12-10-2020

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Citation Details

Reuther, J., Shirar, S., Mason, O., Anderson, S., Coltrain, J., Freeburg, A., . . . Norman, L. (2020). MARINE RESERVOIR EFFECTS IN SEAL (PHOCIDAE) BONES IN THE NORTHERN BERING AND CHUKCHI SEAS, NORTHWESTERN ALASKA. Radiocarbon, 1-19. doi:10.1017/RDC.2020.127

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Radiocarbon, Vol 00, Nr 00, 2020, p 1–19 DOI:10.1017/RDC.2020.127

MARINE RESERVOIR EFFECTS IN SEAL (PHOCIDAE) BONES IN THE NORTHERN BERING AND CHUKCHI SEAS, NORTHWESTERN ALASKA

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ABSTRACT. We explore marine reservoir effects (MREs) in seal bones from the northern Bering and Chukchi Seas regions. Ringed and bearded seals have served as dietary staples in human populations along the coasts of Arctic northeast Asia and North America for several millennia. Radiocarbon (^{14}C) dates on seal bones and terrestrial materials (caribou, plants seeds, wood, and wood charcoal) were compared from archaeological sites in the Bering Strait region of northwestern Alaska to assess MREs in these sea mammals over time. We also compared these results to ^{14}C dates on modern seal specimens collected in AD 1932 and 1946 from the Bering Sea region. Our paired archaeological samples were recovered from late Holocene archaeological features, including floors from dwellings and cache pits, that date between 1600 and 130 cal BP. ^{14}C dates on seal bones from the northern Bering and Chukchi Seas show differences [R(t)] of 800 ± 140 years from to their terrestrial counterparts, and deviations of 404 ± 112 years (ΔR) from the marine calibration curve.

KEYWORDS: Late Holocene, marine reservoir effect, northwestern Alaska, seals.

INTRODUCTION

Coastal northern Alaska holds an important place with regard to problems focused on understanding climatic and ecological change, as well as human adaptation and migration across the North American Arctic (Friesen et al. 2013; Tackney et al. 2016). The greater Bering Strait region, in particular, has been a center of prehistoric cultural diversity, interaction and innovation for several thousand years (Mason 1998; Mason and Friesen 2017).

Radiocarbon (^{14}C) dating of Arctic coastal archaeological sites can be problematic for several reasons, including, but not limited to (1) the use of driftwood or long-lived shrubs that produce older ^{14}C ages, commonly referred to as the "old wood effect," that incorrectly date the archaeological event; (2) organic materials can be preserved for relatively long periods of time (1000s to 10,000s of years) within permafrost (annually frozen) landscapes and incorporated into archaeological matrices; dating these materials yields erroneously old ages; and (3) some sites and features within sites may not contain terrestrial materials generally preferable for ^{14}C dating, so that marine-derived materials are the only dateable material. In addition, people in

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these regions generally had mixed diets that included a large portion of sea mammals and anadromous fish that tend to contribute more marine carbon to their isotopic signature than terrestrial-based sources causing much older ^{14}C ages than the date of a person's death. Thus, understanding the marine reservoir effects (MREs) of different marine mammal species is essential to establishing accurate chronologies for Arctic coastal prehistory (Krus et al. 2019).

Research around Arctic coastlines has focused on estimating regional MREs by either (1) calculating the difference in the ^{14}C content of modern pre-Bomb marine specimens in relation to the calendar year in which they were collected; (2) using ^{14}C dates on ancient marine and terrestrial remains from geological and archaeological deposits that are assumed to be contemporaneous; or (3) comparing ^{14}C dates on marine organisms from geological deposits that contain an established date of a singular depositional event, such as tephra deposition from well-dated volcanic eruptions. Many of these studies show variance in MRE values between different marine species, and fluctuations through time and across regional geography (Arundale 1981; Dyke et al. 1996; Fitzhugh and Brown 2018).

Several attempts have been made at providing corrective MRE values for ^{14}C dates on marine species and human remains from populations that were highly reliant on marine-derived food sources from Arctic coastal zones. Marine mollusks are a focus in many MRE studies and useful in establishing local variations for oceanographic purposes (e.g., Kuzmin et al. 2007; McNeely et al. 2006; Pearce et al. 2017; Martindale et al. 2018). However, marine mollusks are generally not important to Arctic coastal populations as a dietary resource, as indicated by the dearth of mollusks in the archaeological record. Migratory marine mammals, such as seals, walrus and whales, as well as fish, held much more prominent roles in subsistence systems in the Arctic (Park 1994; Saleeby et al. 2009; Darwent 2011; Betts 2016; Coltrain et al. 2016; Britton et al. 2018; Dyke et al. 2019). In the archaeology of coastal high Arctic Canada, ^{14}C dating of marine mammals has been problematic since McGhee and Tuck (1976) discovered that marine-derived dates were older than contemporaneous terrestrial materials such as short-lived shrubs. A similar offset was noted in archaeological samples from northwestern Alaska beach ridge sites (Mason and Ludwig 1990).

Despite this need for accurate and precise MRE values, until the last decade, few researchers sought to understand the differences between ^{14}C dates of marine mammal and terrestrial organisms over time across coastal northern Alaska (notable exceptions include Dumond and Griffin 2002; Khassanov and Savinetsky 2006; Ledger et al. 2016; Krus et al. 2019). In this paper, we document MREs in ^{14}C dated seal remains from several sites spanning the last 1600 years in the Bering Strait and northern Bering Sea and Chukchi Sea regions (Figure 1), encompassing a period of significant cultural and climatic changes during the late Holocene (Mason and Jordan 1993; Mason and Gerlach 1995; Anderson et al. 2018, 2019; Mason et al. 2019). We present both the differences between ^{14}C dated marine-terrestrial pairs, R(t) values, and from the global marine curve, ΔR values (Reimer and Reimer 2017).

REGIONAL SETTING

The Chukchi Sea and northern Bering Sea are shallow, less than 100 m deep, and are the flooded continental shelves of the former Beringian subcontinent (Naidu and Gardner 1988). The Holocene transgression followed the flooding of the Bering Strait ca. 11,000 BP (Keigwin et al. 2006) and continued until the establishment of near modern sea level and marine ecology ca. 5000 BP (Jordan and Mason 1999; Khim et al. 2018). Opening north at

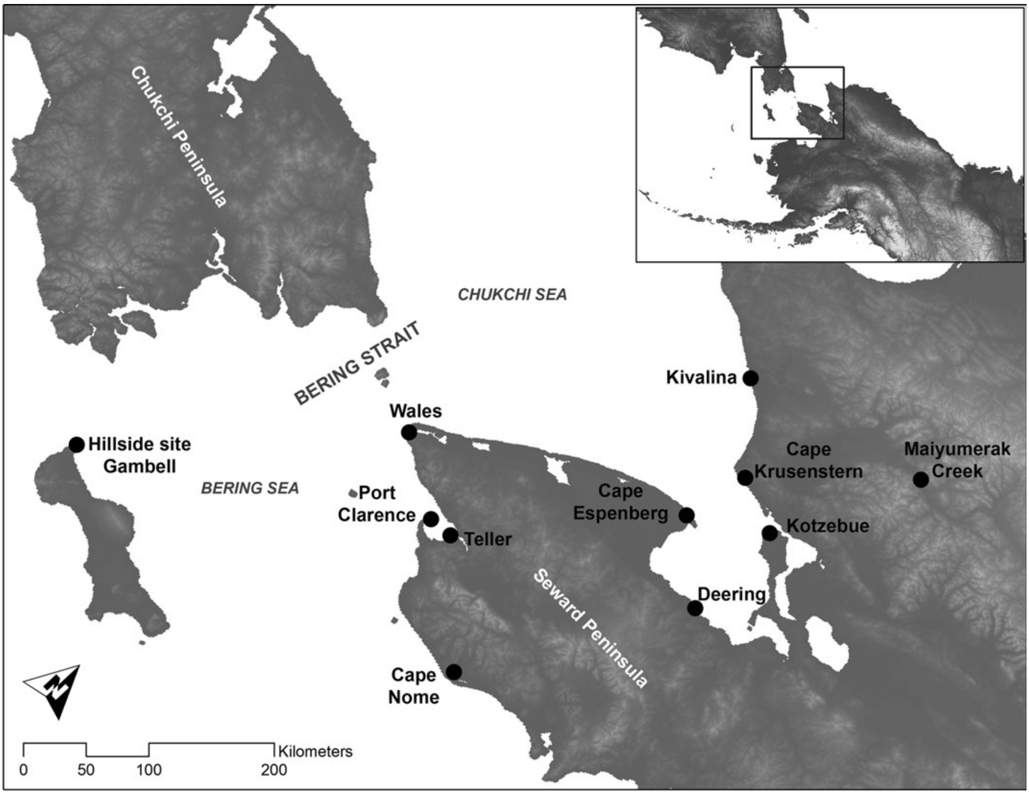

Figure 1 Map of the Bering Strait, northern Bering Sea and Chukchi Sea regions and the study site locations.

64°N at the Bering Strait, the microtidal Chukchi Sea is a triangular shaped compartment of the Arctic Ocean, oriented northwest/southeast and is subject to a complex array of atmospheric and marine processes that include frequent storm surges (Wise et al. 1981) and the intrusion of water masses from both the Pacific and Atlantic Oceans (Coachman and Aagaard 1988; Lee et al. 2007; Pisareva et al. 2015; Pickart et al. 2016). Occasionally, warm, salty Atlantic water reaches the northern Chukchi Sea due to upwelling from Herald Canyon and southward transport along the Siberian coast. Several water masses flow through Bering Strait (Pisareva et. al. 2015) and provide organic carbon onto the Chukchi shelf; on the west, the Bering Sea and Anadyr water masses contribute old carbon derived from the world ocean (Grebmeier and McRoy 1989). Organic carbon from Alaskan rivers is discharged into the eastern water mass (Grebmeier and McRoy 1989); the geostrophically propelled Alaska current that continues along the northwest coast of Alaska spiraling into the shallow embayment of Kotzebue Sound (Aagaard 1987). The current regime produces an upwelling of benthic nutrients (Grebmeier and McRoy 1989; Walsh et al. 1989) and supports a high biomass of ice-obligate migrating sea mammals (e.g., seal, walrus, and whale [Lentfer 1988]), critically important to human subsistence, with discarded bone deposited near former settlements. While benthic organic carbon concentration varies across the shelf (Naidu et al. 2004), the organic carbon absorption by sea mammals is diluted by migration.

Previous Marine Reservoir Effect Estimates in the Bering Strait

Meyer Rubin (1974) of the U.S. Geological Survey obtained two ^{14}C ages on the valve of a living *Astarte borealis* dredged from the floor of the Bering Sea in 1969 and obtained an averaged ^{14}C age of 540 ± 200 BP (W-2768), providing the first "disconcerting" confirmation that MRE should be a concern in the western Arctic (Rowland 1972). Knowledge of the marine carbon offset led Mason and Ludwig (1990) to compare marine and non-marine archaeological materials from St. Lawrence Island and Cape Krusenstern, noting an offset of between 400 to 500 years. Since 2000, several studies estimated MREs in the Bering Strait and northern Bering Sea. Dumond and Griffin (2002) calculated R(t) values from ^{14}C dates on seal, walrus and whale bones and mussel shells and their terrestrial counterparts—grass, wood, charcoal, and peat samples—in the same archaeological contexts (e.g., strata and features). Dumond and Griffin (2002) obtained a wide range of R(t) values across the Alaska side of the Bering Sea, from the southern Seward Peninsula to the western Alaska Peninsula, spanning 383 ± 77 to 783 ± 50 years. Their data also displayed a difference of 330 ± 41 years between walrus-ivory and seal bone ^{14}C dates, and mussel shells. Dumond and Griffin (2002) did not calculate ΔR values from their data.

Khassanov and Savinetsky (2006) calculated R(t) values between marine-terrestrial pairs from archaeological deposits on the northeastern coast of the Chukchi Peninsula in Siberia. This study used ^{14}C ages on whale bones and baleen, human hair and unidentified sea-mammal bones and produced a wide range of R(t) values from 220 ± 202 to 927 ± 52 years. They subsequently calculated ΔR values for the northern Bering Sea using their Chukchi Peninsula estimates and Dumond and Griffin's (2002) data from St. Lawrence Island, Wales and Teller. Khassanov and Savinetsky (2006) suggest that an average ΔR value of 188 ± 27 years be used as an MRE correction for the northern Bering Sea region.

McNeely et al. (2006) ^{14}C dated marine mollusk (*Hiatella*, *Mytilus*, *Serripes*, and *Mya* sp.) shells that were collected live in 1913 around the Chukchi and Bering Seas. Four *Hiatella arctica* and *Mytilus edulis* shells from Port Clarence and Teller on the southern Seward Peninsula near the Bering Strait were dated. R(t) values from these four specimens range from 700 ± 50 to 930 ± 40 years, and ΔR values between 350 ± 50 and 580 ± 40 years with a weighted mean of 486 ± 65 years. In a marine core from the Chukchi Sea, just north of the Bering Strait, Pearce et al. (2017) calculated similar ΔR value of 477 ± 60 years based a comparison of ^{14}C dates on *Macoma* sp. shells in close association with an Aniakchak tephra deposit that has a known age of ~3600 cal BP.

MATERIALS AND METHODS

Sample Selection

We ^{14}C dated marine-terrestrial paired samples from archaeological sites along the coast of northwestern Alaska and surrounding the Bering Strait: Cape Espenberg, Cape Krusenstern, Deering, Kivalina, and Kotzebue (Figure 1). This broad sampling across the region allowed us to assess geographic differences in ^{14}C offsets between seals and terrestrial samples, and compare reservoir values from previous research on shell, seals, walrus and whales in the Chukchi Sea, Bering Strait, and northern regions of the Bering Sea. Paired dates from several different periods over the last 1600 cal BP years were compared to understand potential MRE changes through time.

Our study hinges on the selection of closely associated seal and terrestrial samples in well-defined archaeological features, including house floors and fill, and cache pits (Table 1; see

Table 1 Summary of ^{14}C samples by locations.

	Seals		Caribou		Charcoal/wood/seed	
Location (site, feature)	^{14}C age BP	Lab ID	^{14}C age BP	Lab ID	^{14}C age (BP)	Lab ID
Cape Espenberg (KTZ-087, House 68A)	1343 ± 28	AA97494	250 ± 40	Beta-286171* AA97493	395 ± 15	OS-96067
			355 ± 27	Beta-286172	480 ± 30	Beta-347937
			360 ± 40			
Cape Espenberg (KTZ-087, House 87)	1422 ± 30	AA97492	551 ± 42	AA97491	485 ± 20	OS-96130
Cape Espenberg (KTZ-304, F21)	1599 ± 45	AA97488	640 ± 40	Beta-286169	—	—
	1671 ± 45	AA97490	650 ± 15	UCIAMS-184426		
			660 ± 30	Beta-453398		
			670 ± 15	UCIAMS-184430		
			680 ± 40	Beta-286168		
			685 ± 15	UCIAMS-184428		
			710 ± 20	UCIAMS-184427		
			715 ± 15	UCIAMS-184429		
			730 ± 42	AA97487		
			923 ± 43	AA97489*		
Cape Krusenstern (NOA-0463, House 4A)	880 ± 30	Beta-326111	60 ± 30	Beta-326112	—	—
Cape Krusenstern (NOA-473, Cache Pit 1A)	1550 ± 30	Beta-326113	840 ± 25	OS-81578	—	—
Cape Krusenstern (NOA-474, Unidentified 1B)	810 ± 30	Beta-326119	210 ± 30	Beta-326114	—	—
Cape Krusenstern (NOA-513, House 10)	1170 ± 30	Beta-326109	—	—	280 ± 40	Beta-223219
Cape Krusenstern (NOA-513, House 2)	1020 ± 30	Beta-326106	—	—	400 ± 40	Beta-226149

(Continued)

Table 1 (*Continued*)

	Seals		Caribou		Charcoal/wood/seed	
Location (site, feature)	^{14}C age BP	Lab ID	^{14}C age BP	Lab ID	^{14}C age (BP)	Lab ID
Cape Krusenstern (NOA-513, House 4)	1110 ± 30	Beta-326107	—	—	570 ± 40	Beta-226151
Cape Krusenstern (NOA-513, Activity Area 361XH070108A)	2230 ± 30	Beta-326105	—	—	1590 ± 40	Beta-223220
Cape Krusenstern (NOA-538, House 2)	1020 ± 30	Beta-326106	—	—	400 ± 40	Beta-226149
Cape Krusenstern (NOA-558, House 1A)	1450 ± 30	Beta-326116	510 ± 30	Beta-326115	—	—
Cape Krusenstern (NOA-558, Unidentified 3B)	1280 ± 30	Beta-326118	—	—	765 ± 35	OS-96756
Cape Krusenstern (NOA-558, Unidentified 7B)	1410 ± 30	Beta-326117	640 ± 30	Beta-326120	—	—
Cape Nome	830 ± 20	UGAMS21160	—	—	—	—
Deering	2007 ± 46	AA97484	1220 ± 40	Beta-231493	1250 ± 40	Beta-138562
(KTZ-299,	2024 ± 46	AA97486	1310 ± 45	AA97485		
Ipiutak house)						
Deering	1566 ± 28	AA97497*	830 ± 40	Beta-224229	870 ± 40	Beta-138568
(KTZ-300, House 1)	1633 ± 32	AA97495	850 ± 40	Beta-224231	920 ± 40	Beta-138565
	1669 ± 40	AA97496	870 ± 40	Beta-224232		
	1680 ± 28	AA97498	900 ± 40	Beta-224230		
Deering	1682 ± 45	AA97483	817 ± 43	AA97481	790 ± 40	Beta-189091
(KTZ-301, House 2)	1718 ± 51	AA97482	827 ± 42	AA97480		
Kivalina	2262 ± 47	AA97477	1470 ± 40	Beta-266435	—	—
(NOA-362, Ipiutak "wooden	2327 ± 47	AA97478				
feature")	2336 ± 47	AA97479				
	2340 ± 47	AA97476				

Table 1 (*Continued*)

	Seals		Caribou		Charcoal/wood/seed	
Location (site, feature)	^{14}C age BP	Lab ID	^{14}C age BP	Lab ID	^{14}C age (BP)	Lab ID
Kotzebue (KTZ-031, House 3)	1150 ± 20	UGAMS20318	340 ± 20	UGAMS20319	—	—
Kotzebue (KTZ-036, House Pit 3)	1537 ± 48 1642 ± 48	AA100195 AA97475	313 ± 42 660 ± 47 743 ± 31	AA97475* AA100198 AA101140	—	—
Kotzebue (KTZ-036, House Pit 8)	1150 ± 20	UGAMS41355	230 ± 30	UGAMS41354	—	—
Maiyumerak Creek (XBM-131, House Pit 8)	1350 ± 20	UGAMS20320	170 ± 50 280 ± 40 280 ± 40 325 ± 40	Beta-223359 Beta-223358 Beta-228015 CAMS-142693	—	—
St. Lawrence Island	860 ± 20	UGAMS21161	—	—	—	—

*^{14}C date outliers based on χ^2 tests reported in Table S2.

also Supplemental Information for detailed site information). Some features, such as the house Features 21 and 87 at Cape Espenberg, had multiple occupations, and potential reuse, that were distinguished in the stratigraphy and through ^{14}C dating. In these contexts, paired samples were only used if they were from the same excavation units, stratigraphic levels and depths in order to minimize the potential combining of ^{14}C dates from different occupational episodes.

Terrestrial samples consist of caribou remains, wood, wood charcoal fragments, and plant seeds. A total of 84 ^{14}C dates were compiled for this study: 34 on seal bones, 37 on caribou bones, and 13 on wood, wood charcoal fragments, and seeds (see Supplemental Table S1 for individual date information).

The context of each sample was scrutinized to avoid the selection of samples from archaeological features that potentially had multiple periods of deposition (i.e., long periods of occupation) or post-depositional disturbance. In instances with more than three dates on terrestrial or marine samples from an archaeological feature, we statistically compared dates (described below) to identify potential outliers within the groups. Outlier ^{14}C dates can occur from subtle differences in depositional contexts that create the mixture of two different periods of materials, by exogenous contamination that was not fully removed from samples during pretreatments, or by laboratory error. Outlier dates can increase the inaccuracy of local reservoir values (Ascough et al. 2009). Outliers were removed from the study prior to calculating MRE values for seals. The total number of outliers and marine-terrestrial pairs are discussed below.

In addition to the archaeological samples, we ^{14}C dated two seal (*Erignathus barbatus* and *Pusa hispida*) skulls collected by Otto William Geist in AD 1932 and 1946 from Cape Nome and the St. Lawrence Island region. These modern-aged specimens are housed in the Mammals Collection at the University of Alaska Museum of the North. The archaeology sites and features and the modern seal crania are described in more detail in the Supplemental Materials.

Laboratory Methods

^{14}C AMS ages were assayed at six different labs: Beta Analytic, Inc., Center for Accelerator Spectrometry at Lawrence Livermore National Laboratory, Center for Applied Isotope Studies at the University of Georgia, the National Ocean Sciences AMS Facility, W.M. Keck Carbon Cycle Accelerator Mass Spectrometer Facility at the University of California Irvine, and the University of Arizona Accelerator Mass Spectrometry Laboratory. The species and skeletal element of each bone were identified by zooarchaeologists Carol Gelvin-Reymiller, then of Northern Land Use Research, Inc., and Dr. Holly McKinney of the University of Alaska Fairbanks, in addition to several of the coauthors on this paper (CD, AF, LN). We ideally aimed to sample from multiple individuals of caribou and seals from each archaeological feature to account for some variability within a species at any given particular time.

Seventy-one bones were sampled with pretreatments conducted at ^{14}C labs (n = 37), and by Joan Coltrain at the Archaeological Center Research Facility for Stable Isotope Chemistry at the University of Utah (n = 34). All of the sites used in this study have substrates (such as perennially frozen ground) in Arctic settings that generally promotes relatively slow diagenetic changes in organic materials. Bones in these settings are typically well-preserved. Nevertheless, the atomic C:N ratios and collagen yields by weight (%yield) were measured for 41 of the 71 bone samples (58%) to establish the pattern of collagen diagenesis and potential for significant amounts of exogenous carbon contamination to alter the ^{14}C ages. The methods used by each lab to pretreat samples and conduct stable isotope and ^{14}C AMS and stable isotope measurements are provided in the Supplementary Materials.

Statistical Approaches

Groups of dates on either marine or terrestrial samples from the same archaeological feature were evaluated for statistical similarities using the χ^2 tests (Ward and Wilson 1978; Ascough et al. 2009) in Calib 7.1 (Stuiver et al. 2013). Groups of dates that showed statistically different results were then segregated into individual χ^2 test comparisons to distinguish possible outliers within the groups (Table S2 in Supplementary Materials). Outliers were subsequently removed from the analysis (Table 1). Statistically similar dates for marine and terrestrial sample groups within features were combined into weighted mean ages using Calib 7.1 (Ward and Wilson 1978). Several features (n = 13) had only single sets of marine and terrestrial ^{14}C dates.

Paired samples from features at sites were grouped by a general location and into four periods based on the ^{14}C age BP of a pair's terrestrial sample: >200 BP, 200–600 BP, 600–1000 BP, and 1100–1600 BP. The two historic samples from St. Lawrence Island and Cape Nome were defined as "Modern" considering the recorded dates of their collection in AD 1932 and 1946. Supplementary Materials Tables S4 through S8 provide detailed information on ^{14}C pairs by general location and by the four periods.

We define R(t) as the difference, or offset, between paired marine and terrestrial (assumed "atmospheric") ^{14}C ages, along with the associated standard errors of the differences (Stuiver et al. 1986; Taylor and Bar-Yosef 2014: 152). R(t) is calculated by subtracting the marine ^{14}C age from the associated terrestrial ^{14}C age. R(t) values for the two modern seal samples collected in 1932 and 1946 were calculated by subtracting the expected ^{14}C age in IntCal13 (Reimer et al. 2013) that is associated with the calendrical terrestrial date of collection.

ΔR weighted mean values and standard deviations were calculated using the *deltar* function in the Marine Radiocarbon Database from the 14CHRONO Centre (Reimer and Reimer 2017). Modern seal ΔR values were calculated using the known collection date as the independent age determination. ΔR values for archaeological paired marine-terrestrial samples >200 BP were calculated in *deltar*, outlined in Reimer and Reimer (2017) using the Northern Hemisphere curve. Because the *deltar* program cannot calculate ΔR values for paired-samples with terrestrial pairs that have ages <200 BP, we followed procedures outlined in Southon et al. (1995) to derive ΔR values for these pairs. Terrestrial ^{14}C ages <200 BP were calibrated in OxCal v4.3 (Bronk Ramsey 2009) using IntCal13, then terrestrial calibrated age range was converted to modelled ^{14}C ages using the Marine14 curve (Reimer et al. 2013). The Marine14 modelled ^{14}C age was subtracted from the original ^{14}C age of the marine sample of the marine-terrestrial pair to produce a ΔR value. Weighted means and errors (the square root of the sum of squares of individual uncertainties) were calculated for R(t) and ΔR values for a given group, along with overall all R(t) and ΔR values for seals in the Bering Strait and northern Bering Sea region

Shapiro-Wilk tests shows R(t) and ΔR values do not significantly deviate from normal distributions: R(t) (n = 23; W = 0.973693; critical W value = 0.914154; p = 0.776418), and ΔR (n = 23; W = 0.92713; critical W value = 0.914154; p = 0.094824). One-way analysis of variance (ANOVA) with Tukey HSD post-hoc tests were used to assess variation within and across groups of R(t) and ΔR values. R(t) and ΔR values for

Dumond and Griffin (2002), Khassanov and Savinetsky (2006), and McNeely et al. (2006) were also recalculated using the same procedures outlined above for reliable comparisons to our study's results (Tables S9 and S10). ANOVA and Tukey HSD post-hoc tests were used to assess variation among our study's overall R(t) and ΔR values and those from the previous studies.

RESULTS AND DISCUSSION

Quality Control of Bone Samples and Radiocarbon Data

The atomic C:N ratios and collagen yields for 58% of the study's bone samples were scrutinized to assess the potential for severe protein degradation and for significant amounts of exogenous carbon contamination that would alter the ^{14}C ages. Atomic C:N ratios are between 3.1 and 3.5 with an average of 3.3 ± 0.1 falling within the recommended ranges of 2.9–3.5 or 3.1–3.5 for accepting collagen as preserved enough to yield an accurate ^{14}C age (DeNiro 1985; van Klinken 1999).

Collagen yields on these samples are between 2.3% and 31.0 %yield, with an average of 17.6 ± 6.4 %yield, well above acceptable levels >1-to-3.5 %yield for well-preserved collagen (Ambrose 1990; van Klinken 1999). Therefore, we consider the collagen quality to be high and exogenous carbon contamination to be minimal in contributing to inaccurate ^{14}C ages.

Chi-square tests for within groups of terrestrial and marine dates from a given feature were also preformed to define and reduce the influence of outliers on R(t) and ΔR values (Ascough et al. 2009) (Table S2). Five of the 84 (5.9%) ^{14}C dates were removed due to internal inconsistencies (outliers) within groups of terrestrial and marine samples within a given feature (Table 1). Four bone ages (three caribou and one seal) were removed from the data set, as well as one ^{14}C date on a piece of structural wood in the tunnel of a house feature at Cape Espenberg that may be driftwood.

As a result, the total included 80 paired samples after the statistical outliers were removed from the total data set. Features with multiple ^{14}C dates on terrestrial and marine samples that were statistically similar were subsequently averaged to create 24 marine-terrestrial paired data sets to use in our calculations of R(t) and ΔR. Paired data sets are distributed across the general localities of the study area by the following (from highest to lowest amount): 11 at Cape Krusenstern, three at Deering, three at Cape Espenberg, three at Kotzebue, one at Kivalina, one at Maiyumerak Creek, and the sole modern sets from St. Lawrence Island and Cape Nome regions. When divided by general periods, the paired data sets are distributed as such (from most recent to oldest periods): three <200 BP, 10 between 200–600 BP, seven between 600–1000 BP, and four between 1000–1600 BP.

R(t) and ΔR values across general periods and locations across the northern Bering Sea.

R(t) and ΔR values for each pair and feature and ANVOA and Tukey HSD results for groups are detailed in the Supplemental Materials (Tables S4 through S8).

General Periods

Weighted means for R(t) values by period are between 875 ± 155 and 699 ± 50 years, a span of 176 years, with an overall weighted mean of 800 ± 140 years (Table 2; Figure 2). Weighted mean ΔR values are between 429 ± 148 and 384 ± 90 years, a 45-year span, with an overall weighted mean of 404 ± 112 years. The weighted means of the R(t) and ΔR values show significant variation within 2 out of the 4 periods (Table S4). However, there is little

Table 2 R(t) and ΔR values across locations and by period.

Location (site, feature)	Marine sample (^{14}C BP)	Atmospheric sample (^{14}C BP)	R(t) (1 σ)	ΔR (1 σ)
Cape Espenberg				
KTZ-087, House 68A	1343 ± 28	383 ± 12*	960 ± 30	498 ± 36
KTZ-087, House 87	1422 ± 30	497 ± 13*	925 ± 36	490 ± 33
KTZ-304, House 21	1635 ± 32*	683 ± 7*	952 ± 33	524 ± 33
Cape Espenberg—overall			948 ± 18	504 ± 18
Cape Krusenstern				
NOA-0463, House 4A	880 ± 30	60 ± 30	820 ± 42	387 ± 34
NOA-474, Unidentified 1B	810 ± 30	210 ± 30	600 ± 42	161 ± 46
NOA-513, House 10	1170 ± 30	280 ± 40	890 ± 50	448 ± 58
NOA-513, House 2	1020 ± 30	400 ± 40	620 ± 50	169 ± 55
NOA-558, House 1A	1450 ± 30	510 ± 30	940 ± 42	510 ± 39
NOA-513, House 4	1110 ± 30	570 ± 40	540 ± 50	122 ± 52
NOA-558, Unidentified 7B	1410 ± 30	640 ± 30	770 ± 42	338 ± 48
NOA-473, Cache Pit 1A	1550 ± 30	840 ± 25	710 ± 39	334 ± 41
NOA-558, Unidentified 3B	1280 ± 30	765 ± 35	515 ± 46	119 ± 39
NOA-538, House 2	1920 ± 30	1200 ± 40	720 ± 50	342 ± 59
NOA-513, Activity Area 361XH070108A	2230 ± 30	1590 ± 40	640 ± 50	292 ± 52
Cape Krusenstern—overall			713 ± 138	302 ± 138
Cape Nome				
	860 ± 20	188 ± 8	681 ± 22	404 ± 20
Deering				
KTZ-301, House 2	1698 ± 34*	811 ± 25*	887 ± 42	510 ± 40
KTZ-300, House 1	1662 ± 19*	873 ± 17*	789 ± 25	422 ± 30
KTZ-299, Ipiutak house	2016 ± 33*	1256 ± 24*	760 ± 41	359 ± 47
Deering—overall			803 ± 54	434 ± 66
Kivalina				
NOA-362, Ipiutak wooden feature	2316 ± 24*	1470 ± 40	846 ± 47	491 ± 43
Kotzebue				
KTZ-036, House Pit 8	1150 ± 20	230 ± 20	872 ± 28	487 ± 26

(Continued)

Table 2 (*Continued*)

Location (site, feature)	Marine sample (^{14}C BP)	Atmospheric sample (^{14}C BP)	R(t) (1 σ)	ΔR (1 σ)
KTZ-031, House 3	1150 ± 20	340 ± 20	920 ± 28	384 ± 54
KTZ-036, House Pit 3	1590 ± 34*	718 ± 26*	810 ± 43	462 ± 38
Kotzebue—overall			866 ± 61	466 ± 42
Maiyumerak Creek				
XBM-131, House Pit 8	1350 ± 20*	274 ± 21*	1076 ± 29	644 ± 50
St. Lawrence Island				
	830 ± 20	153 ± 8	677 ± 22	374 ± 20
Bering Strait seals—overall by location			834 ± 159	446 ± 73
Periods			R(t) (1 σ)	ΔR (1 σ)
<200 BP			696 ± 56	389 ± 17
200–600 BP			875 ± 155	429 ± 148
600–1000 BP			800 ± 126	400 ± 137
1200–1600 BP			746 ± 82	384 ± 90
Bering Strait seals—overall by period			800 ± 140	404 ± 112

*Combined average ages are detailed in Table 1 and Table S2.

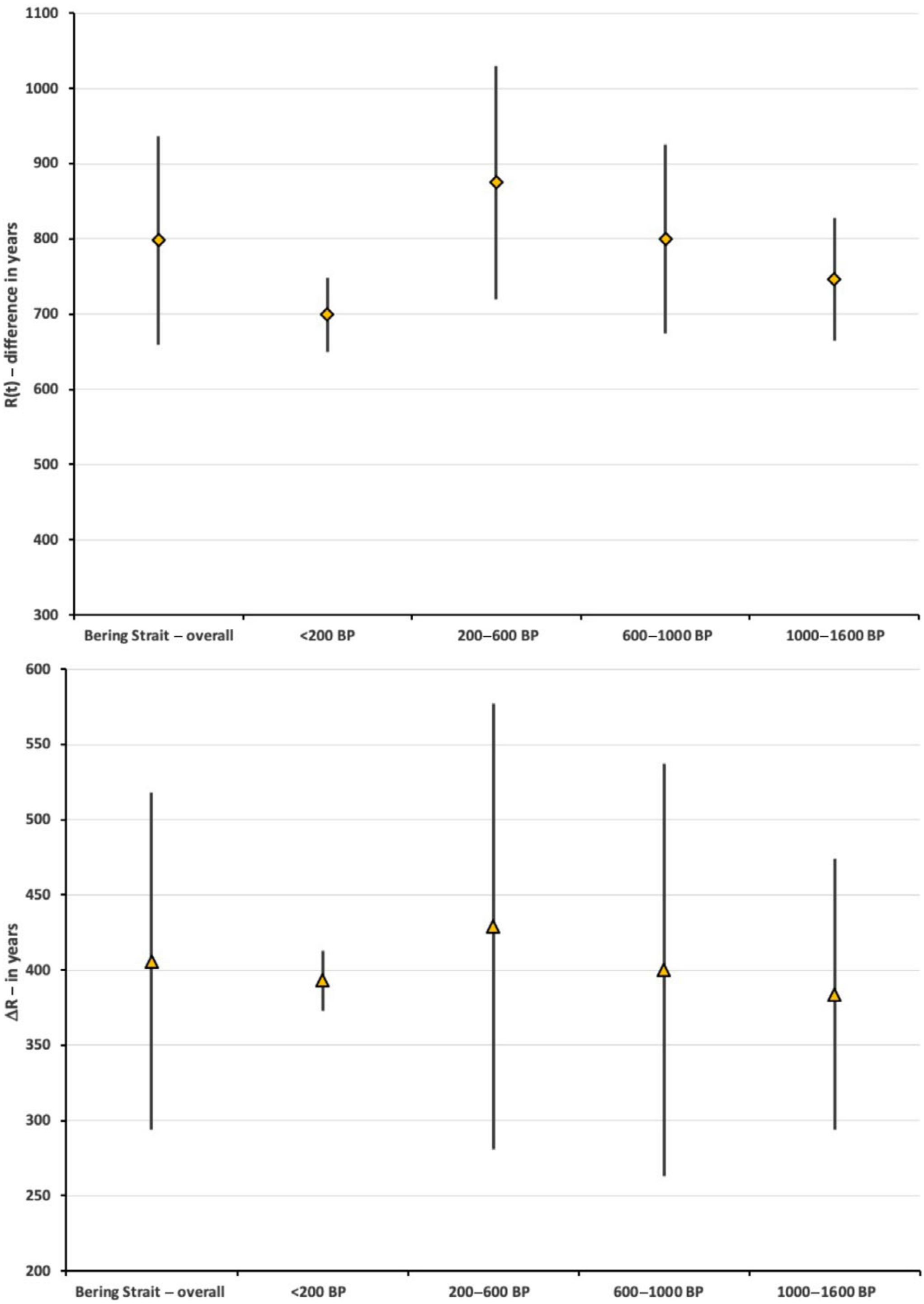

Figure 2 Weighted mean R(t) (above) and ΔR values (below) by general period from this study. Data summarized in Table 2.

Table 3 Comparison of marine reservoir effect values from studies in northwestern Alaska.

Location	Taxa/material	R(t) (1 σ)	ΔR (1 σ)	Reference
Bering Strait region	Seal bone (n = 33)	800 ± 140	404 ± 112	This study
Port Clarence/Teller	Macoma, Serripes, Hiatella, Mytilus, Mya shells (n = 4)	836 ± 65	486 ± 65	McNeely (2006)
Cape Wales (TEL026 and TEL079)	Seal bone (n = 3)	633 ± 90	195 ± 74	Dumond and Griffin (2002)
St. Lawrence Island—Hillside (XSL-001)	Walrus ivory (n = 4)	621 ± 118	265 ± 126	Dumond and Griffin (2002)
St. Lawrence Island—Gambell Burials	Whale bone (n = 6)	546 ± 193	154 ± 171	Dumond and Griffin (2002)
Chukchi Peninsula	Whale bones and baleen, human hair and unidentified sea mammal bones (n = 6)	778 ± 189	350 ± 201	Khassanov and Savinetsky (2006)

variation across the R(t) and ΔR weighted means of the periods (R(t) $F_{[3,75]} = 0.11$, $p = 0.95$; ΔR $F_{[3,75]} = 0.02$, $p = 1.00$).

By Location

Weighted mean R(t) values by location show a spread of 677 ± 22 and 948 ± 18 years, while ΔR values range between 302 ± 138 and 644 ± 50 years (Table 2). R(t) and ΔR values have overall weighted means of 834 ± 159 and 446 ± 73 years, respectively. ANOVA values for the weighted means for R(t) and ΔR values show no significant variation across locations (R(t) $F_{[7,74]} = 0.90$, $p = 0.51$; ΔR $F_{[7,74]} = 0.70$, $p = 0.67$; see Table S4).

The overall ΔR weighted mean of 404 ± 112 years based on values for the periods should be used as an MRE correction because it takes into account larger uncertainty than the overall ΔR value calculated for the locations. As expected, there are changes in the percent differences between the calibrated mean ages for terrestrial and seal samples occurs once the weighted mean of ΔR values 404 ± 112 years is applied as a corrective measure for seal ^{14}C ages (see Table S4). The percent of change between uncorrected and corrected marine ages ΔR is between –83.7 to –36.8% for an average of –54.8 ± 14.3%. The difference between mean ages of terrestrial and seal calibrated ages range between 428 and 1020 years with percent differences between 40.9 and 149.2% and an average of 78.9 ± 29.1% when a ΔR value correction is not applied. The mean ages range between –262 and 197 years with percent differences between –57.8 and 46.5% with an average of 1.1 ± 23.7% after the application of the ΔR value quoted above.

Comparisons to Previous Studies

Our weighted mean R(t) and ΔR values are 165–252 years and 143–250 years, respectively, greater than Dumond and Griffin's (2002) values. Our weighted mean R(t) and ΔR values are 20 and 56 years greater than the Khassanov and Savinetsky (2006) values (Table 3). The weighted means of the McNeely et al. (2006) R(t) and ΔR values are 38–80 years

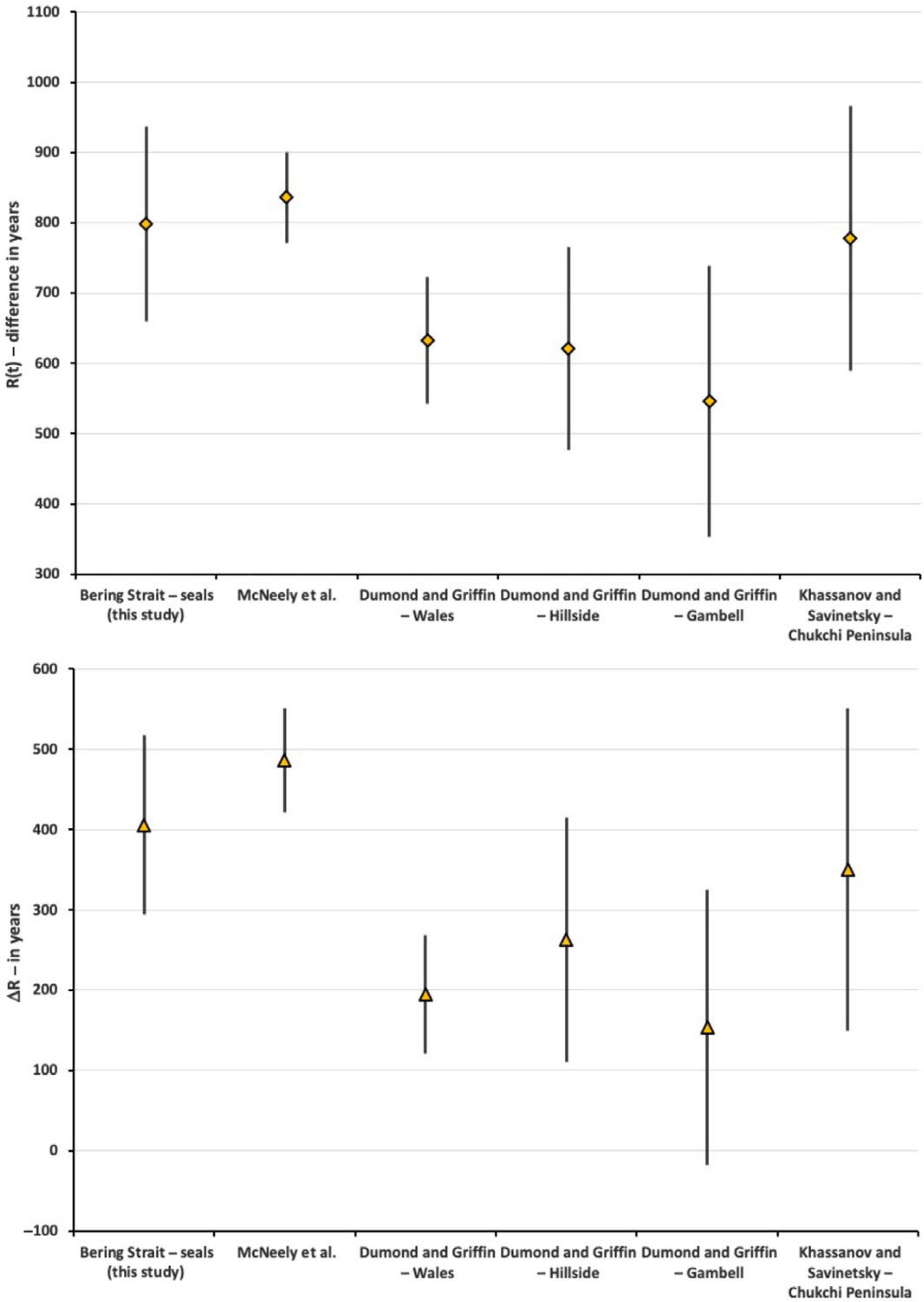

Figure 3 Weighted mean R(t) (above) and ΔR values (below) on Bering Strait seals from this study in comparison to data from McNeely et al. (2006), Dumond and Griffin (2002), and Khassanov and Savinetsky (2006). Data summarized in Table 3.

greater than ours. However, the large standard errors of weighted mean R(t) and ΔR values for all of the data sets (our study and previous studies) overlap in their ranges displaying little variation (Figure 3). ANOVA values show no significant variation across the R(t) and ΔR values of our study and the previous studies (R(t) $F_{[5,51]} = 0.20$, $p = 0.96$; ΔR $F_{[5,51]} = 0.31$, $p = 0.90$; see Table S10).

CONCLUSIONS

Our study provides an assessment of MREs of ^{14}C content among seals in the northern Bering Sea over the last 1600 years. Weighted mean R(t) and ΔR values, given their large uncertainties, display little variation over the last 1600 years and across our sampling locations. The overall R(t) and ΔR weighted means for seal remains in the northern Bering Sea is 800 ± 140 and 404 ± 112 years, respectively; these values are similar to values calculated on marine mollusks by McNeely et al. (2006) but larger than values calculated on seal, walrus and whale remains by Dumond and Griffin (2002) for the region. If the standard error of predicted values, as suggested by Cook et al. (2015), is applied to the weighted mean to account for increased uncertainty in using archaeological sample association than the R(t) and ΔR values are 800 ± 202 and 404 ± 176, respectively.

We suggest that the weighted mean ΔR value of 404 ± 112 years can be used as a local ΔR estimate to correct for MREs for ^{14}C ages on seals in the region and for human remains for populations that relied on these types of pinnipeds as a food staple. Our estimate is slightly less than the Krus et al. (2019) value of 450 ± 84 years for the Point Barrow area based on paired caribou and seal ^{14}C dates. However, both values overlap at 1 σ.

MRE corrections for human remains should consider the species that provide the largest contributions to a regional population's diet, as well as accounting for potential subsistence preference changes over time. Dietary modeling using stable isotopes of human remains and summaries of zooarchaeological remains from sites for a given period provide a necessary context for which ΔR value corrections to use (Coltrain et al. 2016; Krus et al. 2019). The use of an accurate ΔR value in corrections can have profound differences in how we interpret changes in the archaeological record (Coltrain et al. 2006; Coltrain 2010; Kuzmin 2010; Misarti and Maschner 2015; West et al. 2019).

ACKNOWLEDGMENTS

We thank zooarchaeologists Carol Gelvin-Reymiller, then of Northern Land Use Research, Inc., and Dr. Holly McKinney of the University of Alaska Fairbanks for aiding in the identification of seal and caribou remains from many of the study sites. Northern Land Use Research Alaska, Inc. funded ^{14}C ages for the Deering, Kivalina, and Kotzebue sites and modern seal skulls. We thank the Deering, Kivalina, Kotzebue, and Shishmaref communities for supporting these archaeological projects and allowing us to sample these collections for the purpose of this study. Eric Carlson, former NLURA archaeologist, supported us in selection of Kotzebue samples and provided notes on their context. National Park Service supported the Maiyumerak Creek excavations and analyses. The National Park Service also funded research at Cape Krusenstern through a cooperative agreement (J8W07070032) managed by the Pacific Northwest Cooperative Ecosystem Study Unit. The Cape Espenberg research has involved several successive projects, first supported by the National Park Service (1988–1995), and then through two consortia of researchers; the first consortia was supported from 2009–2013 by a National Science

Foundation (NSF) grant to J. F. Hoffecker, O. K. Mason, C. M. Darwent, and N. H. Bigelow (ARC-0755725), and the second consortia of researchers were supported from 2015-present by a collaborative NSF grant to C. Alix and N. H. Bigelow (ARC-1523160), O.K. Mason (ARC-1523205), S. Anderson (ARC-1523059), and D.H. O'Rourke (ARC-1523059). Link Olson and Aren Gunderson of the University of Alaska Museum of the North Mammalogy Lab allowed for sampling of the modern seal skulls from their collection. Brian Hemphill generously advised us on the statistical procedures we used in this study. Sam Coffman drafted the main map for this article. We thank the reviewers that provided extremely valuable comments making this study fundamentally higher in its quality.

SUPPLEMENTARY MATERIAL

To view supplementary material for this article, please visit https://doi.org/10.1017/RDC.2020.127

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