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Palaeontology

Rewriting the history of an extinction—was a population of Steller's sea cows (*Hydrodamalis gigas*) at St Lawrence Island also driven to extinction?

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The Kommandorskiye Islands population of Steller's sea cow (*Hydrodamalis gigas*) was extirpated *ca* 1768 CE. Until now, Steller's sea cow was thought to be restricted in historic times to Bering and Copper Islands, Russia, with other records in the last millennium from the western Aleutian Islands. However, Steller's sea cow bone has been obtained by the authors from St Lawrence Island, Alaska, which is significantly further north. Bone identity was verified using analysis of mitochondrial DNA. The nitrogen-15 ($\delta^{15}N$)/carbon-13 ($\delta^{13}C$) values for bone samples from St Lawrence Island were significantly ($p \leq 0.05$) different from Bering Island samples, indicating a second population. Bone samples were dated to between 1030 and 1150 BP (approx. 800–920 CE). The samples date from close to the beginning of the mediaeval warm period, which could indicate that the population at St Lawrence Island was driven to extinction by climate change. A warming of the climate in the area may have changed the availability of kelp; alternatively or in addition, the animals may have been driven to extinction by the expansion of the Inuit from the Bering Strait region, possibly due to opening waterways, maybe following bowhead whales (*Balaena mysticetus*), or searching for iron and copper. This study provides evidence for a previously unknown population of sea cows in the North Pacific within the past 1000 years and a second Steller's sea cow extirpation event in recent history.

1. Introduction

In a classic story of human hunting to excess, Steller's sea cow (*Hydrodamalis gigas*; Order Sirenia) was driven to extinction by human hunting within a few decades after its discovery by Europeans [1]. Giant sea cows were first observed and described by Georg Wilhelm Steller on Bering Island, Russia, in the winter of 1741–42 [2]: by 1768, the species had been extirpated [1]. According to the fossil record, animals in the genus *Hydrodamalis* inhabited coastal waterways from Japan through the Aleutian Island chain to Baja California during the Late Miocene, Pliocene, and Pleistocene. *Hydrodamalis gigas* was still present in the Aleutian Islands and central California less than 20 000 years ago [3,4]. According to historical records, by the eighteenth century the species had declined to remnant populations around only Bering and Copper Islands, Russia [1–5] (figure 1).

In 2009, vendors at the Blade Show in Atlanta, GA, were discovered selling possible sea cow bone (used to craft knife handles). The bones were collected from St Lawrence Island, Alaska (63.8° N, 171.7° W), during personal visits by dealers to the island from 2008 to 2010. All samples appeared to be sections of rib but were not large enough to positively identify as *H. gigas*. A complete rib

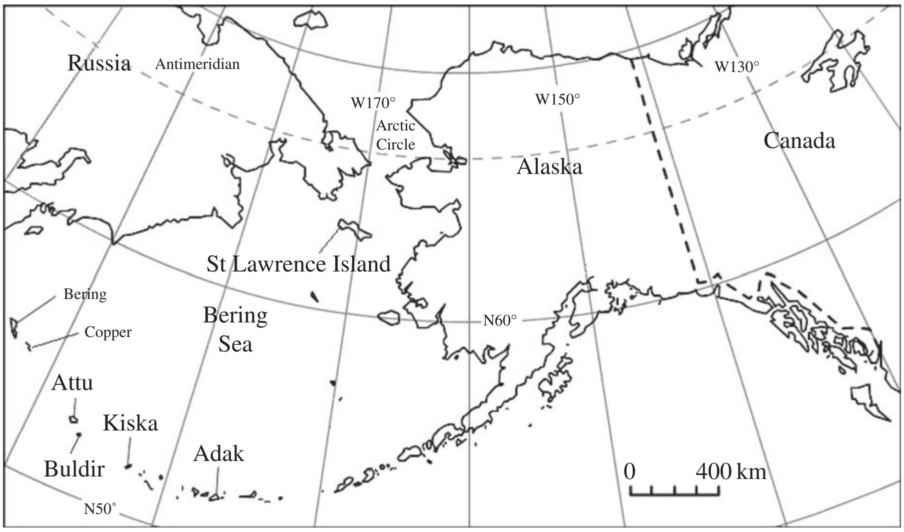

Figure 1. The Aleutian Island chain showing relevant islands.

from a Bering Island sea cow was obtained by the authors from the Smithsonian's National Museum of Natural History for comparison. The identity of the sample was verified using morphology by the museum curator, Charley Potter. The objective of this study was to determine whether these samples could be identified as *H. gigas* and whether they could have come from a location other than the Kommandorskiye Islands.

2. Material and methods

Bone samples used in this analysis were obtained from Alaska Fossil Ivory and David Boone Traders. Dr L. Crerar has spoken to both of these dealers at length about the bone and its origin. David Boone assured her that the bones had come from St Lawrence Island, obtained by natives in middens on the island. These deposits are located within 10 km of the town of Gambell, according to Mr Boone. Dr L. Crerar spoke to Jerry Kochheiser of Alaskan Fossil Ivory on many occasions. Mr Kochheiser detailed his visits to the town of Gambell on St Lawrence Island. Evidence, such as airline receipts, exists to verify his visits to St Lawrence Island. He stated that he dealt with the native people and that the bones come from 'areas of the island that have piles of bones'. The bones are gathered into burlap bags and brought into the town for sale to people like Mr Kochheiser for use in handle-making for high-end custom knives.

Before extracting DNA from the bone, bone samples were cleaned using 30% NaClO [6] and cleaned again by grinding the dry surface of the bone; removed material was discarded. The bones were drilled with a Proxxon Micromot 50/E (no. 28510) and 2.78 mm tungsten vanadium drilling bit (no. 28722). DNA was extracted using a modification of the Qiagen DNeasy Blood and Tissue Kit protocol (product no. 69504). Primers were used to amplify 230 base pairs of the cytochrome *b* gene [7]. A Qiagen TopTaq DNA Polymerase Kit (product number 200203) was used to amplify the DNA. The DNA was sequenced using ABI automated sequencers at Eton Biosciences (Research Triangle, NC, USA). The sequences were compared to *H. gigas* voucher sequences in GenBank [7] using DNA BASER.

Pieces of bone weighing less than 10 g were sent to Beta Analytic (Miami, FL) for carbon dating and stable isotope analysis. Collagen was extracted from the bones for use in accelerator mass spectrometry (AMS) dating. AMS dating was chosen for this analysis because it is much more sensitive than carbon decay counting. In the AMS dating procedure, after a sample has been converted to graphite, it is placed into an AMS cathode and the atoms in the sample are converted to ions. The mass of the ions is separated using electric and magnetic fields. The numbers of ^{12}C, ^{13}C and ^{14}C atoms were counted, as were the number of ^{14}N and ^{15}N in the samples. A small portion of the extracted collagen was placed into a Carlo Erba elemental analyzer (EA) connected directly to a Thermo Delta-Plus IRMS. The EA served to oxidize the collagen to CO_2 and N_2; the IRMS served to provide the separation of the carbon and nitrogen masses. THERMO ISODAT software was used to calculate the $\delta^{15}N$ and the $\delta^{13}C$ was obtained by relative signature to NIST RM-8548 and/or RM-8550 (Beta Analytic, Miami, FL).

The $\delta^{13}C$ collagen values and $\delta^{15}N$ collagen values for six new samples, from Bering and St Lawrence Island, were added to 10 samples from Clementz *et al.* [8], from Bering Island only (figure 2), and a Mann–Whitney *U*-test was conducted on the stable isotope data for nitrogen.

3. Results

The DNA sequence confirmed that bone samples were *H. gigas* (based on a better than 99% match with the cytochrome *b* voucher sequence in GenBank [7]). Radiocarbon dating for six bones showed a conventional age range from 1030 to 1150 ± 30 years BP (table 1). The bone from Bering Island was dated to 1060 ± 30 years BP. All five bones from St Lawrence Island were between 1030 and 1150 ± 30 years BP.

A significant difference was found in the comparison $\delta^{15}N$ collagen values (figure 2 and table 2): the mean $\delta^{15}N$ collagen value for the Bering Island samples was 11.0 ± 0.5‰ and the mean for the St Lawrence samples was 15.5 ± 0.6‰ ($W = 59$; $p = 1.963 \times 10^{-3}$). No significant difference was found in the comparison $\delta^{13}C$ collagen (figure 2 and table 2): the mean $\delta^{13}C$ collagen value for the Bering Island samples was −15.2 ± 0.8‰ and the mean for the St Lawrence samples was −14.5 ± 0.9‰ ($W = 39.5$; $p = 0.192$).

4. Discussion

Small changes in $\delta^{15}N$ can indicate geographical variation in feeding location [8–18], including in marine mammals [12,13], whereas small changes in $\delta^{13}C$ can indicate changes in trophic level [8,9,11]. As DNA confirmed the identity of these bones as originating from Steller's sea cow and the populations from Bering Island and St Lawrence Island likely both ate kelp, the significant change in $\delta^{15}N$ values is

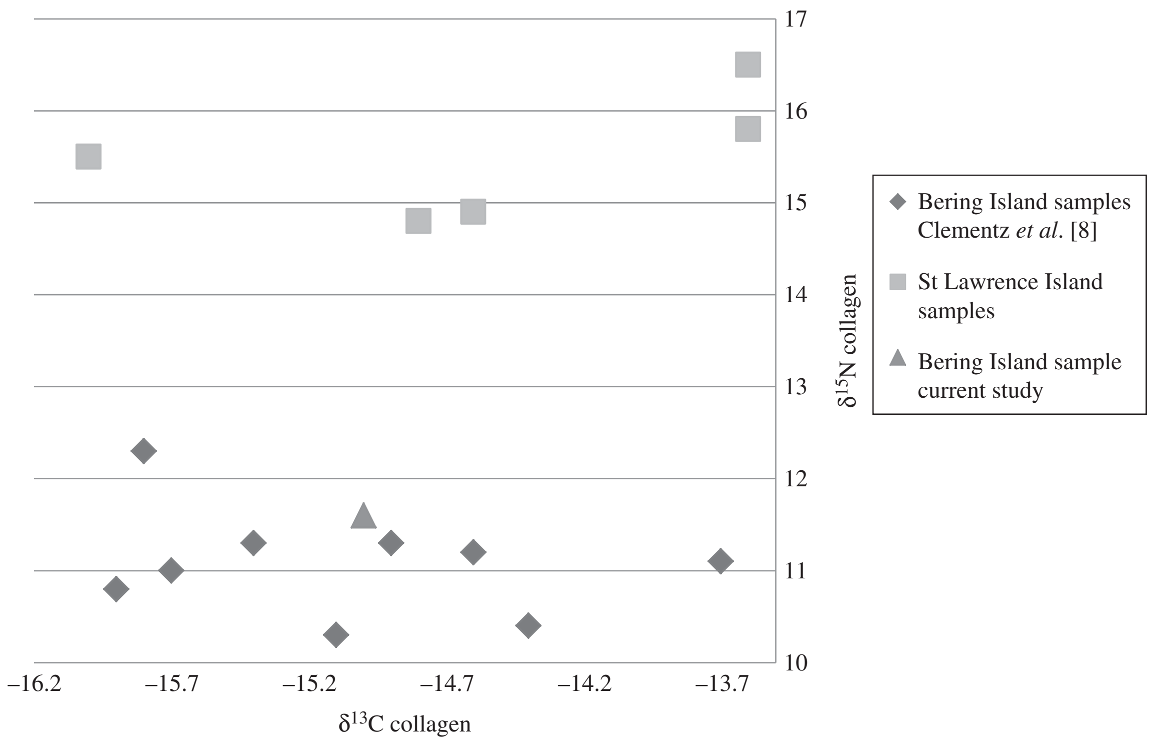

Figure 2. Comparison of $\delta^{13}C$ versus $\delta^{15}N$ from *H. gigas* samples from Bering and St Lawrence Islands. The scatter plot includes data from Bering Island samples published in Clementz *et al.* [8]. Specimen ID for samples not from this study is detailed in table 2; numbers correspond to the latter part of the specimen ID.

Table 1. Radiocarbon dating information.

sample name	sample location	material pre-treatment	measured age (BP)	conventional age (BP)	2-sigma calibration
CRERAR 001	St Lawrence Island	(bone collagen): collagen extraction: with alkali	860 ± 30	1030 ± 30	CE 970–1030 BP 980–920
CRERAR 002	St Lawrence Island	(bone collagen): collagen extraction: with alkali	910 ± 30	1100 ± 30	CE 890–1020 BP 1060–940
CRERAR 003	St Lawrence Island	(bone collagen): collagen extraction: with alkali	980 ± 30	1150 ± 30	CE 780–790 BP 1170–1160
CRERAR 004	St Lawrence Island	(bone collagen): collagen extraction: with alkali	900 ± 30	1090 ± 30	CE 890–1020 BP 1060–930
CRERAR 005	St Lawrence Island	(bone collagen): collagen extraction: with alkali	970 ± 30	1120 ± 30	CE 880–990 BP 1070–960
CRERAR 006	Bering Island	(bone collagen): collagen extraction: with alkali	900 ± 30	1060 ± 30	CE 900–920 BP 1050–1030

most consistent with a change in location. Stable nitrogen isotopes have been used to verify distinct populations for animals only 50 km apart [15].

The carbon dates for six bones showed a range of conventional ages from 1030 to 1150 ± 30 years BP. The bone from Bering Island was dated to 1060 ± 30 years BP ($\delta^{13}C$, −15.0). The youngest sample was from St Lawrence Island at 1030 ± 30 years BP ($\delta^{13}C$, −14.8). All samples from St Lawrence Island produced radiocarbon dates within 100 years. This could suggest a short period of existence for the population or it could represent a sampling bias. More samples from St Lawrence Island should be radiocarbon dated to discriminate between these possibilities.

The stable isotope analysis of the $\delta^{15}N$ values plotted with the $\delta^{13}C$ indicates a distinct population of Steller's sea cows feeding at some distance from the Komandorskiye Islands at about the same time in history, 1030–1060 years BP. The values for $\delta^{13}C$ all fall into the range of −13.5 to −16.5‰. The $\delta^{15}N$ values fall into two distinct groups along that gradient. Given the reported provenance of the samples, this population likely occurred around St Lawrence Island. Therefore, the range of Steller's sea cows in recent history may not have been confined to Bering and Copper Islands, or even the western Aleutian Islands as reported by Domning *et al.* [19].

The approximately 100 year age range of the samples raises the question of whether there may have been an earlier Steller's sea cow extirpation event at St Lawrence Island between 980 and 1160 BP (800 and 920 CE). This is a much earlier date than the 1768 CE extinction of Bering Island animals. The samples date from close to the beginning of the

Table 2. Stable isotope values for ^{13}C and ^{15}N. Samples 1–10 are from Clementz *et al.* [8].

species	specimen ID	location	$\delta^{13}C_{collagen}$	$\delta^{15}N_{collagen}$	2-sigma calibration (%)
1. *Hydrodamalis gigas*	USNM 218444	Bering Island, Russia	−14.4	10.4	±0.5
2. *H. gigas*	USNM 21258	Bering Island, Russia	−14.6	11.2	±0.5
3. *H. gigas*	USNM 218427	Bering Island, Russia	−13.7	11.1	±0.5
4. *H. gigas*	USNM 218380	Bering Island, Russia	−15.4	11.3	±0.5
5. *H. gigas*	USNM 218411	Bering Island, Russia	−14.9	11.3	±0.5
6. *H. gigas*	USNM 21259	Bering Island, Russia	−15.7	11.0	±0.5
7. *H. gigas*	USNM 218450	Bering Island, Russia	−15.9	10.8	±0.5
8. *H. gigas*	USNM 218445	Bering Island, Russia	−17.0	10.4	±0.5
9. *H. gigas*	USNM 218437	Bering Island, Russia	−15.8	12.3	±0.5
10. *H. gigas*	UCMP 23050	Bering Island, Russia	−15.1	10.3	±0.5
11. *H. gigas*	CRERAR 001	St Lawrence Island, USA	−14.8	14.8	±0.5
12. *H. gigas*	CRERAR 002	St Lawrence Island, USA	−13.6	16.5	±0.5
13. *H. gigas*	CRERAR 003	St Lawrence Island, USA	−14.6	14.9	±0.5
14. *Unknown*	CRERAR 004	St Lawrence Island, USA	−16.0	15.5	±0.5
15. *H. gigas*	CRERAR 005	St Lawrence Island, USA	−13.6	15.8	±0.5
16. *H. gigas*	CRERAR 006	Bering Island, Russia	−15.0	11.6	±0.5

mediaeval warm period [12,20], making it possible that climate change contributed to the extirpation of this sea cow population by changing the availability of kelp. The time period also coincides with the expansion of the Inuit [21] from the Bering Strait region. This expansion could be due to opening waterways, following bowhead whales (*Balaena mysticetus*), or searching for mineral resources, like iron [22]. Steller [23] stated that, even though Bering Island is very close to Kamchatka, the natives did not live on the island. This fact may have preserved the isolated population of sea cows until they were discovered by Europeans.

Whatever the reason for the migration, this movement of people could have coincided with increased hunting on St Lawrence Island. The Yupik people, who have inhabited St Lawrence Island for at least 2000 years, have a dietary culture rich in marine mammals [23,24]. It is possible that human hunting pressure on an isolated population led to an earlier extirpation of the sea cows at St Lawrence Island.

Data accessibility. Sequence data were uploaded to National Center for Biotechnology Information (NCBI), accession numbers KP134338–KP134342, and to Dryad (doi:10.5061/dryad.vf86p).

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