FOG-Aleut-16R Rec'd 8/17/2004

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

DOUGLAS CAUSEY[1,*], DEBRA G. CORBETT[2], CHRISTINE LEFÉVRE[3], DIXIE WEST[4], ARKADY B. SAVINETSKY[5], NINA K. KISELEVA[5], BULAT F. KHASSANOV[5]

[1] *Museum of Comparative Zoology, Harvard University, Cambridge, MA 02138, USA,* *dcausey@oeb.harvard.edu*

[2] *US Fish and Wildlife Service, 1011 E. Tudor Road, Anchorage, AK 99503, USA,* *Debbie_Corbett@fws.gov*

[3] *Département Écologie et Gestion de la Biodiversité, Muséum national d'Histoire naturelle, Paris, France,* *lefevre@cimrs1.mnhn.fr*

[4] *University of Kansas Museum of Natural History, Lawrence, Kansas, 66045, USA,* *dlwest@ku.edu*

[5] *A. N. Severtsov Institute of Ecology and Evolution, Russian Academy of Sciences, 33 Leninsky pr., Moscow 119071, Russia,* *histecol@orc.ru*

* Corresponding author

Running title: Aleutian paleoenvironment

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 Slender-billed 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 murres and kittiwakes increased in abundance. 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: 90)

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 detailed reports were by William Dall, a naturalist associated with the California Academy of Sciences, who observed Black Brants (*Branta nigricans*) breeding in the Near Islands, Ancient Murrelets (*Synthliboramphus antiquus*) in high abundances throughout the Aleutians, and Parakeet Auklets (*Aethia psittacula*) 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 as common species that are rarely or never seen today (e.g., Red-legged Kittiwake *Rissa brevirostris*) and, based on eyewitness accounts by native Attuans, reported that extinct Pallas's Cormorant (*Phalacrocorax perspicillatus*) 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 (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 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. 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 1944, Spaulding 1962, Lippold 1966, 1972, Bouchet *et al.* 1999), 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 with corrections as years before present (ybp) ± error (Table 2). 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 and Kodiak islands, located on the extreme western and eastern boundaries of the archipelago (Finney *et al.* 2000, Razyigaeva *et al.* 2004). These and several others are based on standard analysis of diatom presence and abundance in buried soils (e.g., (Mann *et al.* 1998, Sawada *et al.* 1999, Finney *et al.* 2000, Calkin *et al.* 2001, Tunicliffe *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 derived from analysis of layer-by-layer changes in ash content of peat and the degree of its decomposition sampled from Shemya Island (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 precipiation 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 depositional 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-Uribe 1984). 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-Uribe 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, murres, 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:

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

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:

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

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

$$d_{ij} = \frac{e_{ij}}{\sqrt{v_{ij}}} \tag{3}$$

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):

$$D = \max\left|F_1(i) - F_2(i)\right| \tag{4}$$

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):

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

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:

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

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 y ^{14}C bp), H (1980 ± 95 y ^{14}C bp), and J (2550 ± 95 y ^{14}C). 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 cormorants 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: $z_E = +4.74$, $P << 0.001$). 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 Slender-billed 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: $z_{E(N)} = +6.32$, $P << 0.001$) 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: $z_E = +4.72$, $z_H = +3.88$; $P << 0.001$). Observed abundances were lower in adjacent levels later in time, i.e. levels D and G, but not significantly.

Buldir Island

Buldir Island (52 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 ybp) 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, 6,069 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 jubata*. 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: $D_{OF/OP} = 0.206$, $\chi^2 = 15.5$, $P = 0.004$; $D_{OF/N} = 0.212$, $\chi^2 = 14.6$, $P = 0.007$; $D_{OP/N} = 0.232$, $\chi^2 = 75.2$, $P << 0.001$). 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: $D_{S\text{-}L/B\text{-}X} = 0.339$, $\chi^2 = 201.82$, $P << 0.001$). 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: $z_{\mathrm{C}} = -16.96$, $z_{\mathrm{E}} = +11.63$; $\mathrm{P} << 0.001$).

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-003, 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 $P << 0.001$). 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

(*Sythliboramphus 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: $z_{021} = +2.35$, $P << 0.001$; $z_{022} = +3.51$, $P << 0.001$; $z_{003} = -3.86$, $P << 0.001$, $z_{061} = +0.14$, 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 $P << 0.001$).

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 $P << 0.001$). 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 $P << 0.001$). 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 signicantly 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 ybp on Attu Island, 6500 ^{14}C ybp on Amchitka Island, and 11,000 ^{14}C ybp 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 ^{14}C ybp (Razjigaeva *et al.* 2004). Sea levels oscillated within this period (Fig. 3a), however, with peaks at about 3800 ^{14}C ybp (+2.0 m), 2700 ^{14}C ybp (+1.5 m), and 1000 ^{14}C ybp (+0.9 m); and regressions at 3100 ^{14}C ybp (-0.9 m), 1800 ^{14}C ybp (-0.5 m), and 400 ^{14}C ybp (-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 ^{14}C ybp 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 fluctations 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 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 ^{14}C ybp. It then decreased monotonically until about 2000 ^{14}C ybp 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 mmH_20), with noticeable decreases at about 3700 ^{14}C ybp and 2200 ^{14}C ybp (Heusser *et al.* 1985).

Temperatures varied over time, with peaks observed at about 5500 - 5250 ^{14}C ybp, and 3000 - 2750 ^{14}C ybp (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 ^{14}C ybp 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, murres, 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, 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, murres and puffins, varied considerably and inconsistently through time: during some periods, murres 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 Slender-billed 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: $r_s(\mathrm{T})_\mathrm{N} = +0.518$, $r_s(\mathrm{P})_\mathrm{N} = +0.571$; $p < 0.05$). 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: $r_s(\mathrm{T})_\mathrm{OF} = -0.696$, $p < 0.04$; $r_s(\mathrm{T})_\mathrm{Proc} = -0.554$; $p < 0.05$).

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, Savinetskii 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: $r_s(\mathrm{T})_{\mathrm{ALL}} = -0.506$, $r_s(\mathrm{P})_{\mathrm{ALL}} = +0.601$; $p < 0.075$).

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. 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 murres 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.

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Table 1. Aleutian Zooarcheological 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, Kachemak Bay	59° 45′ N 151° 03′ W	G Gulf of Alaska	B, M, I	S	Q	1700 – 2300	No	No	Yesner 1977
Kodiak I	Various	G Gulf of Alaska	B, M	G	U	Unknown	No	No	Friedmann, 1935 – 1938, Hrdlicka 1945
Larsen Bay, Kodiak I	57° 56′ N 154° 02′ W	G Gulf of Alaska	B, M, I	S	Q	620 - 1290	No	No	Yesner 1989
Peterson Lagoon, Unimak I	54° 45′ N 165° 58′ W	E Unimak Pass	F	S	Q	100 – 1000	Yes	L	Hoffman et al. 2000
Amoknak I	53° 53′ N 166° 32′ W	E Unalaska	M, I	S	U	Unknown	No	No	Eyerdam 1934

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

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. Radiocarbon dates (ybp ^{14}C) for levels and sites used in this study.

Island	Site	Level	Date	Lab Reference
Amchitka	RAT-031	B	890 ± 90	I-4736 (1)
		H	1980 ± 95	I-4737 (1)
		J	2550 ± 95	I-4735 (1)
Buldir	KIS-008, pit 1	1	460 ± 50	Beta-54253 (2)
		6	280 ± 50	Beta-54254 (2)
	KIS-008, pit 2	C	530 ± 60	Beta-54255 (2)
		G	1160 ± 50	Beta-54256 (2)
Shemya	ATU-003	7	2120 ± 135	IEMAE-117 (3)
	ATU-021	2	1980 ± 60	Beta-131313 (2)
	ATU-022	1	2020 ± 110	Beta-110114 (2)
	ATU-061	Bottom	3105 ± 80	Beta-39104

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 (Corbett 1990).

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]
Aethia cristatella	Crested Auklet	C	O	P
Aethia pusilla	Least Auklet	C	O	P
Aethia pygmaea	Whiskered Auklet	C	N	P
Brachyramphus marmoratus	Marbled Murrelets	S	N	F
Branta canadensis	Canada Goose	S	N	V
Cyclorhamphus psittacula	Parakeet Auklet	C	N	P
Fratercula cirrhata	Tufted Puffin	B	O	F
Fratercula corniculata	Horned Puffin	C	N	F
Fulmarus glacialis	Northern Fulmar	S	O	P
H histrionicus	Harlequin Duck	S	N	V
Larus spp.	Gulls	S	N	F

Oceanodroma spp	Storm-petrel	B	O	P
Phalacrocorax spp	Cormorants	L	N	F
Phoebastria albatrus	Short-tailed Albatross	X	O	F
Ptychorhamphus aleuticus	Cassin's Murrelet	B	O	P
Puffinus tenuirostris	Slender-billed Shearwater	X	O	F
Rissa spp	Kittiwakes	L	O	F
Somateria mollissima	Common Eider	S	N	F
Sterna aleuticus	Aleutian Tern	S	N	F
Synthliboramphus antiquus	Ancient Murrelet	B	O	P
Uria 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									
Levels [1]	**A**	**B**	**C**	**E**	**G**	**H**	**I**	**J**	**K**	**Total** [2]
Date ^{14}C ybp [3]		890 ybp			1,890 ybp			2,650 ybp		
Phoebastria albatrus	3	9	9	4	3	5	6	2	0	293(41)
Fulmarus glacialis	0	2	3	3	1	2	10	1	1	75(23)
Puffinus tenuirostris	2	6	2	2	2	2	12	3	0	178(31)
Phalacrocorax auritus [4]	0	9(3)	2(2)	1(1)	2(2)	0	2(1)	0	0	16(9)
Phalacrocorax pelagicus [4]	12(3)	323(29)	217(25)	363(48)	55(6)	94(15)	199(25)	9(3)	22(3)	1294(157)
Phalacrocorax urile [4]	1(1)	76(14)	33(7)	76(12)	14(3)	18(3)	35(5)	0(0)	4(1)	257(50)
Branta canadensis	1	7	12	29	5	3	2	0	6	23(65)
Somateria mollissima	1	11	9	7	5	4	10	1	2	279(50)
Larus glaucescens	1	6	3	5	3	2	4	1	3	143(28)

Uria spp.	1	8	10	7	2	4	6	1	1	201(40)
Aethia 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 Lefévre et al. 1997.

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

Uria spp.	14 (6)	2 (1)	0	2 (1)	0	0	0	0	18 (8)
Synthliboramphus antiquus	250 (35)	6 (1)	12 (5)	0	3 (1)	0	17 (3)	20 (4)	308 (49)
Ptychoramphus aleuticus	25 (7)	2 (1)	17 (2)	6 (2)	4 (1)	410 (54)	14 (3)	37 (4)	515 (74)
Cyclorrhynchus psittacula	57 (15)	0	0	2 (1)	0	0	1 (1)	0	60 (17)
Aethia spp.	525 (7)	11 (2)	16 (5)	311 (32)	14 (4)	405 (64)	20 (4)	25 (5)	1327 (206)
Cerorhinca monocerata	11 (3)	1 (1)	7 (2)	14 (6)	0	147 (21)	3 (1)	8 (3)	191 (37)
Fratercula 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	1888	43	90	3037
Totals	1528 (226)	43 (6)	111 (18)	915 (53)	103 (9)	3084 (202)	101 (14)	184 (18)	6069 (541)

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[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**	
Species	1980 ybp	2020 ybp	2120 ybp	3105 ybp	**Totals**
Phoebastria albatrus	338 (10)	321 (17)	175 (10)	27 (4)	861 (41)
Fulmarus glacialis	54 (8)	254 (38)	117 (14)	5 (1)	430 (61)
Oceanodroma spp.	22 (7)	2 (1)	5 (2)	1 (1)	30 (11)
Puffinus spp.	204 (25)	371 (68)	313 (56)	56 (7)	944 (156)
Phalacrocorax spp.	101 (8)	61 (7)	30 (5)	27 (4)	219 (24)
Branta canadensis	2 (1)	4 (1)	13 (2)	1 (1)	20 (5)
Somateria spp.	9 (2)	20 (4)	8 (2)	2 (1)	39 (9)
Larus spp.	11 (3)	23 (2)	7 (4)	8 (3)	49 (12)
Rissa spp.	1 (1)	15 (3)	4 (2)	2 (2)	22 (8)

Uria spp.	18 (5)	34 (5)	14 (6)	47 (6)	113 (22)
Synthliboramphus antiquus	107 (9)	78 (18)	17 (6)	16 (3)	218 (36)
Ptychoramphus aleuticus	0	0	7 (2)	1 (1)	8 (3)
Cyclorrhynchus psittacula	0	0	0	8 (3)	8 (3)
Aethia spp.	43 (9)	32 (12)	14 (5)	50 (3)	139 (29)
Cerorhinca monocerata	0	6 (3)	4 (1)	6 (3)	16 (7)
Fratercula 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] Radiocarbon dating reported by Corbett et al. In Press.

2 NISP (MNI).

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). 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: all 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 (^oC) 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 H_2O), dashed line is mean July temperature (^oC), based on standard transfer functions of diatom presence and abundance. Data redrawn from Heusser *et al.* (1985).

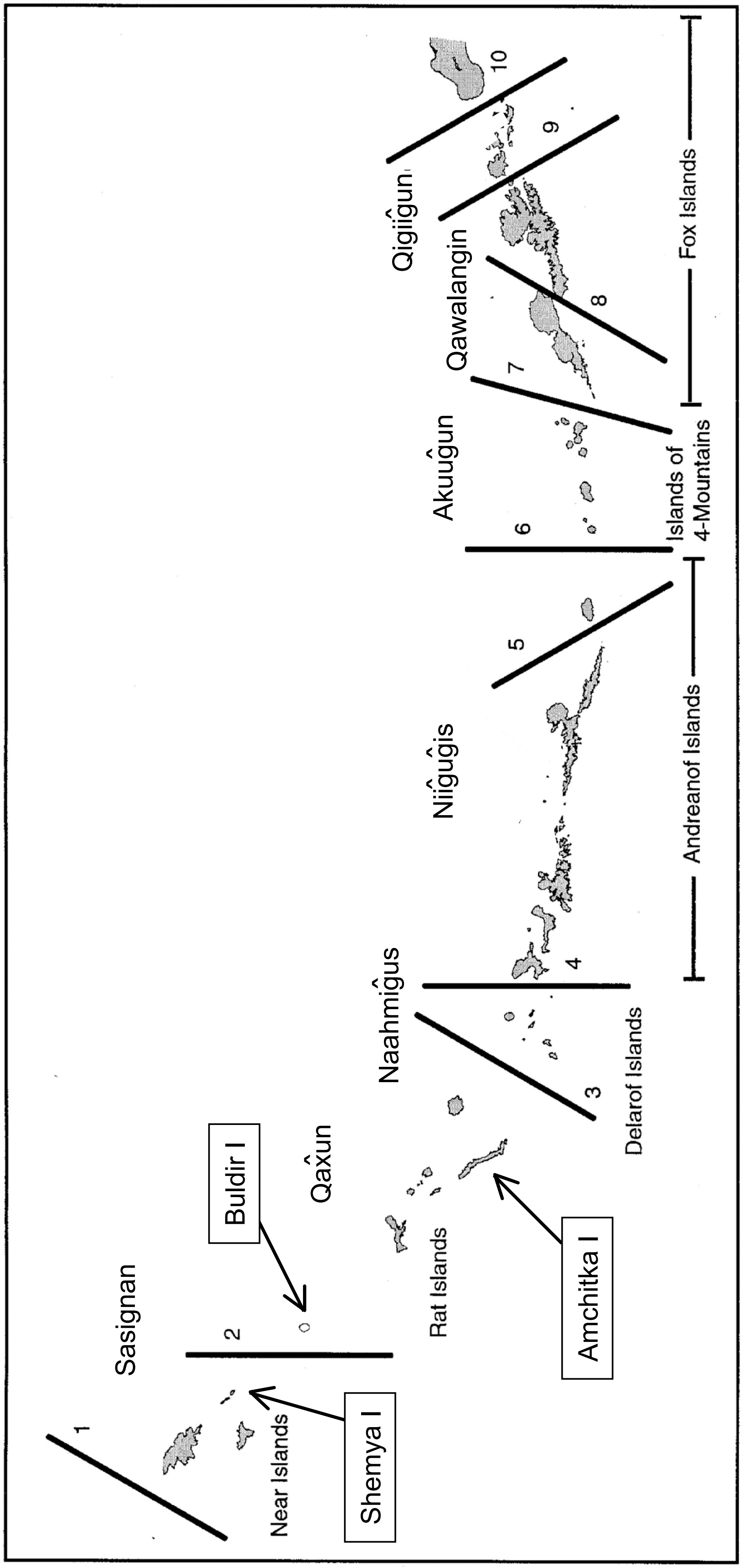
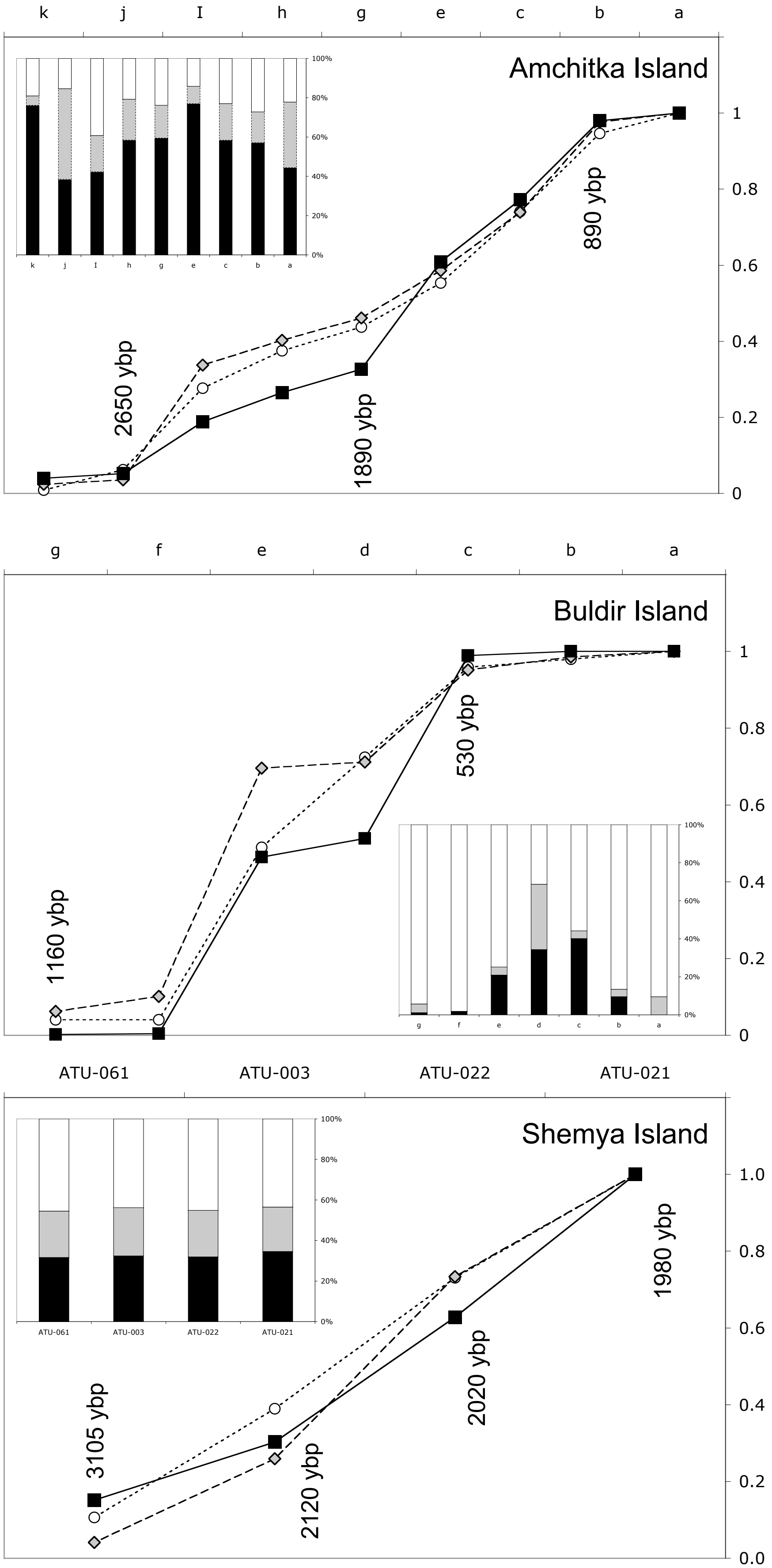

Near Islands
Shemya I
1
Sasignan
2
Buldir I
Rat Islands
Amchitka I
Qax̂un
Delarof Islands
3
Naahmiĝus
4
Andreanof Islands
Niiĝuĝis
5
6
Islands of
4-Mountains
Akuuĝun
7
Qawalangin
8
Fox Islands
9
Qigiiĝun
10

Fig. 1.



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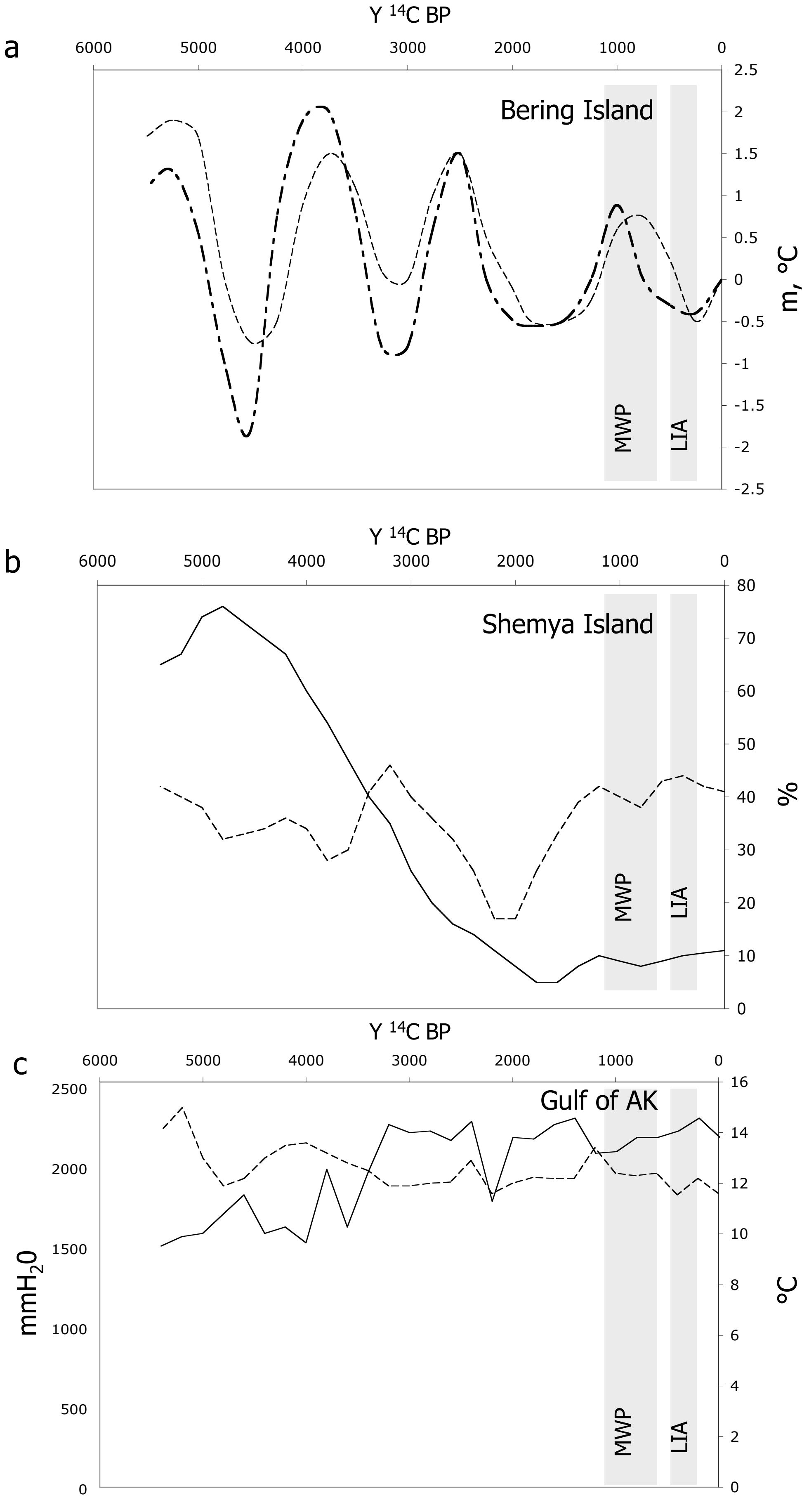
a
Amchitka Island
100%
80%
60%
40%
20%
0%
2650 ybp
1890 ybp
890 ybp
1
0.8
0.6
0.4
0.2
0
g
f
e
d
c
b
a
Buldir Island
1160 ybp
530 ybp
ATU-061
ATU-003
ATU-022
ATU-021
Shemya Island
3105 ybp
2120 ybp
2020 ybp
1980 ybp
1.0
0.8
0.6
0.4
0.2
0.0

Fig. 2.


a
Y ^{14}C BP
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4000
3000
2000
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Bering Island
2.5
2
1.5
1
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0
-0.5
-1
-1.5
-2
-2.5
m, °C
MWP
LIA
b
Y ^{14}C BP
6000
5000
4000
3000
2000
1000
0
Shemya Island
80
70
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40
30
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10
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Y ^{14}C BP
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Gulf of AK
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Fig. 3.