of the whole layer, we used the allogenic ash content of the layers. The ash content of pure peat cannot exceed 15% (P'yavchenko, 1963), and all proportions that exceed this figure are caused by the introduction of mineral particles into the accumulating peat through the surface drainage of atmospheric precipitation from adjoining slopes, or during periods of flooding. To estimate the change in the summer temperature regime, we used indicators of layer-by-layer changes in the degree of peat decomposition. The degree of decomposition is determined by the percentage content of unstructured matrix, containing

small particles of non-humified remains along with humic matter. Aerobic microorganisms, which actively function only in the upper, peat-forming layer, play the primary role in the decomposition of organic remains. After being covered with a developing layer of peat, the degree of decomposition attained remains practically unchanged (Tyuremnov, 1976). Microorganism activity in the peat layer is only possible with suitable warmth and sufficient moisture, and is suppressed by low temperatures, drying, or waterlogging. If the humidity of the peat does not exceed its moisture capacity, the deciding factor influencing decomposition is temperature (Prozorova, 1988). Protracted waterlogging of a well-drained peat bog is unlikely, so that changes in the degree of peat decomposition reflect changes in the temperature regime during the warm half of the year (Savinetsky *et al.*, 2004).

Analytical methodology

The material analyzed here was originally excavated in 1 x 1 m quadrats by natural layers; that is, each layer of homogeneous depositional matrix was considered a single unit regardless of thickness. (However, the cultural deposit Pit 1 on Buldir Island was approximately 0.6 m deep but appeared to be a single unit; due to the high density of material, excavations were made from 10 cm horizons). All excavated material was screened by 6 mm (1/4 inch) and 3 mm (1/8 inch) mesh, and all retained material was reserved for identification using standard quantitative methodology (Klein and Cruz-Urbe, 1984; Lyman, 1994). Only bones identified to species were used in this analysis; however, for analytical purposes, some groups of closely related species were lumped together (e.g., Thick-billed Murres [*Uria lomvia*] and Common Murres [*U. aalge*], are reported as *Uria* spp. in Tables 4 - 6). Absolute numbers of bones for each species were grouped by anatomical element and position. The total number of identified specimens (NISP) for each

species from each discrete level and the Minimum Number of Individuals (MNI) index—which estimates the least number of birds responsible for the observed material—were calculated using the total assemblage of elements (Grayson, 1984; Klein and Cruz-Urbe, 1984). The NISP and MNI are directly related (Grayson, 1984), but the former relies on fewer assumptions and is less sensitive to errors associated with artificial aggregation of elements and depositional histories. We report both indices, except for the material excavated from Amchitka Island, where the original data were given primarily in MNI values (Harrington, 1987).

The use of archeological faunal assemblages as proxy indicators of historical biological patterns is becoming increasingly common (Eyerdam, 1936; Lefèvre *et al.*, 1997; Bouchet *et al.*, 1999; Ervynck, 1999; Savinetsky *et al.*, 2004). There are, however, several intrinsic biases associated with these data, such as site-specific variability in preservation; misidentification of material; preference by the early hunters for particular species or cultural prohibitions for others (Yesner, 1981); and local effects by hunters on abundances of available prey (Broughton, 1994; Grayson, 2001). Preservation biases are minimized with the material used here. Due to the high volume of calcareous material in archeological midden sites in the Aleutians, it has long been recognized that bones and artifacts preserve extremely well (Dall, 1877; Jochelson, 1925; Corbett *et al.*, 1997; McCartney and Veltre, 1999). We minimized misidentification errors by using extensive reference collections and independent determinations by several of the authors. Only material identified to species were employed in these analyses.

Birds were classed by nesting, diet, and foraging strategies (Table 3) based on data in Byrd et al. (in press). To test whether there were hunter-associated effects in the avifaunal

remains, we used as a control the temporal frequency of non-breeding pelagic species (i.e., albatrosses and shearwaters) in midden levels. These birds rarely are found on land in the Aleutian Islands and are minimally affected by human depredation or contact as are those species breeding in accessible surface- or ledge-based colonies (i.e., cormorants, murre, gulls).

Statistical Analyses

Several of the statistical tests we use are uncommon, so details are provided here. Residual Analysis [RA] (Haberman, 1972; Everitt, 1977) makes it possible to isolate sources of deviations from row-column independence in a comparison table. The standardized residual of each cell can be used to assess the particular nature of association between row and column profiles (i.e., individual cells in the comparison table). For cell (i,j) , the standardized residual is defined as:

$$e_{ij} = \frac{(n_{ij} - E_{ij})}{\sqrt{E_{ij}}} \quad (1)$$

In simple terms, the standardized residual is the square root of a chi-square term with the sign of the deviation intact. An estimate of the variance of e_{ij} can be calculated as follows:

$$v_{ij} = \left(1 - \frac{n_{i+}}{n_{++}}\right) \left(1 - \frac{n_{+j}}{n_{++}}\right) \quad (2)$$

where “+” indicates row or column totals. The residual can be transformed to a standard normal deviate with mean of zero and unit variance with an estimate of term variance calculated from marginal totals. The transformation yields an adjusted standardized residual

$$d_{ij} = \frac{e_{ij}}{\sqrt{v_{ij}}} \quad (3)$$

that indicates the contribution of a cell to the total deviation of the table from independence. The significance of the adjusted standardized residual is equivalent to the one-tailed probability of Z in a Normal distribution (Zar, 1999).

Goodness-of-Fit Analysis [GFA] is useful to determine whether two temporal profiles of midden remains have the same underlying pattern or whether they differ significantly in the proportion of bony elements recovered through time. The Kolmogorov-Smirnov Two-Sample test compares paired cumulative frequencies of the element proportions for each time strata and calculates the test statistic D by the following (Hollander and Wolfe, 1973):

$$D = \max|F_1(i) - F_2(i)| \quad (4)$$

where $F_1(i)$ and $F_2(i)$ are the cumulative frequencies of category i for profiles F_1 and F_2 . For large samples, which are met with these data, the statistic D has a sampling distribution that is approximated by the chi-square distribution with $df = 2$ (Goodman, 1954):

$$\chi^2 = 4D^2 \left(\frac{n_1 n_2}{n_1 + n_2} \right) \quad (5)$$

where n_1 and n_2 are the sample sizes for each profile.

Significance levels were assessed using the Bonferroni inequality (Holm, 1979), which partitions the critical value α by the number of multiple tests performed. Specifically, the critical level $\hat{\alpha}_k(y)$ for rejection of a null hypothesis for the outcome y of the test statistic Y_k for test k of n total tests is:

$$\hat{\alpha}_k(Y_k) = \frac{\alpha}{n} \quad (6)$$

TEMPORAL PATTERNS OF BIOTIC CHANGE

Amchitka Island

Amchitka Island (51°23' N 179°16' E) is located approximately midway between the Alaska Peninsula and Kamchatka (Fig. 1), and is about 65 km long and 2 to 7 km wide with large expanses of cliffs and shoreline habitats suitable for seabird colonies (Krog, 1953; Emison *et al.*, 1971; White *et al.*, 1977). Numerous archeological sites have been identified, but only a few have been investigated. The most detailed study to date was made by Desautels *et al.* (1971) at four sites on the southwestern (Pacific) coast of the island. Sites were excavated in 1 x 1 m quadrats using standard procedures, and material was recovered from natural layers. Site 31 was the largest midden found on Amchitka Island (53 m x 29 m) and comprised 11 discrete strata; levels D, F, L, and M were not used in this analysis due to their small number of bony elements (< 5). Radiocarbon dates are available for three levels (Table 2): B (890 ± 90 ¹⁴C y BP), H (1980 ± 95 ¹⁴C y BP), and J (2550 ± 95 ¹⁴C y BP). Details on analysis methodology are given in Siegel-Causey *et al.* (1991).

The bird bones were studied subsequently by Harrington (1987) and Siegel-Causey *et al.* (1991); results are summarized in Table 4. Harrington (1987) only reported MNIs for individual species; Siegel-Causey *et al.* (1991) reidentified all cormorant bones and report both NISP and MNI indices for all strata. In total, 4,723 bones representing at least 909 individuals of 38 species were recovered and identified. Most of the taxa were found in all levels, and cormorants (*Phalacrocorax* spp.) were the most abundant. Of the 1,567 cormorant bones excavated from site 31, those of Pelagic Shags (*P. pelagicus*) predominated (83%). Cormorants taken together were found in expected frequencies, except that they were more common than expected in level E (RA: $z_E = +4.74$, $P \ll 0.001$). Short-tailed

Albatrosses were evident in nearly every level excavated, absent in only the earliest (deepest) levels, and occurred in proportions expected from the overall distribution of taxa through time. Northern Fulmars (*Fulmarus glacialis*) and Short-tailed Shearwaters (*Puffinus tenuirostris*) were more abundant than expected early on, in levels I and J (RA: fulmar, $z_I = +2.77$; shearwater, $z_I = +2.61$, $z_J = +3.25$; $P < 0.01$). Canada Geese were present in most levels, but abundances were lower than expected in levels B and I, and greater than expected in levels E and K (RA: $z_B = -2.21$, $z_E = +4.74$, $z_I = -3.12$, $z_K = +3.03$; $P < 0.01$). The small auklets (*Aethia* spp.) were significantly less frequent in level E and more frequent in level I (RA: $z_E = -3.07$, $z_I = +2.87$; $P < 0.01$).

Overall, levels E, I, and K differed markedly from the overall pattern of bird bones excavated from site 31. Multivariate analysis (Correspondence Analysis, $\chi_c^2 = 29.5$, $df = 66$, $P = 0.99$) reported in Siegel-Causey et al. (1991) revealed that the greatest sources of divergences were the high proportion of cormorants in level E, high proportions of fulmars, shearwaters, and small auklets in level I, and greater than expected numbers of geese in level K.

When grouped into classes representing diet and foraging preferences (see Table 3), the temporal profile (Fig. 2a)—that is, the pattern of bone abundances in levels through time—of planktivorous birds feeding offshore differed significantly from birds feeding in nearshore waters (GFA: $D_{OP/N} = 0.149$, $\chi^2 = 10.6$, $P = 0.005$). The sources of the divergences were an overabundance of nearshore birds in level E (RA: $z_{E(N)} = +6.32$, $P \ll 0.001$) and of offshore planktivorous birds in level I (RA: $z_{I(OP)} = +3.13$, $P < 0.01$). The profiles of piscivorous offshore birds and nearshore birds were similar. The temporal

profiles of birds classed within each foraging group were alike and indicates that the differences (and similarities) of profiles were not strongly driven by individual species.

The temporal profile of midden bones from ledge-nesting birds differed from that seen of non-breeding pelagic birds (GFA: $D_{S/X} = 0.134$, $\chi^2 = 9.07$, $P = 0.011$), while all other species had similar distributions to the controls through time. The sources of difference were that ledge-nesting birds were more frequent than non-breeding birds in levels E and H (RA: $z_E = +4.72$, $z_H = +3.88$; $P \ll 0.001$). Observed abundances were lower in adjacent levels later in time, i.e. levels D and G, but not significantly.

Buldir Island

Buldir Island (51°22'N 176°55'E) is the most isolated island in the Aleutian archipelago and is the westernmost island of the Rat Islands group (Fig. 1). It is the only landfall between Shemya Island, 104 km to the west, and Kiska Island, 117 km to the east (Byrd and Day, 1986; Lefèvre *et al.*, 1997). The only known archaeological site on the island was first located in 1962 (Jones, 1963), and was excavated over several years by the authors (Lefèvre and Siegel-Causey, 1993; Corbett *et al.*, 1997; Lefèvre *et al.*, 1997). The preservation of artifacts and bones is exceptional and the numerous seabird colonies were not disturbed by the introduction of foxes as was the case for many other islands (Bailey, 1993).

The first unit, Pit 1, a 1 x 1 m test pit, was located at the west end of the midden. Under thin vegetation cover, 80 cm of sterile sand was observed over a single 60 cm thick black cultural deposit, which was excavated in 10 cm horizons. Two radiocarbon dates indicate a range of occupation between the late 15th and the late 17th centuries (Table 2), and indicate mixing and continuous occupation rather than separate depositional events (Lefèvre *et al.*, 1997). The latest date (280 ¹⁴C y BP) was used as representative of the entire stratum.

The second unit, Pit 2, was located near the east end of the midden, 143 m east of Pit 1. Seven alternating cultural and sterile sandy layers were observed, each with distinct characteristics and artifact densities. Level C dated from the early 15th century and level G from the late 8th century (Table 2). Profiles of both pits and other supporting details are given in Corbett et al. 1997. In total, 6,087 bones representing at least 541 individuals of 45 species were recovered.

Analysis of the animal taxa from the Buldir Island excavations indicated a nearly equal representation of mammal and bird remains by volume, but birds predominated in abundance and diversity (Lefèvre *et al.*, 1997). Fish were less numerous and represented primarily by Scorpaeniformes, with rock greenling (*Hexagrammos lagocephalus*) as the most abundant. Pacific cod and Pacific halibut (*Hippoglossus stenolepis*) were represented by only a few vertebrae. The only mammal bones recovered were from Steller sea lions, *Eumetopias jubatus*. Table 5 gives the distribution of avian bones by stratigraphic level for both excavation sites.

At present, the breeding avifauna of Buldir comprises 32 species, 21 of them seabirds (Byrd and Day, 1986); in terms of numbers or biomass, 99.9% of the breeding birds of the island are seabirds (Lefèvre and Siegel-Causey, 1993; Lefèvre *et al.*, 1997). The results given in Table 5 reveal that there have been dramatic changes in the abundance of bones through time. Cassin's Auklet (*Ptychorhamphus aleuticus*) was found in every layer in similar abundances, except for level E of site 2 where an order of magnitude greater were recovered. This species is uncommonly encountered at present and are rarely noted to breed (Byrd and Day, 1986). Similarly, the Rhinoceros Auklet (*Cerorhinca monocerata*) was found throughout the midden levels in moderate abundances, but today is represented by

less than 20 breeding pairs. By contrast, kittiwakes (*Rissa* spp.) were found only in one level and Leach's Storm Petrels (*Oceanodroma leucorhoa*) were found in only three levels, but they are both common breeding species today on Buldir Island. Short-tailed Albatrosses were found only in two levels as well, but they are extraordinarily common in archeological contexts elsewhere in the Aleutians (Yesner, 1976; Causey, In Press). Unlike Amchitka, where cormorants were the most common species in the midden deposits, on Buldir they were rarely found in zooarcheological contexts. Cormorants breed in small numbers on Buldir and associated islets, but large numbers of non-breeding birds are commonly encountered in nearby waters (Byrd and Day, 1986).

The temporal profiles of bones deposited in the midden levels of groups based on diet and foraging preferences (Fig. 2) were all different (GFA: $D_{OF/OP} = 0.206$, $\chi^2 = 15.5$, $P = 0.004$; $D_{OF/N} = 0.212$, $\chi^2 = 14.6$, $P = 0.007$; $D_{OP/N} = 0.232$, $\chi^2 = 75.2$, $P \ll 0.001$). The sources of the differences primarily were due to the high abundance of nearshore birds in level C, offshore planktivorous birds in level D, and offshore piscivorous birds in level E. Temporal profiles of birds classed within each foraging group were alike, suggesting that the differences were associated with hunting and subsequent deposition within the midden rather than anomalies associated with particular species.

The temporal profile of midden bones from ledge-nesting and surface-nesting birds differed from that seen of non-breeding and other inaccessible birds (GFA: $D_{S-L/B-X} = 0.339$, $\chi^2 = 201.82$, $P \ll 0.001$). The sources of difference were that birds breeding in accessible colonies were less frequent in level C and more frequent in level E than non-breeding birds (RA: $z_C = -16.96$, $z_E = +11.63$; $P \ll 0.001$).

Shemya Island

Shemya Island (52°43'N 174°07'E) lies in the Semichi Islands group of the Near Islands (Fig. 1)—the westernmost group of Alaska's Aleutian Islands—and is a flat-topped seamount approximately 2.4 km wide and 5.7 km long on a west-east axis, with an area of 1,425 ha (3,520 acres) and a shoreline of 22 km (14 miles) on the North Pacific Ocean and Bering Sea. Among the ten archaeological sites located on Shemya Island, two (SH-1 and SH-5) are completely destroyed today, and a third, ATU-212, is represented by only a tiny remnant (Corbett *et al.*, In Press). The seven remaining sites have extensively suffered from WWII and subsequent military impact over the last 50 years, and all the upper levels of these sites have been either totally destroyed or severely disturbed. Four sites (ATU-003, ATU-021, ATU-022, ATU-061) yielded sufficient material from dated levels (Corbett *et al.*, In Press) to allow comparison with the excavations on Amchitka and Buldir Islands (Table 5). In all, 5,482 bones were recovered representing at least 445 individuals and 37 species. Radiocarbon dates are based on the earliest levels obtained for each site (Table 3). The estimation errors associated with the radiocarbon dates obtained for sites ATU-021 and ATU-022 suggest that these may be contemporaneous; however, for analytical purposes the data from each site are reported separately.

Short-tailed Albatrosses, fulmars, and shearwaters were the most numerous birds found in midden deposits on Shemya and represented 69% of the major species identified. In the earliest excavation site ATU-061, however, they are significantly rarer than expected (RA: $z_{\text{alb}} = -6.60$; $z_{\text{fulm}} = -7.72$; $z_{\text{shear}} = -6.09$; all $P \ll 0.001$). Cormorants, which do not breed on Shemya Island but are commonly encountered in the protected nearshore waters, were moderately abundant in the middens and represented about 7% of the total. Their

presence in the midden deposits were within expected abundances, as were most of other non-alcid species.

The relative abundance patterns of alcids (e.g, murrelets, auklets, murres, puffins [*Fratercula* spp.]) complexly varied through time. For example, Ancient Murrelets (*Synthliboramphus antiquus*) were far more common in the most recent sites (ATU-021, ATU-022) than was expected, rarer than expected in ATU-003, and occurred as expected in the earliest levels (RA: $z_{021} = +2.35$, $P \ll 0.001$; $z_{022} = +3.51$, $P \ll 0.001$; $z_{003} = -3.86$, $P \ll 0.001$, $z_{061} = +0.14$, ns). By contrast, puffins showed nearly the opposite pattern, occurring far less than expected in more recent levels, and more commonly in the earliest (RA: $z_{021} = -4.54$; $z_{022} = -6.23$; $z_{003} = -5.16$; $z_{061} = +5.52$; all $P \ll 0.001$).

When the three most recent levels were treated as one, the patterns are a little clearer: the procellariids (albatrosses, fulmars, storm-petrels, and shearwaters) were much more common than the other species roughly 2,000 ybp, while the alcids were more common in ATU-061, a thousand years earlier. Cormorants, geese, eiders, and larids (gulls [*Larus* spp.] and kittiwakes) occurred in expected numbers.

Similar to the pattern observed from Buldir Island, when the birds were grouped into diet and foraging classes (Table 3), the temporal profiles were different (GFA: $D_{OF/OP} = 0.128$, $\chi^2 = 37.7$; $D_{OF/N} = 0.101$, $\chi^2 = 15.1$; $D_{OP/N} = 0.108$, $\chi^2 = 13.6$; all $P \ll 0.001$). The greatest sources of divergence were that offshore planktivorous birds were very underrepresented in the earliest site (ATU-061), offshore piscivorous birds were very abundant in site ATU-003, and nearshore birds were more common than expected in site ATU-021 (RA: $z_{OP} = -5.85$; $z_{OF} = +5.46$; $z_N = +4.49$; all $P \ll 0.001$). As before, the temporal profiles of birds classed within each group were alike.

The temporal profiles of midden bones from ledge-nesting and surface-nesting birds did not differ significantly from that of non-breeding and other inaccessible birds.

TEMPORAL PATTERNS OF CLIMATIC CHANGE

The history of relative sea level in the Aleutian Islands was summarized by Black (Black, 1974, 1977, 1980, 1982). Based on radiocarbon dating of tephra sequences, he suggested that relative Holocene sea level rose to its present level about 5000 ^{14}C y BP on Attu Island, 6500 ^{14}C y BP on Amchitka Island, and 11,000 ^{14}C y BP in Cold Bay (Alaska Peninsula). Data from Shemya Island (Savinetsky *et al.*, 2004) and Bering Island (55° 12'N 165° 59'E)—450 km to the west—indicate that sea levels stabilized within ± 2 m by 6000 y ^{14}C bp (Razjigaeva *et al.*, 2004). Sea levels oscillated within this period (Fig. 3a), however, with peaks at about 3800 ^{14}C y BP (+2.0 m), 2700 ^{14}C y BP (+1.5 m), and 1000 ^{14}C y BP (+0.9 m); and regressions at 3100 ^{14}C y BP (-0.9 m), 1800 ^{14}C y BP (-0.5 m), and 400 ^{14}C y BP (-0.45 m).

These oscillations in sea level had profound local effects on island vegetation, coastlines, and reefs. On Bering Island, for example, the sea level rise of about 3800 y ^{14}C bp caused the development of small estuarine lagoons characterized by brackish and warmer water diatoms. A thousand years later, the time of the next sea level peak, these areas were characterized by interbedded beach sand and peat (Razjigaeva *et al.*, 2004). On Shemya Island, sea level fluctuations of ± 2 m have had great effect on the spatial extent of the intertidal and subtidal areas that provide important foraging grounds for humans and birds. For example, a drop in sea level of 0.5 m at 2880 ypb and 1800 ybp will have expanded outward by 200 m the present shoreline on the northwestern coast where the most extensive reefs on the island are located. This in turn expanded the intertidal and subtidal areas

outward another 500 m from shore, creating an additional 2500 ha of foraging habitat for birds and humans.

Reconstruction of temperature and precipitation changes (Fig. 3) was based on changes in diatom distribution and abundance from Bering Island (Razjigaeva *et al.*, 2004) and Gulf of Alaska (Heusser *et al.*, 1985), and the rate of decomposition and allogenic ash content of peat samples taken from Shemya Island (Savinetsky *et al.*, 2004). During the Early and Middle Holocene, conditions in the western Aleutians were typified by high amounts of precipitation until about 5000 ¹⁴C y BP. It then decreased monotonically until about 2000 ¹⁴C y BP when annual precipitation achieved more or less present conditions. By contrast, in the Gulf of Alaska, precipitation increased approximately 1.5 times over this period (i.e., 1500 to 2250 mmH₂O), with noticeable decreases at about 3700 ¹⁴C y BP and 2200 ¹⁴C y BP (Heusser *et al.*, 1985).

Temperatures varied over time, with peaks observed at about 5500 - 5250 ¹⁴C y BP and 3000 - 2750 ¹⁴C y BP (Fig. 3a,b). The most recent warm periods on Bering and Shemya Islands correspond well with the Medieval Warm Period of Northern Europe (ca. AD 900 – 1350); in the eastern Aleutians and Gulf of Alaska this was a period of moderate cooling or stable temperatures (Fig. 3c). Temperatures dropped considerably from 3000 – 2000 ¹⁴C y BP in the western Aleutians and Commander Islands (Fig. 3a, b), and then stabilized except for a 250 y period experienced throughout the Aleutians and Gulf of Alaska corresponding to the Little Ice Age of Europe (ca. AD 1350 - 1800).

These data support other paleoclimate reconstructions for the region (Bartlein *et al.*, 1998; Mann *et al.*, 1998; Calkin *et al.*, 2001; Gorbarenko *et al.*, 2002; Gorbarenko *et al.*, 2004), which indicate that by the mid-Holocene (i.e., ~ 5000 ybp) the climate of the

Aleutians was changing from relatively warm and dry conditions to the current cool and wet pattern. This change was associated with an intensification of the Aleutian low-pressure center and a corresponding increase in storms and cyclonic activity (Stabeno and Reed, 1992; Niebauer *et al.*, 1999). The role that the ocean environment plays in the interaction between climate and oceanography is less clearly understood (Schumacher and Alexander, 1999), but it is clear from several studies that ocean temperatures, salinities, and currents were similarly variable in the Gulf of Alaska, Aleutian Islands, and North Pacific during the late Holocene (Francis and Hare, 1994; Francis *et al.*, 1998; Finney *et al.*, 2000; Calkin *et al.*, 2001; Tunicliffe *et al.*, 2001; Finney *et al.*, 2002).

Climate change and the response of the oceanic ecosystem to climatic forcing may affect marine foodwebs in both directions: for example, significant shifts in phytoplankton production have been linked with the NE Pacific climatic regime shift of 1976/1977 (Brodeur and Ware, 1992; Polovina *et al.*, 1995; Roemmich and McGowan, 1995), but direct effects on top predators are much more difficult to detect. It is much more likely that indirect responses related to prey availability and abundance of top-trophic level species like birds and mammals will be most evident (Francis *et al.*, 1998). The significant declines in piscivorous marine birds and marine mammals in the Gulf of Alaska since the 1980s have been attributed to fundamental shifts in the distribution and abundance of their food resources (Springer, 1992; Piatt and Anderson, 1995), a pattern well documented throughout Beringia and the North Pacific (Montevecchi, 1993; Decker *et al.*, 1995; Hunt and Byrd, 1999; Jones *et al.*, 2002). For example, shearwaters, murre, and auklets responded quickly to changes in the California Current during 1985-1994 in ways predictable by their morphology and natural history (Oedekoven *et al.*, 2001). This was particularly evident by

lower population sizes (Sooty Shearwaters *Puffinus griseus*, Cassin's Auklets), shifting distributions to avoid areas of low productivity (shearwaters), and feeding on alternative prey (Common Murre). If similar patterns hold for the past, then it is likely that the paleodynamics of the avifauna collected by early human hunters should reflect the paleodynamics of the Aleutian Island ecosystem.

TEMPORAL AND SPATIAL PATTERNS OF LATE HOLOCENE AVIFAUNA

What is immediately evident from the data and analyses presented here is that the populations of very few species in the central and western Aleutians were constant during the past 3,000 years. For example, on Shemya and Buldir Islands the fish-eating alcids, murre and puffins, varied considerably and inconsistently through time: during some periods, murre predominated and during others, puffins. It is difficult to ascertain whether this variability is due to changes in food availability, changes in offshore or onshore environments, or changes associated with indirect effects on breeding habitats. A few patterns stand out, however: procellariids (Short-tailed Albatrosses and Short-tailed Shearwaters) were present and abundant in every level at Amchitka and Shemya Islands. During periods of increased temperatures (e.g., Medieval Warming Period, 650 – 1100 ybp) and precipitation, nearshore foragers rose in abundance (Fig. 2, Spearman rank correlations: $r_s(T)_N = +0.518$, $r_s(P)_N = +0.571$; $p < 0.05$). In addition, during periods of cooling (e.g., Little Ice Ages, 200 – 650 ybp and 1800 – 2100 ybp), offshore piscivorous birds—including the aforementioned procellariids—similarly increased (Fig 2, same test: $r_s(T)_{OF} = -0.696$, $p < 0.04$; $r_s(T)_{Proc} = -0.554$; $p < 0.05$).

These sustained and large-scale patterns over millennia track with analogous studies focused on historical changes in fisheries productivity elsewhere in the North Pacific.

Finney et al. (2002) identified significant multi-century shifts in fish abundance at about 2100 ybp and 800-1200 ybp, which corresponded to periods of major change in the atmospheric and oceanic circulation. The earliest period (~100 BC) was transitional: some areas of the Northeast Pacific (i.e., Gulf of Alaska, Santa Barbara basin) by this time were characterized by warming waters (Heusser *et al.*, 1985; Brodeur and Ware, 1992), while in the Northwest Pacific (Gorbarenko *et al.*, 2004; Razjigaeva *et al.*, 2004; Savinetsky *et al.*, 2004) the warming period had not yet begun. During the centuries immediately preceding this time (i.e., 2200 ybp and earlier), the climate and oceanography was cooler and more turbulent, and characterized by change at the largest scales.

Marine birds were associated with environmental change at the highest scales. Previously, in a separate analysis of twelve studies based on material recovered from all excavated Aleutian middens, Savinetsky *et al.* (2004) found that most late Holocene marine bird populations in the southern Bering Sea region demonstrated a negative correlation with temperature and a positive correlation with precipitation, but small sample sizes made statistical estimates unreliable in their study. We undertook a similar analysis and found that for the western Aleutians, a similar pattern obtained (Spearman rank correlations: $r_s(T)_{ALL} = -0.506$, $r_s(P)_{ALL} = +0.601$; $p < 0.075$).

Other broad scale patterns are obscured by variability in species-level occurrences found in individual levels and sites and local anomalies abound. For example, the excavations from Buldir Island revealed pulses of abundance in the planktivorous species throughout time, which may reflect a corresponding increase in population sizes or chance successes by early Aleut hunters. Also on Buldir, Aleutian Canada Geese were rarely encountered in midden deposits by contrast to Shemya and Amchitka Islands, yet at present

the island represents one of the most critical breeding habitats for the species. Additional studies using higher-resolution reconstruction of local and regional climates, larger sample sizes, and a broader taxonomic base including fish and invertebrates, are needed to clarify and further refine these findings.

HUMAN IMPACTS VS. INTRINSIC CHANGE IN NEAR SHORE ECOSYSTEMS

During precontact times, the Aleutian Islands supported one of the world's densest concentrations of humans with a hunting/fishing/gathering economic base (Liapunova, 1979; Corbett *et al.*, 2001; Corbett *et al.*, In Press). Exact population sizes are unknown due to declines following contact with Russian explorers in the mid-1700s; estimates range from 7,000 to over 30,000 in the Aleutian chain (Laughlin, 1980; Lantis, 1984). The distribution of early Aleut groups (Fig. 1) corresponds almost exactly with the location of major islands passes, for example the territories of the Sasignan and Qaxun Aleut groups were bounded by the Near Islands, Buldir, and Amchitka passes (Bergsland and Dirks, 1990). Island passes define the physical and biological structure of the Aleutian Islands (Byrd *et al.*, In Press; Ladd *et al.*, in press; Sinclair *et al.*, in press), and helped influence the development of human cultural preferences. For example, the Sasignan Aleut evolved a unique and distinctive hunting technology that was finely tuned to the biological conditions of their environment, and was unlike in many aspects from technologies and material cultures found in their neighbors, the Quxun, Naahmigus, and Niigugis Aleuts (McCartney, 1984; Corbett *et al.*, 1997; Veltre, 1998; McCartney and Veltre, 1999; Corbett *et al.*, In Press). Our evidence suggests that the early cultural structure of the central and western Aleutians reflects the environmental structure, that is, the biodiversity, geography, and physical oceanography.

The size of a human population obviously has a direct correlation with the impact of that population on its environment and local depletion of vertebrates used for food have been identified for many early maritime cultures (Gonzalez, 1999; Hildebrandt and Jones, 2002; Broughton and Bayham, 2003). We detected hunter-related depletions of populations breeding in accessible colonies at small scales of space and time, but we did not observe widespread or long-term effects. For example, cormorants, gulls, and murre were harvested in significantly greater numbers than the control group at levels E and H on Amchitka Island and level E on Buldir Island, and were subsequently rarer afterwards. These species were used for food and clothing, and nest on the flat shoulders of cliffs or on wide ledges, often on the flat tops of islets and rock stacks (Whittam and Siegel-Causey, 1981; Lefèvre *et al.*, 1997). Disturbance by harvesting tends to drive the nesting birds to more isolated spots and diminish their availability during breeding season, but solitary birds will continue to forage in the intertidal and nearshore waters far past the breeding season and into winter (Meehan *et al.*, 1996). Numerical abundance of affected species in these cases will decrease but local populations will rarely vanish from a region.

Another example, but based in more recent human activities, is illustrated by the abundance of Short-tailed Albatrosses in the Aleutian Islands. At some localities in the eastern Aleutians (e.g., Kodiak Island, Umnak Island), this species was the most abundant bird in terms of harvested biomass for over 3,000 years (Yesner, 1976; Causey, In Press). These patterns were also seen in the central and western Aleutians, and their abundances as reflected by presence in the midden levels were high yet varied insignificantly through time (Kolmogorov-Smirnov One-Sample tests, $P > 0.10$). The abrupt drop in abundance in the

past century is due entirely to hunting pressure and habitat destruction by European hunters in the early years of the 20th century (Carboneras, 1992; Causey, In Press).

Overall, however, historical hunting practice of the early Aleut hunters did not seem to have a demonstrable impact on the seabird community in the Aleutian Islands. Results shown here indicate that while some changes have taken place, they are not consistent with long-term effects associated with local extirpation by overhunting, selective harvesting, or habitat perturbation. Instead, it appears that trends in abundance for many species have been locally stable (e.g, Short-tailed Albatross, and Pelagic and Red-faced cormorants) or changing in similar patterns over large geographic scales. This is best shown where we have nearly contemporaneous material from approximately 2000 – 2500 ybp on Amchitka and Shemya Islands. These contemporaneous patterns separated by over 800 km suggest ecosystem changes rather than coordinated shifts in hunting patterns among the early Aleut occupants.

The diversity of the marine bird fauna of the central and western Aleutians 3,000 years ago was similar to what it is today, but populations differ primarily in their relative abundance. Then as now, these patterns of species change were very likely driven by environmental changes, particularly by those parameters directly affecting the abundance and distribution of food. If present patterns are indicative of past processes, it appears that local oceanography and regional changes in prey bases had a significant impact on the distribution and abundance of Aleutian birds and mammals.

ACKNOWLEDGMENTS

We thank C. Brunner, L. Freund, C. Fritz, C. Funk, J. Gullotti, D. Holly, G. Hatfield, L. Johnson, H. Lanier, B. Locascio, S. Loring, T. Oliver, M. Schwitters, B. Sterling, E. Manning-Sterling, N. Takahashi, J. Thomas, G. Weinberger, L. Wilmerding, A. Young-McLean, and A. Young for assistance in the field. We are particularly grateful to Vernon Byrd and Jeffrey Williams for logistical support and permission to conduct research on the Aleutian Island Unit of the Alaska Maritime National Wildlife Refuge. Our work on Shemya and Buldir Islands would have been impossible without the assistance and insider knowledge provided by Captain Kevin Bell and First Mate William Pepper of the R/V *Tiglox*, its crew, and many other staff of the US Fish and Wildlife Service. Portions of our field work were supported by the National Geographic Society; the Harvard University Museum of Comparative Zoology and the George Putnam Expedition Fund (Harvard University); the University of Nebraska State Museum; the University of Kansas Biodiversity Research Center and Museum of Natural History; the US Fish and Wildlife Service; and National Science Foundation grants, OPP-9614472 and OPP-0091875. Lefèvre was supported by the Institut Français pour la Recherche et la Technologie Polaires (program 301), the French Centre National de la Recherche Scientifique (UMR 197), and the Muséum national d'Histoire naturelle. Savinetsky, Kiseleva, and Khassanov were funded by the Russian Foundation for Basic Research (Grant No 03-04-49323) and the Russian programs "Origin and Evolution of Biosphere" and "Scientific Basics of Biodiversity of Russia Conservation." Our work over many years has been made possible through the assistance and permission of the Aleut Corporation and the Aleut people.

Literature

Amorosi, T., Woollett, J., Perdikaris, S. and McGovern, T. (1996) Regional Zooarchaeology and Global Change: Problems and Potentials. *World Archeol.* **28**:16-157.

Bailey, E.P. (1993) Introduction of Foxes to Alaska Islands--History, Effects on Avifauna, and Eradication. Report No. Resource Publication 193, USFWS, Washington, DC.

Bartlein, P.J., Anderson, K.H., Anderson, P.M., Edwards, M.E., Mock, C.J., Thompson, R.S., Webb, R.S., Webb, T., III and Whitlock, C. (1998) Paleoclimate simulations for North American over the past 21,000 years: features of the simulated climate and comparisons with paleoenvironmental data. *Quat. Sci. Rev.* **17**:549-585.

Bergsland, K. and Dirks, M.L. (eds) (1990) Unangam Ungiikangin kayux Tunusangin/Aleut Tales and Narratives collected by Waldemar Jochelson, University of Alaska Alaska Native Language Center, Fairbanks, AK.

Berkh, V.N. (1823) Khronologicheskaya isoriya Aleutskikh Ostrovov [Chronological history of the Aleutian Islands], V. Tipografii, N. Grechen, Sanktpetersburg, Russia.

Black, R.F. (1974) Geology and ancient Aleuts, Amchika and Umnak Islands, Aleutians. *Arctic Anthro.* **11**:126-140.

Black, R.F. (1977) Influence of Holocene climatic changes on Aleut expansion into the Aleutian Islands, Alaska. *Anthro. Pap. Univ. Alaska* **18**:31-42.

Black, R.F. (1980) Isostatic, tectonic, and eustatic movements of sea level in the Aleutian Islands, Alaska. In: *Earth Reology, Isostasy, and Eustasy*. N.-A. Morner (ed.), Chichester, UK: Wiley, pp. 231-248.

Black, R.F. (1982) Holocene sea-level changes in the Aleutian Islands: new data from Atka Island. In: *Holocene Sea Level Fluctuations, Magnitude, and Causes*. D. Colquhoun (ed.), London: International Geological Correlation Program, pp. 1-12.

Bouchet, F., Lefèvre, C., West, D. and Corbett, D.G. (1999) First paleoparasitological analysis of a midden in the Aleutian Islands (Alaska): results and limits. *J. Parasitol.* **85**:369-372.

Braham, H.W., Everitt, R.D. and Rugh, D.J. (1980) Northern sea lion decline in the eastern Aleutian Islands. *J. Wildl. Manag.* **44**:25-33.

Brodeur, R.D. and Ware, D.M. (1992) Long-term variability in zooplankton biomass in the subarctic Pacific Ocean. *Fish. Oceanogr.* **1**:32-38.

Broughton, J.M. (1994) Late Holocene resource intensification in the Sacramento Valley, California: the vertebrate evidence. *J. Archeol. Sci.* **21**:501-514.

Broughton, J.M. and Bayham, F.E. (2003) Showing-off, foraging models, and the ascendance of large-game hunting in the California Middle Archaic. *Amer. Antiq.* **68**:783-789.

Byrd, G.V. and Day, R.H. (1986) The avifauna of Buldir Island, Aleutian Islands, Alaska. *Arctic* **39**:109-118.

Byrd, G.V., Renner, H.M. and Renner, M. (In Press) Distribution patterns and population trends of breeding seabirds in the Aleutian Islands. *Fish. Oceanogr.* (**Current Volume**)

Calkin, P.E., Wiles, G.C. and Barclay, D.J. (2001) Holocene coastal glaciation of Alaska. *Quat. Sci. Rev.* **20**:449-461.

Carboneras, C. (1992) Family Diomedidae (Albatrosses). In: *Handbook of the Birds of the World*. J. de Hoyo, Elliott, A. and Sargatal, J. (eds), Barcelona: Lynx Edicions, pp. 198-215.

Causey, D. (In Press) Short-tailed Albatross (*Diomedea albatrus*). In: *Shemya Island Prehistory*. D. G. Corbett, Lefèvre, C. and West, D. (eds), Washington, DC: Smithsonian Institution

Corbett, D.G., Lefèvre, C., Corbett, T.J., West, D. and Siegel-Causey, D. (1997) Excavations at KIS-008, Buldir Island: evaluation and potential. *Arctic Anthro.* **34**:110-117.

Corbett, D.G., Lefèvre, C., West, D. and Corbett, T.J. (eds) (In Press) *Shemya Island Prehistory*, Smithsonian Institution Press, Washington, DC.

Corbett, D.G., West, D. and Lefèvre, C. (2001) Prehistoric village organization in the Western Aleutians. In: *Archaeology in the Aleut Zone of Alaska: Some Recent Research*. D. Dumond (ed.), Ashland: University of Oregon, pp. 251-266.

Dall, W.H. (1874) Notes on the Avifauna of the Aleutian Islands, especially those West of Unalashka. *Proc. Calif. Acad. Sci.* **5**:270-281.

Dall, W.H. (1877) On Succession in the Shell-heaps of the Aleutian Islands. In: *Contributions to North American Ethnology*, Washington, DC: US Government Printing Office, pp. 41-91.

Davydov, G.I. (1810) Dvuratoviye puteshestvoya v Ameriku morskikh, 1802-1807 [Two voyages of discovery to American seas, 1802-1807], V. Tipografii, Sanktpetersbug, Russia.

Decker, M.B., Hunt, G.L., Jr. and Byrd, G.V. (1995) The relationships among sea-surface temperature, the abundance of juvenile walleye pollock (*Theragra chalcogramma*) and the reproductive performance and diets of seabirds at the Pribilof Islands, southeastern Bering Sea. In: *Climate change and northern fish populations*. R. J. Beamish (ed.): Canadian Special Publication of Fisheries and Aquatic Sciences, pp. 425-437.

Desautels, R.J., McCurdy, A.J., Flynn, J.D. and Ellis, R.R. (1971) Archaeological report: Amchitka Island, Alaska, 1969 - 1970. Report No. TID-25481, US Atomic Energy Commission, Washington, DC.

Dinesman, L.G., Kiseleva, N.K., Savinetskii, A.B. and Khassanov, B.F. (1999) Secular dynamics of the coastal ecosystems of Northeastern Chukotka, Mo Vince Verlag, Tubingen, Germany.

Doroff, A.M., Estes, J.A., Tinker, M.T., Burn, D.M. and Evans, T.J. (2003) Sea Otter population declines in the Aleutian archipelago. *J. Mammal.* **84**:55-64.

Dumond, D. and Griffin, D.G. (2002) Measurements of the marine reservoir effect on radiocarbon ages in the eastern Bering Sea. *Arctic* **55**:77-86.

Dumond, D.E. (ed) (2001) Archaeology in the Aleut zone of Alaska: some recent research, University of Oregon Anthropological Papers, Corvallis, OR.

Emison, W.B., Williamson, F.S.L. and White, C.M. (1971) Geographical affinities and migrations of the avifauna on Amchitka Island, Alaska. *Bioscience* **21**:627-631.

Ervynck, A. (1999) Possibilities and limitations of the use of archaeozoological data in biogeographical analysis: A review with examples from the Benelux region. *Belgian J. Zool.* **129**:125-137.

Everitt, B.S. (1977) *The Analysis of Contingency Tables*, Chapman and Hall, London.

Eyerdam, W.J. (1934) Invertebrate remains dug from kitchen middens of an old Aleut stone age village near Dutch Harbor, Alaska. *Nautilus* **47**:100-103.

Eyerdam, W.J. (1936) Mammal remains from an Aleut Stone Age village. *J. Mammal.* **17**:61.

Finney, B.P., Gregory-Evans, I., Douglas, M.S.V. and Smol, J.P. (2002) Fisheries productivity in the northeastern Pacific Ocean over the past 2,200 years. *Nature* **416**:729-733.

Finney, B.P., Gregory-Evans, I., Sweetman, J., Douglas, M.S.V. and Smol, J.P. (2000) Impacts of climatic change and fishing on Pacific salmon abundances over the past 300 years. *Science* **290**:795-799.

Francis, R.C. (ed) (1996) *The Bering Sea Ecosystem*, National Academy of Sciences, Washington, DC.

Francis, R.C. and Hare, S.R. (1994) Decadal-scale regime shifts in the large marine ecosystem of the north-east Pacific: a case for historical science. *Fish. Oceanogr.* **3**:279-291.

Francis, R.C., Hare, S.R., Hollowed, A.B. and Wooster, W.S. (1998) Effects of interdecadal climate variability on the oceanic ecosystems of the NE Pacific. *Fish. Oceanogr.* **7**:1-21.

Friedmann, H. (1934) Bird bones from Eskimo ruins on St. Lawrence Island, Bering Sea. *J. Wash. Acad. Sci.* **24**:83-96.

Friedmann, H. (1935a) Avian bones from prehistoric ruins on Kodiak Island, Alaska. *J.*

Wash. Acad. Sci. **25**:44-51.

Friedmann, H. (1935b) The birds of Kodiak Island, Alaska. *Bull. Chicago Acad. Sci.* **5**:13-

54.

Friedmann, H. (1937) Bird bones from archeological sites in Alaska. *J. Wash. Acad. Sci.*

27:431-438.

Friedmann, H. (1941) Bird bones from Eskimo ruins at Cape Prince of Wales, Alaska. *J.*

Wash. Acad. Sci. **31**:401-404.

Gonzalez, J.A. (1999) Effects of harvesting of waterbirds and their eggs by native people in

the northeastern Peruvian Amazon. *Col. Waterbirds* **22**:217-224.

Goodman, L.A. (1954) Kolmogorov-Smirnov tests for psychological research. *Psych. Bull.*

51:160-168.

Gorbarenko, S.A., Khusid, T.A., Basov, I.A., Oba, T., Southon, J.R. and Koizumi, I. (2002)

Glacial Holocene environment of the southeastern Okhotsk Sea: evidence from geochemical and palaeontological data. *Palaeo.* **177**:237-263.

Gorbarenko, S.A., Southon, J.R., Keigwin, L.D., Cherepanova, M.V. and Gvozdeva, I.G.

(2004) Late Pleistocene-Holocene oceanographic variability in the Okhotsk Sea: geochemical, lithological and paleontological evidence. *Palaeo.* **209**:281-301.

Grayson, D.K. (1984) Quantitative Zooarcheology: topics in the analysis of archaeological faunas, Academic Press, Orlando.

Grayson, D.K. (2001) The archaeological record of human impacts on animal populations. *J. World Prehist.* **15**:1-68.

Haberman, S.J. (1972) The analysis of residuals in cross-classified tables. *Biometrics* **29**:205-220.

Harrington, T.R. (1987) Avifaunal comparison of middens on Amchitka Island, Alaska. MS Thesis, Cal. St. Coll., Long Beach.

Heusser, C.J. (1973) Postglacial vegetation on Umnak Island, Aleutian Islands, Alaska. *Review of Palaeobotany and Palynology* **15**:277-285.

Heusser, C.J., Heusser, L.E. and Peteet, D.M. (1985) Late-Quaternary climatic change on the American North Pacific Coast. *Nature* **315**:486-487.

Hildebrandt, W.R. and Jones, T.L. (2002) Depletion of prehistoric pinniped populations along the California and Oregon coasts: were humans the cause? In: *Wilderness and*

Political Ecology: Aboriginal Influences and the Original State of Nature. C. Kay and Simmons, R. (eds), Salt Lake City: University of Utah Press, pp. 72-110.

Hoffman, B.W., Czederpiltz, J.M.C. and Partlow, M.A. (2000) Heads or tails: the zooarchaeology of Aleut salmon storage on Unimak Island, Alaska. *J. Archeol. Sci.* **27**:699-708.

Hollander, M. and Wolfe, D.A. (1973) *Nonparametric Statistical Methods*, John Wiley and Sons, New York.

Holm, S. (1979) A simple sequentially rejective multiple test procedure. *Scand. J. Stat.* **6**:65-70.

Hrdlicka, A. (1945) *The Aleutian and Commander Islands and Their Inhabitants*, Wistar Institute of Anatomy and Physiology, Philadelphia.

Hunt, G.L., Jr. and Byrd, G.V. (1999) Marine bird populations and the carrying capacity of the Eastern Bering Sea. In: *Dynamics of the Bering Sea*. T. R. Loughlin and Ohtani, K. (eds), Fairbanks, AK: University of Alaska Sea Grant Program, pp. 631-650.

Jackson, J.B.C., Kirby, M.X., Berger, W.H., Bjorndal, K.A., Botsford, L.W., Bourque, B.J., Bradbury, R.H., Cooke, R., Erlandson, J.M., Estes, J.A., Hughes, T.P., Kidwell, S., Lange, C.B., Lenihan, H.S., Pandolfi, J.M., Peterson, C.H., Steneck, R.S., Tegner, M.J. and Warner,

R.R. (2001) Historical overfishing and the recent collapse of coastal ecosystems. *Science* **293**:629-638.

Jochelson, W.I.s., V. I.) (1925) Archeological Investigations in the Aleutian Islands. *Carnegie Institution of Washington Publication 367*

Jones, I.L., Hunter, F.M. and Robertson, G.J. (2002) Annual adult survival of Least Auklets (Aves, Alcidae) varies with large-scale climatic conditions of the North Pacific Ocean. *Oecol.* **133**:38-44.

Jones, R.D., Jr (1963) Buldir Island, site of a remnant breeding population of Aleutian Canada Geese. *Wildfowl Trust Ann. Rept.* **14**:80-84.

Klein, R.G. and Cruz-Uribe, K. (1984) The analysis of animal bones from archeological sites, University of Chicago Press, Chicago.

Krog, J. (1953) Notes on the birds of Amchitka Island, Alaska. *Condor* **55**:299-304.

Ladd, C., Jahncke, J., Hunt, G.L., Jr., Coyle, K.O. and Stabeno, P.J. (in press) Hydrographic features and seabird foraging in Aleutian passes. *Fish. Oceanogr.* (**Current Volume**)

Lantis, M. (1984) Aleut. In: *Handbook of North America Indians*. D. Damas (ed.), Washington, DC: Smithsonian Institution

Laughlin, W.S. (1980) *Aleuts: Survivors of Bering Land Bridge*, Holt, Rinehart, Winston, New York.

Lefèvre, C., Corbett, D.G., West, D. and Siegel-Causey, D. (1997) A Zooarchaeological Study at Buldir island, Western Aleutians, Alaska. *Arctic Anthro.* **34**:118-131.

Lefèvre, C. and Siegel-Causey, D. (1993) First report on bird remains from Buldir Island, Aleutian Islands, Alaska. *Archeofauna* **2**:83-96.

Liapunova, R.G. (1979) Novyi dokument o rannikh plavaniakh na Aleutskii Ostrova. *Strany i narody vostoka* **20**:97-105.

Lippold, L.K. (1966) Chaluka: the economic base. *Arctic Anthro.* **3**:125-131.

Lippold, L.K. (1972) Mammalian remains from Aleutian archeological sites: a preliminary report. *Arctic Anthro.* **9**:113-114.

Lyman, R.L. (1994) Quantitative units and terminology in zooarcheology. *Amer. Antiq.* **59**:36-71.

Lyman, R.L. (1996) Applied Zooarchaeology: the relevance of faunal analysis to wildlife management. *World Archeol.* **28**:110-125.

Mann, D.H., Crowell, A.L., Hamilton, T.D. and Finney, B.P. (1998) Holocene geologic and climatic history around the Gulf of Alaska. *Arctic Anthro.* **35**:112-131.

Mantua, N.J., Hare, S.R., Zhang, Y., Wallace, J.M. and Francis, R.C. (1997) A Pacific interdecadal climate oscillation with impacts on salmon production. *Bull. Amer. Meteor. Soc.* **78**:1069-1079.

McCartney, A.P. (1984) Prehistory of the Aleutian Region. In: *Handbook of North American Indians: Arctic*. D. Damas (ed.), Washington, DC: Smithsonian Institution, pp. 119-135.

McCartney, A.P. and Veltre, D.W. (1999) Aleutian Island prehistory: living in insular extremes. *World Archeol.* **30**:503-515.

Meehan, J.P., Kron, M.A., Williams, J.C. and Scharf, L.M. (1996) Winter wildlife suveys at Eareckson Air Station, Shemya Island, Alaska, winter 1994/1995. Report No. USFWS Rept. AMNWR 95/11, Adak, Alaska.

Montevecchi, W.A. (1993) Birds as indicators of change in marine prey stocks. In: *Birds as monitors of environmental change*. R. W. Furness and Greenwood, J. J. D. (eds), London: Chapman and Hall, pp. 217-266.

Niebauer, H.J., Bond, N.A., Yakunin, L.P. and Plotnikov, V.V. (1999) An update on the climatology and sea ice of the Bering Sea. In: *Dynamics of the Bering Sea*. T. R. Loughlin and Ohtani, K. (eds), Fairbanks, AK: University of Alaska Sea Grant

Oedekoven, C.S., Ainley, D.G. and Spear, L.B. (2001) Variable responses of seabirds to change in marine climate, 1985-1994. *Mar. Ecol. Prog. Ser.* **212**:265-282.

P'yavchenko, N.I. (1963) Stepen' razlozheniya torfa i metody ee opredeleniy [Degree of Decomposition of Peat and the Methods of Determining It], Nauka, Krasnoyarsk, Russia.

Piatt, J.F. and Anderson, P.M. (1995) Response of common murrelets to the Exxon Valdez oil spill and long-term changes in the Gulf of Alaska marine ecosystem. In: *Proceedings of the Exxon Valdez Oil Spill Symposium*. S. D. Rice, Spies, R. B., Wolfe, D. A. and Wright, B. A. (eds): American Fisheries Society, pp. 720-737.

Polovina, J.J., Mitchum, G.T. and Evans, G.T. (1995) Decadal and basin-scale variation in mixed-layer depth and the effect on biological production in the Central and North Pacific. *Deep Sea Res.* **42**:1701-1716.

Prozorova, M.I. (1988) Vliyaniye vlazhnosti i temperatury na skorost mineralizatsii torfa [The Influence of Moisture and Temperature on the Rate of Mineralization of Peat]. *Ekologiya* **2**:3-7.

Razjigaeva, N.G., Grebennikova, T.A., Ganzey, L.A., Mokhova, L.M. and Bazarova, V.B.

(2004) The role of global and local factors in determining the middle to late Holocene environmental history of the South Kurile and Komandar islands, northwestern Pacific.

Palaeo. **209**:313-333.

Reitz, E.J. (2004) "Fishing down the food web:" A case study from St. Augustine, Florida,

USA. *Amer. Antiq.* **69**:63-84.

Roemmich, D. and McGowan, J.A. (1995) Climatic warming and the decline of zooplankton

in the California Current. *Science* **267**:1324-1326.

Savinetsky, A.B. and Khassanov, B.F. (2004) Dynamics of ancient eskimo whaling catch in

the coast of Chukotka--a calibrated 14C chronology. *Opus* **3**:193-196.

Savinetsky, A.B., Kiseleva, N.K. and Khassanov, B.F. (2004) Dynamics of sea mammal and

bird populations of the Bering Sea region over the last several millenia. *Palaeo.* **209**:335-

352.

Sawada, M., Gajewski, K., de Vernal, A. and Richard, P. (1999) Comparison of marine and

terrestrial Holocene climatic reconstructions from northeastern North America. *The*

Holocene **9**:267-277.

Schumacher, J.D. and Alexander, V. (1999) Variability and role of the physical environment in the Bering Sea ecosystem. In: *Dynamics of the Bering Sea*. T. R. Loughlin and Ohtani, K. (eds), Fairbanks, AK: University of Alaska Sea Grant

Siegel-Causey, D. (1991) Foraging habitat selection by American and Magellanic oystercatchers (*Haematopus palliatus* and *H. leucopodus*) on Patagonian tidal flats. *Canadian Journal of Zoology* **69**:1636-1643.

Siegel-Causey, D., Lefèvre, C. and Savinetskii, A.B. (1991) Historical diversity of cormorants and shags from Amchitka Island, Alaska. *Condor* **93**:840-852.

Sinclair, E., Moore, S., Friday, N., Zeppelin, T. and Waite, J. (in press) Physical mechanisms influencing regional distribution and abundances of apex predators: relevance to ecosystem management. *Fish. Oceanogr.* (**Current Volume**)

Spaulding, A.C. (1962) Archeological Investigations on Agattu, Aleutian Islands. *U. Mich. Anthro. Pap.* **18**:3-74.

Springer, A.M. (1992) Walleye pollock in the North Pacific: how much difference do they really make? *Fish. Oceanogr.* **1**:80-96.

Stabeno, P.J. and Reed, R.K. (1992) A major circulation anomaly in the western Bering Sea. *Geophy. Res. Lett.* **19**:1671-1674.

Steneck, R.S., Graham, M.H., Bourque, B.J., Corbett, D.G., Erlandson, J.M., Estes, J.A. and Tegner, M.J. (2002) Kelp forest ecosystems: biodiversity, stability, resilience, and future. *Envir. Conserv.* **29**:436-459.

Trenbeth, K.E. and Hurrell, J.W. (1994) Decadal atmosphere-ocean variations in the Pacific. *Clim. Dynam.* **9**:303-319.

Trites, A.W. (1992) Northern fur seals: why have they declined? *Aquat. Mammal.* **18**

Trites, A.W. and Donnelly, C.P. (2003) The decline of Steller sea lions *Eumetopias jubatus* in Alaska: a review of the nutritional stress hypothesis. *Mammal Rev.* **33**:3-28.

Tunicliffe, V., O'Connell, J.M. and McQuoid, M.R.A. (2001) A Holocene record of marine fish remains from the Northeastern Pacific. *Mar. Geol.* **174**:197-210.

Turner, L.M. (1886) Contributions to the Natural History of Alaska, Govt. Publ. Office, Washington, DC.

Tyuremnov, S.I. (1976) Torfyanye mestorozhdeniya [Peat Deposits], Nauka, Moscow.

Veltre, D.W. (1998) Prehistoric maritime adaptations in the western and central Aleutian Islands, Alaska. *Arctic Anthro.* **35**:223-233.

White, C.M., Williamson, F.S.L. and Emison, W.B. (1977) Avifaunal investigations. In: *The environment of Amchitka Island, Alaska*. M. L. Merritt and Fuller, R. G. (eds), Springfield, VA: NTIS, pp. 227-260.

Whittam, T.S. and Siegel-Causey, D. (1981) Species interactions and community structure in Alaska seabird colonies. *Ecol.* **62**:1515-1524.

Yesner, D.R. (1976) Aleutian island albatrosses: a population history. *Auk* **93**:263-280.

Yesner, D.R. (1977) Avian exploitation, occupational seasonality, and paleoecology of the Chugachik Island Site. *Anthro. Pap. Univ. Alaska* **18**:23-36.

Yesner, D.R. (1981) Archeological Applications of Optimal Foraging Theory: Harvest Strategies of Aleut Hunter-Gatherers. In: *Hunter-Gatherer Foraging Strategies: Ethnographic and Archeological Analyses*. B. Winterhalder and Alden Smith, E. (eds), Chicago: University of Chicago Press, pp. 148-170.

Yesner, D.R. (1988) Effects of prehistoric human exploitation on Aleutian sea mammal populations. *Arctic Anthro.* **25**:28-43.

Yesner, D.R. (1989) Osteological remains from Larsen Bay, Kodiak Island, Alaska. *Arctic Anthro.* **26**:96-106.

Yesner, D.R. (1992) Evolution of subsistence in the Kachemak tradition: evaluating the North Pacific maritime stability model. *Arctic Anthro.* **29**:167-181.

Yesner, D.R. (1998) Origins and development of maritime adaptations in the Northwest Pacific region of North America: a zooarcheological perspective. *Arctic Anthro.* **35**:204-222.

Yesner, D.R. and Aigner, J.S. (1976) Comparative biomass estimates and prehistoric cultural ecology of the southwest Umnak region, Aleutian Islands. *Arctic Anthro.* **13**:91-112.

Zar, J.H. (1999) Biostatistical Analysis, Fourth Edition, Prentice Hall, Upper Saddle River, NJ.

Table 1. Aleutian Zooarchaeological Studies.

Site ¹	Location ²	Region and Pass ³	Material ⁴	Species ID ⁵	Sampling Design ⁶	Inclusive Dates (ybp) ⁷	Levels Dated ⁸	Metadata ⁹	Reference ¹⁰
Chugachik I,	59° 45' N	G	B, M, I	S	Q	1700 – 2300	No	No	Yesner 1977
Kachemak Bay	151° 03' W	Gulfof Alaska							
Kodiak I	Various	G	B, M	G	U	Unknown	No	No	Friedmann, 1935 – 1938,
Larsen Bay,	57° 56' N	G	B, M, I	S	Q	620 - 1290	No	No	Yesner 1989
Kodiak I	154° 02' W	Gulfof Alaska							Hrdlicka 1945
Peterson Lagoon,	54° 45' N	E	F	S	Q	100 – 1000	Yes	L	Hoffman et al. 2000
Unimak I	165° 58' W	Unimak Pass							
Amoknak I	53° 53' N	E	M, I	S	U	Unknown	No	No	Eyerdam 1934
	166° 32' W	Unalaska							

		Pass									
Chaluka, Umnak Island	59° 45' N 151° 03' W	E	M	G	Q	200 - 3700	M	No	Lippold 1966, 1972		
Oglodax, Anangula, Umnak Island	59° 45' N 151° 03' W	E	B, M	S	Q	200 - 2400	No	No	Yesner and Aigner 1976		
Atka I	52° 12' N 174° 12' E	C	B, M	M	Q	500 - 1900	Yes	No	Veltre 1979		
Amchitka Island	51° 23' N 179° 16' E	C	B, M	S	Q	890 - 2650	Yes	L	Harrington 1987, Siegel-Causey et al. 1991		
Buldir Island	52° 22' N 176° 55' E	W	B, M, F, I	S	Q	460 - 1160	Yes	L	Lefevre et al. 1977		
Shemya Island	52° 43' N 174° 07' E	W	B, M, F, I	S	Q	1790 - 3540	Yes	L	Siegel-Causey et al. 1994, Corbett et al.		
Attu Pass											

In Press

- 1 Sites identified by geographic name and ordered from East to West.
- 2 Geographic location is mid-point for densely aggregated archeological sites (e.g., SW Umnak Island)
- 3 C: Central Aleutians; G: Gulf of Alaska; E: Eastern Aleutians; W: Western Aleutians
- 4 B: birds, M: mammals, F: fish, I: invertebrates.
- 5 M: Missing, identified only by group (i.e., “fish”); G: General, identified or accurate to genus (i.e., “Gull” or “Larus”); S: Species, identified or accurate to species.
- 6 U: Uncontrolled; Q: Quadrat test pits.
- 7 Dates represent ranges of uncorrected radiocarbon dates associated with faunal deposits.
- 8 Individual excavation levels with published dates.
- 9 No: metadata missing or unreported; L: Faunal material listed by levels or dated
- 10 Unpublished work is not listed.

Table 2. Uncorrected radiocarbon dates (ybp ^{14}C) for levels and sites used in this study.

Island	Site	Level	Date	Lab Reference
Amchitka	RAT-031	B	890 \pm 90	I-4736 (1)
		H	1980 \pm 95	I-4737 (1)
		J	2550 \pm 95	I-4735 (1)
Buldir	KIS-008, pit 1	1	460 \pm 50	Beta-54253 (2)
		6	280 \pm 50	Beta-54254 (2)
	KIS-008, pit 2	C	530 \pm 60	Beta-54255 (2)
		G	1160 \pm 50	Beta-54256 (2)
Shemya	ATU-003	7	2556 \pm 135	IEMAE-1177 (3)
	ATU-021	2	1980 \pm 60	Beta-131313 (2)
	ATU-022	1	2020 \pm 110	Beta-110114 (2)
	ATU-061	Bottom	3325 \pm 60	Beta-39104 (2)

1 Unknown laboratory (Desautels et al. 1971).

2 Beta Analytic (Corbett et al. 1997).

3 Institute of Ecology and Evolution, Russian Academy of Sciences, Moscow

Table 3. Nesting, Foraging, and Diet strategies of common seabirds found in the Aleutian Islands. Data are based on Byrd et al. (in press).

Species	Common	Nesting ¹	Foraging ²	Diet ³
<i>Aethia cristatella</i>	Crested Auklet	C	O	P
<i>Aethia pusilla</i>	Least Auklet	C	O	P
<i>Aethia pygmaea</i>	Whiskered Auklet	C	N	P
<i>Brachyramphus marmoratus</i>	Marbled Murrelets	S	N	F
<i>Branta canadensis</i>	Canada Goose	S	N	V
<i>Cyclorhamphus psittacula</i>	Parakeet Auklet	C	N	P
<i>Fratercula cirrhata</i>	Tufted Puffin	B	O	F
<i>Fratercula corniculata</i>	Horned Puffin	C	N	F
<i>Fulmarus glacialis</i>	Northern Fulmar	S	O	P
<i>Histrionicus</i>	Harlequin Duck	S	N	V
<i>Larus</i> spp.	Gulls	S	N	F

<i>Oceanodroma</i> spp	Storm-petrel	B	O	P
<i>Phalacrocorax</i> spp	Cormorants	L	N	F
<i>Phoebastria albatrus</i>	Short-tailed Albatross	X	O	F
<i>Ptychorhamphus aleuticus</i>	Cassin's Murrelet	B	O	P
<i>Puffinus tenuirostris</i>	Short-tailed Shearwater	X	O	F
<i>Rissa</i> spp	Kittiwakes	L	O	F
<i>Somateria mollissima</i>	Common Eider	S	N	F
<i>Sterna aleutica</i>	Aleutian Tern	S	N	F
<i>Synthliboramphus antiquus</i>	Ancient Murrelet	B	O	P
<i>Uria</i> spp	Murres	L	O	F

1 B: burrow, C: crevice, L: ledge, S: surface, X: non-breeder in Aleutians.

2 N: nearshore, O: offshore.

3 F: fish, P: plankton, V: vegetarian

Table 4. Distribution of identified avian bony elements excavated from Amchitka Island, site 31, by stratigraphic level. Data are summarized from Harrington (1987) and Siegel-Causey et al. (1991). Values are MNI or NISP(MNI).

	Site 31											Total ²
	A	B	C	E	G	H	I	J	K			
Date ¹⁴ C ybp ³		890			1,890			2,650				
		ybp			ybp			ybp				
<i>Phoebastria albatrus</i>	3	9	9	4	3	5	6	2	0			293(41)
<i>Fulmarus glacialis</i>	0	2	3	3	1	2	10	1	1			75(23)
<i>Puffinus tenuirostris</i>	2	6	2	2	2	2	12	3	0			178(31)
<i>Phalacrocorax auritus</i> ⁴	0	9(3)	2(2)	1(1)	2(2)	0	2(1)	0	0			16(9)
<i>Phalacrocorax pelagicus</i> ⁴	12(3)	323(29)	217(25)	363(48)	55(6)	94(15)	199(25)	9(3)	22(3)			1294(157)
<i>Phalacrocorax urile</i> ⁴	1(1)	76(14)	33(7)	76(12)	14(3)	18(3)	35(5)	0(0)	4(1)			257(50)
<i>Branta canadensis</i>	1	7	12	29	5	3	2	0	6			23(65)
<i>Somateria mollissima</i>	1	11	9	7	5	4	10	1	2			279(50)
<i>Larus glaucescens</i>	1	6	3	5	3	2	4	1	3			143(28)

	1	8	10	7	2	4	6	1	1	Causey et al. 3/15/05
<i>Uria</i> spp.	1	8	10	7	2	4	6	1	1	201(40)
<i>Aethia</i> spp.	4	56	44	39	11	16	43	6	8	557(146)
Misc spp.	8	62	51	44	12	20	53	7	12	1407(269)
NISP	26	201	161	175	63	71	178	24	39	4723(909)

1 A – M, discrete levels. Levels D, F, L, and M are not reported here because of small samples (< 5 elements).

2 Totals abstracted from Tables 5 and 7 in Harrington (1987).

3 Radiocarbon dating for levels B, G, and J reported by Desautels et al. (1971).

4 Data abstracted from Siegel-Causey et al. (1991).

Table 5. Distribution of identified avian bony elements excavated from Buldir Island by stratigraphic level. Data are from Lefèvre et al. 1997.

Level	Pit 1	Pit 2						Total	
		A	B	C	D	E	F		G
	280			530				1160	Total
Species	ybp ¹			ybp				ybp	
<i>Phoebastria albatrus</i>	2 (2) ²	0	0	1 (1)	0	0	0	3 (1)	6 (4)
<i>Fulmarus glacialis</i>	3 (1)	0	0	0	0	0	0	0	3 (1)
<i>Oceanodroma</i> spp.	59 (13)	0	0	0	0	85 (19)	1 (1)	0	145 (33)
<i>Phalacrocorax</i> spp.	14 (5)	0	0	1 (1)	0	0	0	0	15 (6)
<i>Branta canadensis</i>	18 (7)	0	0	4 (2)	0	51 (21)	0	0	73 (30)
<i>Larus</i> spp.	61 (14)	0	3 (1)	0	0	11 (5)	0	0	75 (20)
<i>Rissa</i> spp.	119 (19)	0	0	0	0	0	0	0	119 (19)

	Causey et al. 3/15/05									
<i>Uria</i> spp.	14 (6)	2 (1)	0	2 (1)	0	0	0	0	0	18 (8)
<i>Synthliboramphus antiquus</i>	250 (35)	6 (1)	12 (5)	0	3 (1)	0	17 (3)	20 (4)	308 (49)	
<i>Ptychoramphus aleuticus</i>	25 (7)	2 (1)	17 (2)	6 (2)	4 (1)	410 (54)	14 (3)	37 (4)	515 (74)	
<i>Cyclorhynchus psittacula</i>	57 (15)	0	0	2 (1)	0	0	1 (1)	0	60 (17)	
<i>Aethia</i> spp.	525 (90)	11 (2)	16 (5)	311 (32)	14 (4)	405 (64)	20 (4)	25 (5)	1327 (206)	
<i>Cerorhinca monocerata</i>	11 (3)	1 (1)	7 (2)	14 (6)	0	147 (21)	3 (1)	8 (3)	191 (37)	
<i>Fratercula</i> spp.	9 (4)	0	10 (3)	44 (7)	24 (3)	87 (18)	2 (1)	1 (1)	177 (37)	
Misc spp. ³	361	21	46	530	58	1906	43	90	3037	
Totals	1528 (221)	43 (6)	111 (18)	915 (53)	103 (9)	3102 (202)	101 (14)	184 (18)	6087 (541)	

¹ Radiocarbon dating reported by Corbett et al. 1997.

² NISP (MNI).

³ MNI were not calculated for miscellaneous and unidentifiable bone fragments.

Table 6. Distribution of identified avian bony elements excavated from Shemya Island by excavation pits. Data are from Corbett et al. In Press.

Excavation	ATU-021	ATU-022	ATU-003	ATU-061	Totals
Species	1980 ybp	2020 ybp	2556 ybp	3325 ybp	
<i>Phoebastria albatrus</i>	338 (10) ¹	321 (17)	175 (10)	27 (4)	861 (41)
<i>Fulmarus glacialis</i>	54 (8)	254 (38)	117 (14)	5 (1)	430 (61)
<i>Oceanodroma</i> spp.	22 (7)	2 (1)	5 (2)	1 (1)	30 (11)
<i>Puffinus</i> spp.	204 (25)	371 (68)	313 (56)	56 (7)	944 (156)
<i>Phalacrocorax</i> spp.	101 (8)	61 (7)	30 (5)	27 (4)	219 (24)
<i>Branta</i> spp. ²	2 (1)	4 (1)	13 (2)	1 (1)	20 (5)
<i>Somateria</i> spp.	9 (2)	20 (4)	8 (2)	2 (1)	39 (9)
<i>Larus</i> spp.	11 (3)	23 (2)	7 (4)	8 (3)	49 (12)
<i>Rissa</i> spp.	1 (1)	15 (3)	4 (2)	2 (2)	22 (8)

<i>Uria</i> spp.	18 (5)	34 (5)	14 (6)	47 (6)	113 (22)
<i>Synthliboramphus antiquus</i>	107 (9)	78 (18)	17 (6)	16 (3)	218 (36)
<i>Ptychoramphus aleuticus</i>	0	0	7 (2)	1 (1)	8 (3)
<i>Cyclorhynchus psittacula</i>	0	0	0	8 (3)	8 (3)
<i>Aethia</i> spp.	43 (9)	32 (12)	14 (5)	50 (3)	139 (29)
<i>Cerorhinca monocerata</i>	0	6 (3)	4 (1)	6 (3)	16 (7)
<i>Fratercula</i> spp.	15 (3)	19 (4)	6 (3)	63 (8)	103 (18)
Misc spp. ³	750	482	366	665	2263
Totals	1675 (91)	1722 (183)	1100 (120)	985 (51)	5482 (445)

1. NISP (MNI).
2. Indeterminate; may represent *Branta canadensis*, *B. nigricans*, or *Chen canagica*.
3. MNI were not calculated for miscellaneous and unidentifiable bone fragments.

Figure Captions

Figure 1. Map of island groups and islands passes of the Aleutian Islands and location of precontact Aleut tribal groups (redrawn from Byrd *et al.*, In press, and Bergsland and Dirks, 1990). Passes are indicated by number: 1) Near Island Pass; 2) Buldir Pass; 3) Amchitka Pass; 4) Tanaga Pass; 5) Seguam Pass; 6) Amukta Pass; 7) Umnak Pass; 8) Samalga Pass; 9) Akutan Pass; 10) Unimak Pass.

Figure 2. Cumulative and relative (inset) frequencies of bird bones in midden deposits. Solid black: nearshore species; shaded: offshore, piscivorous species; open: offshore, planktivorous species. See Table 3 for species assignments.

Figure 3. Paleoenvironment of the Aleutian Islands reconstructed by several proxy studies. Shaded boxes indicate the approximate period of the Medieval Warm Period (MWP) and the Little Ice Age (LIA). A) Bering Island: bold dashed-dotted line is sea level change (m) from present, dashed line is temperature change (°C) from present, based on standard transfer functions of diatom presence and abundance. Data redrawn from Razjigaeva *et al.* (2004). B) Shemya Island: solid line is percent decomposition of dated peat samples (precipitation), dashed line is percent ash content of peat (temperature). Data redrawn from Savinetsky *et al.* (2004). C) Gulf of Alaska: solid line is mean annual precipitation (mm H₂O), dashed line is mean July temperature (°C), based on standard transfer functions of diatom presence and abundance. Data redrawn from Heusser *et al.* (1985).





