

Invited research papers

## Temporal and population trends in human exploited pinnipeds from Tierra del Fuego

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## ABSTRACT

Archaeological sites on the coast of Tierra del Fuego, Argentina, provide a biogeochemical record that can inform us about those ecological dynamics. An abundance of southern fur seal (*Arctocephalus australis*) and southern sea lion (*Otaria flavescens*) remains provide a valuable resource to reconstruct ancient and modern food webs. To quantify ecological relationships, we measured bulk stable isotope ratios from bone collagen in otariids and other associated animals, several of which are potential otariid prey. Variations in bulk stable isotope ratios of carbon ( $\delta^{13}\text{C}$ ) and nitrogen ( $\delta^{15}\text{N}$ ) are linked to potential dietary differences and habitat specialization between coastal areas or the open ocean in populations ranging in age from 7000 cal. Years BP to modern. We observed increases in the variability of these isotopic compositions over time, which suggests a diversity in the diets and habitats of otariids. Shifts in marine food webs occurred during the transition from subsistence hunting of otariids to industrial hunting and expanded human influence. We conclude that direct human influences, such as hunting and habitat alteration, were the major drivers of ecological change in southern South American marine ecosystems.

### 1. Introduction

Humans significantly impacted animal populations and food webs worldwide prehistorically as well as historically (Barnosky et al., 2012). However, the extent and cumulative impacts at regional scales are less understood, especially at high latitudes (Hunt et al., 2016). Southernmost South America is one such region. Researchers studying the Fuegian archipelago have yet to come to a consensus on the relative impacts of human and non-human entities on ecological communities (Saporiti et al., 2014; Bas et al., 2018; Fernández et al., 2018). Furthermore, quantifying these relative impacts is compounded by uncertainty of ecological responses to disturbance of communities, whether from humans, abiotic influences, interspecies interactions or the varying contributions of all three of these factors.

At higher trophic levels, two primary species of marine mammals, both pinnipeds, are found in southern South American marine ecosystems: The South American sea lion (*Otaria flavescens*) and the South American fur seal (*Arctocephalus australis*) (Vaz-Ferreira, 1978; Bastida and Rodríguez, 2003; De Carvalho et al., 2018). Most of these otariids are located within the continental shelf break, with fur seals and sea lions feeding in shallow waters (Campagna et al., 2001; Riet-Sapiriza et al., 2013; Franco-Trecu et al., 2014).

The objectives of this study are to 1) elucidate dynamics of the prehistoric marine ecological record, 2) define potential variation within a population to characterize potential ontogenetic dietary variation, 3) compare the transition between prehistoric and historic human actions on marine ecology, and 4) compare these human mediated prehistoric and historic ecological paradigms with the post-industrial recovery of this ecosystem. We measured stable isotopes in prehistoric and historic fur seals and sea lions. Unlike previous studies (Saporiti et al., 2014; Zenteno et al., 2015; Tafuri et al., 2017; Bas et al., 2018), individuals from more recently excavated and remote sites were measured to examine temporal gaps in the ecological record. Furthermore, measurement of modern specimens of otariids and potential dietary components were conducted. We hypothesize that there will be an increased dependence on offshore predation by fur seals and sea lions coincident with lower abundance of these species found in archaeological sites. Furthermore, we expect a similar response in historic industrial hunted populations, due to coastal pinniped population decreases resulting from human hunting practices and habitat encroachment. Both patterns should result in lower  $\delta^{13}\text{C}$  as the reliance on kelp beds (higher  $\delta^{13}\text{C}$ ) would decrease. We expect the isotopic niche size of otariids to vary with changes in human activities.

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## 2. Background

The marine food webs of southern South America are supported by coastal/nearshore kelp forests and open pelagic phytoplankton (Friedlander et al., 2018). The proximity of this region to the nutrient rich Southern Ocean and warm waters of the Atlantic Ocean results in high primary productivity (Garzón et al., 2016). This productivity supports a rich array of different organisms due to high endemism, including resident and migratory fish, birds and marine mammals (Friedlander et al., 2018).

Southern fur seals are generalist species and their diets vary geographically. Fish and cephalopods make up a majority of their diets, with a small contribution from crustaceans (Baylis et al., 2018; Casper et al., 2006; Vales et al., 2015). *A. australis* and *O. flavescens* undergo dietary shifts between different life history stages, much like other marine mammals (Vales et al., 2015; Zenteno et al., 2015). Fur seals have a short weaning period within their first year, attaining high quality protein from milk (Cane et al., 2005). Younger, smaller fur seals will hunt for prey closer to shore while older, bigger adults have access to prey from deeper and more distant waters, with some hunting beyond the continental shelf break (Drago et al., 2017).

Since fur seals and sea lions are largely generalists, sea lions have been observed to have a very similar diet to fur seals. However, dietary specialization has been observed in contemporary contexts, in particular with common fish and invertebrate species such as merluccid hakes, octopus, squid and anchovy (Crespo and Pedraza, 2000; Drago et al., 2017). Ontogenetic intraspecific diet specialization in sea lions follows a similar pattern to fur seals, where larger more mature individuals are able to forage farther and deeper than younger individuals (Drago et al., 2009). Heightened interspecific dietary variation has been observed in north-eastern extent of the two species ranges but is less well constrained in southern South America (Drago et al., 2017). However, the amount of overlap in diets of these two otariids and how much feeding habits of these animals has changed over time is still an area of active research.

A variety of investigations into the diets and associated food webs of South American fur seals and sea lions have shown the importance of these species in their ecosystems (De Carvalho et al., 2018). Studies of modern Pinnipeds from gut content, fecal matter and stable isotopic studies show a variety of potential prey for these predators. However, each of these types of observations include potential biases (Nielsen et al., 2018). Stable isotope analyses (SIA) provide an optimal method for dietary analysis for long time scales and where traditional visual inspection of dietary items is either difficult or impossible, as in the species and time scales studied here.

In archaeological specimens, SIA have been applied to both species of otariids from different populations from different time periods in southern South America (Zangrando et al., 2014; Drago et al., 2017), however significant gaps in knowledge remain, specifically due to limited sample sizes and gaps in time. Zooarchaeological analysis suggests increases in hunting intensity may have led to decreases in body size of fur seals and sea lions and an increase in the hunting of younger animals, though SIA indicates that  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  did not vary significantly over time (Zangrando et al., 2014; Martinoli, 2018). Further SIA suggests slight changes in the diets near the end of the archaeological sequence (2600 calibrated years BP, (cal yr BP)) with fur seals feeding on more benthic based organisms coincident with the reduction observed in body size, which may have been associated with reduced primary productivity off the coast of Tierra del Fuego (Saporiti et al., 2014; Vales et al., 2016).

In modern settings, these organisms represent apex predators in overlapping food webs (Drago et al., 2017). *Otaria* is known to feed more prevalently in offshore/pelagic contexts while *Arctocephalus* typically is observed feeding nearshore ecosystems, though commonly feeds pelagically as well (Casper et al., 2006; Drago et al., 2017).

Pinnipeds are vulnerable to direct hunting as well as habitat

encroachment, especially where rookeries are present. Periods of mass exploitation subject populations to shifts in community dynamics, such as alterations to interspecific and intraspecific competition, changes in dispersal and colonization as well as the long-term survival of a species (Romiguer et al., 2014).

Hunting of pinnipeds ensured the survival of marine hunter gatherers of southern South America for thousands of years, between 7500 cal yr BP (calibrated years before present) and the 19th century (Orquera and Piana, 2009). Pinnipeds, bearing a high energetic and nutritional density, were valued for subsistence of human populations and valued for their material resources (Zangrando, 2009). Pinniped remains are abundant throughout the archaeological record of coastal marine hunter gatherers and provide a valuable resource for studying the ecology of this region and its dynamics through several thousand years (Tivoli and Zangrando, 2011).

Coastal sites have been occupied since at least 8500 cal yr BP, when open sub-Antarctic forests colonized the south coast of Tierra del Fuego (Heusser, 1989, 1998; Zangrando et al., 2018). Several distinct indigenous groups have populated the Tierra del Fuego region, with the marine hunter-gatherers occupying the area around the Beagle Channel (Orquera et al., 2011). The archaeological record indicates that the early hunter-gatherer populations maintained long-distance interaction networks along coastal fjords of the Fuegian archipelago in the middle Holocene and remained nomadic until European contact (Orquera and Piana, 2009; Orquera et al., 2011). Ethnographic accounts stipulate that the Yamana would occupy sites along the coast for several weeks, then travel to new sites via canoe (Lothrop, 1928). They would most commonly hunt *A. australis* with harpoons, which the Yamana could easily haul in with their canoes (Orquera and Piana, 1999; Martinoli, 2015). These canoes generally could hold the smaller *A. australis* individuals, rather than larger and heavier prey items like male *O. flavescens* which could potentially capsize the canoes (Martinoli, 2018). Skeletal remains of vertebrates found in early Yamana sites show these people tended to rely almost entirely on *A. australis* for food (Schiavini, 1993) but eventually included a more varied diet including fish and guanacos (Zangrando, 2009).

Pinnipeds were also highly valued in the 18th and 19th centuries by European colonists for their oil (Kovacs et al., 2012). Many of these remains have also been recovered and in this study compared to both more ancient and modern remains, collected after the practice of industrial seal/sea lion exploitation was banned in 1949 (Grandi et al., 2015; Romero et al., 2017). Both species face threats today from competition with fisheries and population depression from recent hunting, as well as vulnerability to climate change (Kovacs et al., 2012). Trophic interactions of the current and past populations of these species remain understudied relative to pinniped species in other parts of the world due to unevenness in resource allocation for research in southern South America (Jarić et al., 2015).

## 3. Materials and methods

### 3.1. Collection

Samples of Otariids were collected via excavation of shell middens and from collections at the Centro Austral de Investigaciones Científicas-Consejo Nacional de Investigaciones Científicas y Técnicas (CADIC-CONICET). Bones were selected based on associated zooarchaeological information, such as species, sex and ages of individuals. Anatomical factors such as bone type and laterality were also considered in the identification of sampled individuals. A variety of sites were chosen, with the Túnel locality containing the highest number of individuals (Table 1). Sites selected vary temporally and longitudinally (Fig. 1, Table 1), including Beagle Channel sites such as Túnel I (7500–4900 cal yr BP and 2200–1600 cal yr BP), Imiwaia I (Zangrando et al., 2016), Bahía Valentín (BVS11) (5700–4800 cal yr BP) (Borrero, 2010), Ajej I (1400–800 cal yr BP) (Piana et al., 2008), Shamakush I

**Table 1**  
Average stable isotope ratios of nitrogen and carbon of all otariids organized by archaeological site.

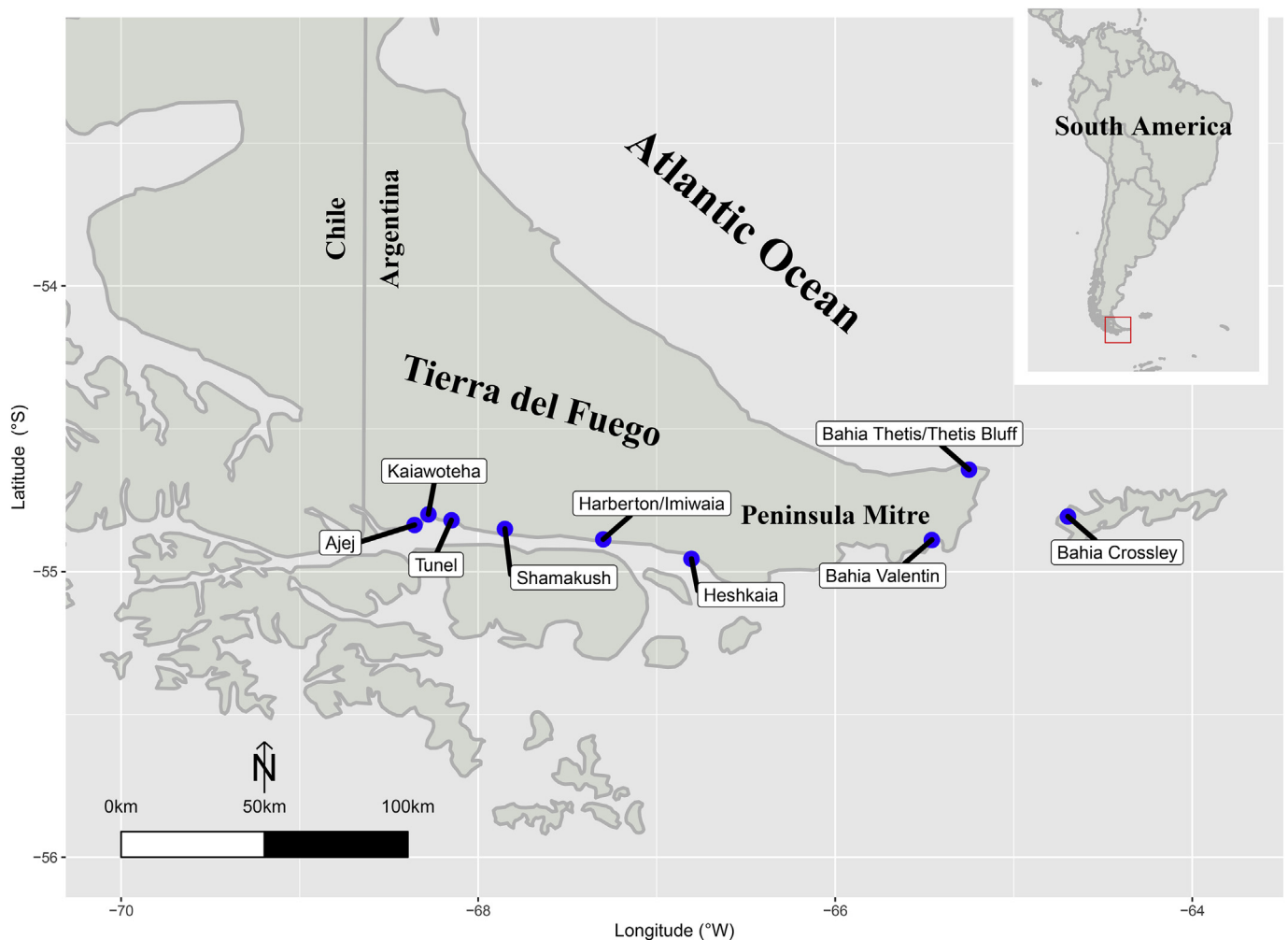
Site	Cal yr BP (approximate ranges)	$\delta^{15}\text{N}$ (‰)			$\delta^{13}\text{C}$ (‰)			C:N ratio		n
		Mean	SD	Range	Mean	SD	Range	SD		
Túnel I (Second Component)	7500–4900	18.2	0.8	5.0	-12.6	1.1	5.1	3.3	0.1	176
Bahía Valentín (BVS11)	5700–4800	20.9	0.9	1.9	-12.9	0.9	2.0	3.7	0.1	4
Bahía Crossley I	3000–1300	18.5	2.1	5.6	-11.7	1.0	2.3	3.6	0.1	6
Túnel I (layer C1)	2200–1600	17.4	1.0	4.0	-12.0	0.6	2.2	3.3	0.2	19
Ajei I	1400–800	16.3	0.7	2.2	-12.5	0.5	1.4	3.5	0.2	7
Shamakush I	1100–1000	17.7	1.6	3.6	-13.4	0.8	1.4	3.3	0.1	4
Kaiyawoteha II	690–560	16.6	0.7	2.5	-12.0	0.7	2.5	3.5	0.2	10
Heshkaia 28	660–550	17.8	1.3	2.7	-14.3	0.5	0.9	3.3	0.0	4
Tres Amigos	Prehistoric (not dated)	14.8	6.2	15.4	-16.1	3.6	8.2	3.2	0.2	6
Thetis Bluff	Historic (not dated)	19.3	0.9	1.7	-12.5	0.5	0.8	3.2	0.1	3
Bahía Thetis	120–70	17.7	1.6	8.7	-13.7	1.2	6.2	3.5	0.3	91
Península Mitre	Post-industrial (not dated)	17.8	3.2	13.1	-13.9	2.5	10.5	3.3	0.2	20

Values for individual species are presented in [Tables A1, A2 and A3](#).

(1100–1000 cal yr BP) ([Orquera et al., 2011](#)) ([Orquera and Piana, 1996](#)), Kaiyawoteha II (690–560 cal yr BP) ([Piana et al., 2007](#)), and Heshkaia 28 (660–560 cal yr BP) ([Zangrando, 2010](#)). Atlantic adjacent sites include Bahía Crossley (3000–1300 cal yr BP) ([Horwitz, 1993](#)), Tres Amigos (prehistoric), and Bahía Thetis (historic) ([Vázquez, 2019](#)). The Tres Amigos and Bahía Thetis sites have not been radiometrically dated, however stratigraphic and contextual evidence such as presence or absence of materials associated with European contact are

considered in their designations as prehistoric or historic ([Nye et al., 2018](#)). Modern samples opportunistically collected along the Peninsula Mitre coastline were measured to represent the post-industrial population

Potential prey and comparative species were also collected from archaeological sites or modern contexts where available. Prey species (summarized in [Table 2](#)) include fish such as the Patagonian grenadier (*Macruronus magellanicus* -Merluccid hakes-) and sardines (*Sprattus*



**Fig. 1.** Distribution of archaeological sites sampled for stable isotope analysis. Most sites are located within the Fuegian archipelago. Sites along the Beagle Channel are terrestrially influenced while Atlantic Coast sites are associated with more open waters of the productive Malvinas/Falkland current.

**Table 2**

Average nitrogen and carbon stable isotope ratios with corresponding carbon to nitrogen ratios, an indicator of preservation quality, in animals analyzed for stable isotope ratios.

	Species	Common name	$\delta^{15}\text{N}$ (‰)			$\delta^{13}\text{C}$ (‰)			C:N ratio		n
			Mean	SD	Range	Mean	SD	Range		SD	
Otarids	<i>Arctocephalus australis</i>	South American fur seal	18.1	1.1	10.9	-12.6	1.2	9.1	3.3	0.2	201
	<i>Otaria flavescens</i>	South American sea lion	17.8	2.0	13.3	-13.5	1.6	11.7	3.5	0.3	126
	Unidentified	-	16.7	2.8	13.3	-13.2	2.0	8.6	3.4	0.2	23
Fish	<i>Macruronus magellanicus</i>	Patagonian grenadier	17.2	0.6	2.1	-13.6	0.6	2.3	3.5	0.2	13
	<i>Clupeidae</i> spp.	Sardine	12.5	1.0	3.7	-13.6	0.6	2.4	3.5	0.1	19
Birds	<i>Phalacrocorax atriceps</i>	Imperial shag	17.5	2.0	8.7	-12.1	0.8	3.5	3.5	0.2	17
Invertebrates	<i>Loligo gahi</i>	Patagonian squid	11.3	0.9	2.2	-17.6	1.0	2.5	4.3	0.6	5

*fuagensis*, Clupidae), derived from the archaeological sites Túnel I and Imiwaia (7800–5700 cal yr BP), and Shamakush I (1100–1000 cal yr BP). A prey species observed in modern fur seal and sea lion diets, Patagonian squid (*Loligo gahi*), do not occur in archaeological sites but were collected from a local fish market in Ushuaia for comparison. Representing a coastal endmember species, Imperial shag (*Phalacrocorax atriceps*) were collected from Túnel I, Imiwaia I, Bahía Crossley I, Shamakush I, and Kaiyawoteha II. Finally, four blades of giant kelp (*Macrocystis pyrifera*) were collected from Harberton Bay, Bahía Thetis, and Tres Amigos locality.

### 3.2. Preparation

Bone samples were demineralized and purified into collagen by suspending 0.5–1 g of samples in 5 ml 0.5 M HCl, which was refreshed every 24 h until completely demineralized or up to a week. Samples were then suspended in 5 ml 0.1 M NaOH to remove humic acid contaminants and refreshed daily until the solution was transparent (Schlacher and Connolly, 2014; Sealy et al., 2014). Collagen pseudo-morphs were dried at 50 °C, followed by weighing 0.5–1.0 mg into a 3 × 5 mm tin boat, then combusted on a Costech EA interfaced with Conflo IV into a Thermo Delta V Plus IRMS at the UC Merced Stable Isotope Laboratory and a Thermo Delta V Advantage at the UC Riverside EDGE Laboratory for bulk carbon and nitrogen stable isotope analysis. If samples returned C:N ratios higher than expected for collagen (> 4), samples were treated for lipid extraction using a 2:1 chloroform methanol solution and re-analyzed (van Klinken, 1999). Kelp blades and squid muscle were washed, dried and weighed into tin boats in a similar manner to collagen samples. All samples are summarized in Table 2.

Stable isotope geochemistry has been well established as a method for identifying marine trophic relationships (Zangrando et al., 2014; Newsome et al. 2010; Boecklen et al., 2011). Stable isotopes fractionate as organic matter is metabolized via enzymatic reactions, with heavier isotopes becoming more abundant in higher trophic levels. SIA can be applied to many different types of tissues, however bone collagen represents an excellent resource for representation of animal diets over several years of the animal's lifespan due to its long turnover rate, while often being the only available tissue in archaeological sites (Ambrose 1990). Stable isotopic measurements are reported in delta notation, which relates the ratio of the heavy to light isotope in the sample to a standard. Values are expressed in parts per mil (Eq. (1)).

$$\delta X_j = \left[ \frac{\left( \frac{X_j}{X_i} \right)_{\text{Sample}}}{\left( \frac{X_j}{X_i} \right)_{\text{Standard}}} \right] - 1 \quad (1)$$

$X_j$  represents the heavy isotope and  $X_i$  the lighter isotope of carbon or nitrogen.  $\delta^{13}\text{C}$  values show habitat preferences and trophic levels, while  $\delta^{15}\text{N}$  values show changes in ocean productivity over time as well as trophic position (Boecklen et al., 2011; Bastos et al., 2017). Isotope values were corrected to international standards, Vienna-Pee Belemnite

Limestone for carbon and atmospheric  $\text{N}_2$ . Internal standards used to correct for drift and linearity were acetanilide, glycine, and USGS 42. Average values for internal standard replicates for  $\delta^{15}\text{N}$  of acetanilide at both laboratories were 0.38‰, 11.45‰ for glycine, and 0.40‰ for USGS 42 while standard deviations were 0.26‰ for acetanilide, 0.35‰ for glycine and 0.20‰ for USGS 42. For  $\delta^{13}\text{C}$ , replicates of acetanilide had averages of -28.27‰, for glycine, -36.05‰, and for USGS 42 -20.92‰ while standard deviations for acetanilide were 0.20‰, for glycine 0.14‰, and for USGS 42, 0.12‰.

Data were then compared in R (Core Team, 2018) to identify potential within population sex or age differences using non-parametric Kruskal–Wallis ANOVA tests, which do not assume a normal distribution of data (Bastos et al., 2017). Similar tests were also employed to compare otariids at different time periods (prehistoric, historic and modern). Stable Isotope Bayesian Ellipses in R (SIBER, Jackson et al., 2011) and Food reconstruction using isotopic transferred signals (FRUITS, Fernandes et al., 2014) were used to model food web dynamics. Groups of organisms were divided into three discrete groups to compare communities across different time periods (early prehistoric, late prehistoric, and modern). This was done to supply the SIBER mixing model with a sample sizes for organisms that would encourage higher degrees of confidence for tandem Ellipse Areas (SEAs). Linear regression models and Kendall rank correlation tests were performed to identify any potential relationships between variables. Pairwise Wilcoxon and Kruskal–Wallis similarity indices were applied to identify differences between means for groups rather than  $t$ -tests and ANOVA since Shapiro tests showed sample groups were not normally distributed (Fig. 2).

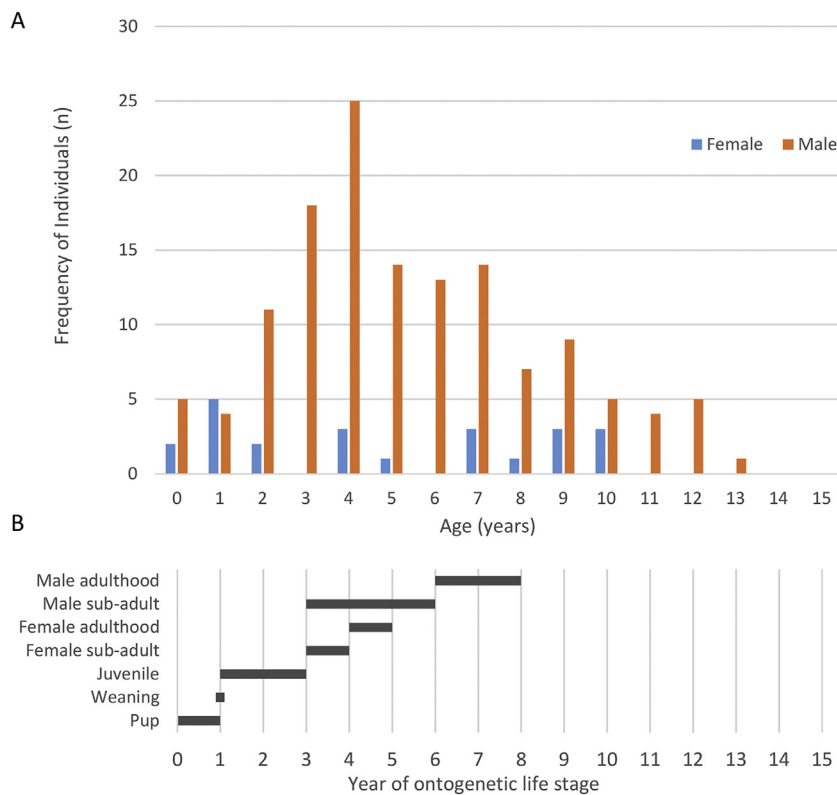
## 4. Results

### 4.1. Interspecific carbon and nitrogen isotopic compositions and differences

Isotopic values for most of species we measured showed significant overlap in both carbon and nitrogen isotopic space (Table 2 and Fig. 3). Kendall Rank correlations were unable to resolve differences between fur seals, sea lions, imperial shag, and Merluccid fish (Table 3). Only Patagonian squid had  $\delta^{15}\text{N}$  ( $11.3 \pm 0.9$ ,  $p < .0003$ ) and  $\delta^{13}\text{C}$  ( $-17.6 \pm 1$ ,  $p < .0002$ ) that were more negative than the organisms above. Sardines also had  $\delta^{15}\text{N}$  values ( $12.5 \pm 1$ ) that were different but similar in terms of  $\delta^{13}\text{C}$ . Kelp showed a very large range in  $\delta^{13}\text{C}$ , primarily due to a single outlier, with the other three kelp samples clustering around -12.5‰.  $\delta^{15}\text{N}$  values for kelp were the lowest measured and did not vary between individuals at around ~6‰.

### 4.2. Spatial and temporal site differences in otariids

Although there were few significant differences in mean values among species, significant variations in  $\delta^{15}\text{N}$  and  $\delta^{13}\text{C}$  in fur seals and sea lions were observed between different time periods and longitude. Kruskal–Wallis measures and Kendall rank correlations comparing  $\delta^{13}\text{C}$



**Fig. 2.** (a) The distribution of *A. australis* individuals divided by sex found at the site Túnel I that are ideal for stable isotope analysis (Schiavini, 1993). The majority of individuals hunted are males. (b) The life history development stage age ranges in age for *A. australis* from Lima and Paez (1997). Males and females mature at different rates, with females reaching adulthood before males.

with mean age and longitude of archaeological sites were both significant, suggesting carbon isotopic values decrease over time. (Table 3,  $p$ -values < .05). Kendall rank correlation  $\tau$  coefficients are non-zero indicating dependence between archaeological sites and  $\delta^{13}\text{C}$ . A positive  $\tau$  coefficient of 0.29

shows  $\delta^{13}\text{C}$  values decrease in otariids as time progresses toward the present (Table 3). Similarly,  $\delta^{15}\text{N}$  expresses significant variation over time as confirmed by these two statistical tests (Table 3). The Kendall rank correlation  $\tau$  coefficient is similarly positive suggesting  $\delta^{15}\text{N}$  values decrease as time progresses. A  $\tau$  coefficient of 0.13, however, indicates that the strength of this correlation is less than that for carbon. Spatially, a  $\tau$  coefficient of  $-0.33$  shows a strong correlation of decreasing  $\delta^{13}\text{C}$  from samples collected at sites from east from the Beagle Channel out to the Atlantic Ocean. The  $\delta^{15}\text{N}$ , on the other hand, shows disagreement between the two statistical measures employed here. While longitude of archaeological site significantly varies with  $\delta^{15}\text{N}$  values, no significant correlation is observed (Table 3).

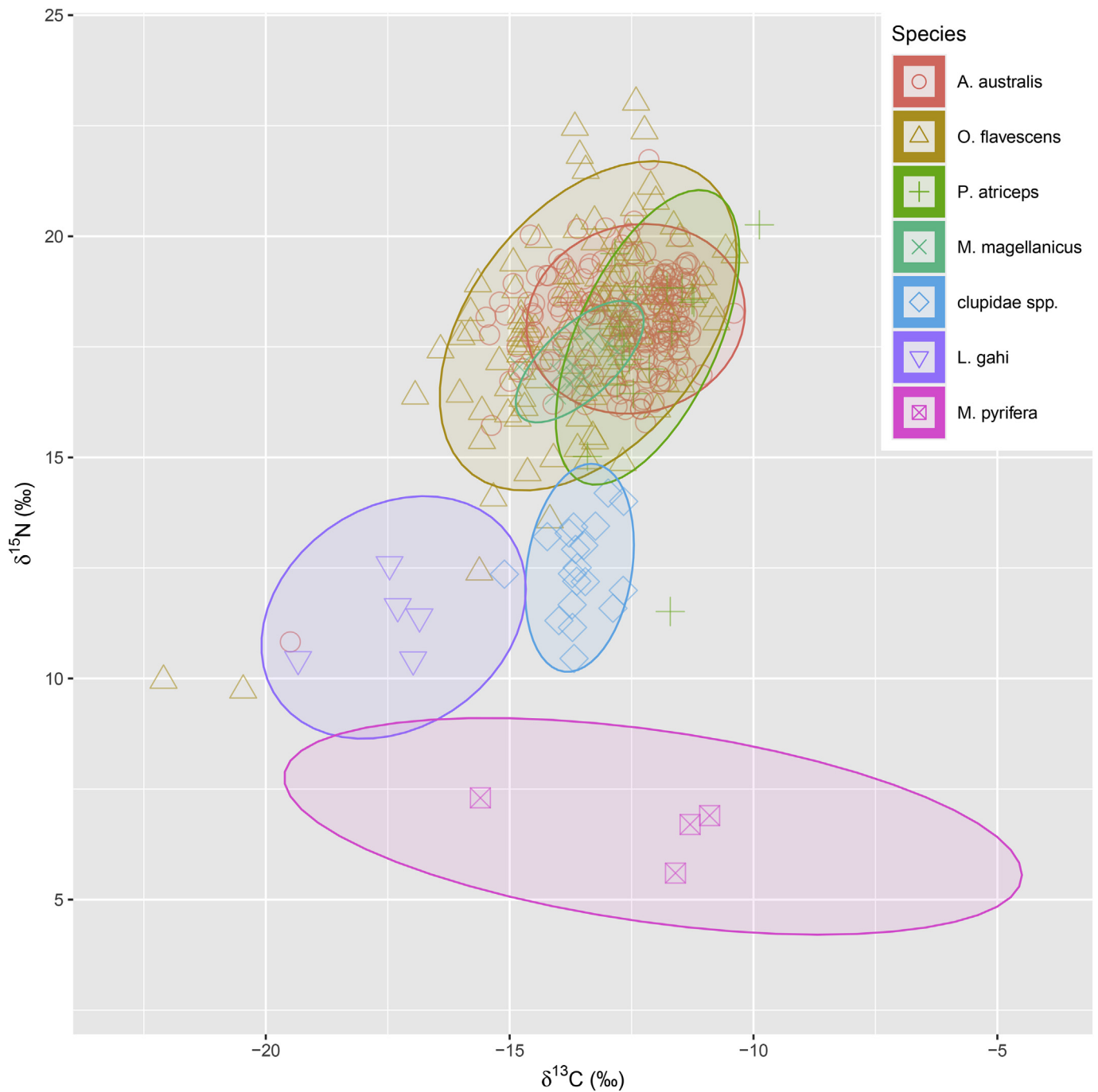
To visualize differences in isotopic ratios of otariids between individual archaeological sites, that vary both in their location and in age of deposition (Table 1), we made density plots to compare probability distributions of nitrogen isotopic ratios (Fig. 4) and carbon isotopic ratios (Fig. 5).  $\delta^{15}\text{N}$  of the different sites tend to have higher probabilities of falling within a smaller range of values (Fig. 4) than for  $\delta^{13}\text{C}$  (Fig. 5) despite an apparent larger absolute range of values for  $\delta^{15}\text{N}$  (Table 1). On the other hand, the probability of an otariid's  $\delta^{13}\text{C}$  falling within a more constrained range is lower. Ultimately the range of the probability distribution in ‰ increases with the number of samples per site, so extremely high-density probabilities for sites with fewer individuals may be biased by a small sample size (Table 1).

#### 4.3. Population dynamics

We found significant differences and correlation between the two otariid species in their  $\delta^{13}\text{C}$  values, but not for  $\delta^{15}\text{N}$  values. Carbon isotopic measurements were significantly more negative in sea lions (*O.*

*flavescens*) than in fur seals (*A. australis*) as indicated by a Kendall rank correlation of 0.29 (Tables 1 and 3). Conversely, no significant differences between species were indicated by a Kruskal–Wallis test and Kendall rank correlation in  $\delta^{15}\text{N}$  ( $p$ -values > .05, Tables 1 and 3). We also found the age class of individuals are not significantly related or correlated with nitrogen isotopic values (Table 3). Age class of individuals may be weakly correlated with their  $\delta^{13}\text{C}$  values ( $\tau = 0.12$ ), however a Kruskal–Wallis test did not show significant variation between the two variables. No significant variation or correlation was found in  $\delta^{13}\text{C}$  and sexes of individuals, however a weak correlation ( $\tau = 0.12$ ) and significant variation was observed in  $\delta^{15}\text{N}$  and sexes of individuals (Table 3).

To assess potential isotopic variability without the complications of location, we measured 164 individuals from the archaeological site with the most abundant fur seal remains (Túnel I, Fig. 2, Tables 1 and 4). Mean  $\delta^{15}\text{N}$  values showed no significant differences for any age class. Variations in  $\delta^{15}\text{N}$  values, however, ranged by 4.3‰ (16.1–20.3‰) and were observed in all age categories from pups to adults. A Kruskal–Wallis comparison of mean  $\delta^{15}\text{N}$  values suggests no significant differences between age categories ( $p = .57$ ), and a Kendall rank correlation likewise suggests no significant differences ( $p = .99$ ). Male adults had the highest maximum  $\delta^{15}\text{N}$  values and pairwise Wilcoxon tests suggest significant variation between mean values of male and female adult fur seals ( $p = .032$ ). Variation in  $\delta^{13}\text{C}$  was significant as well, with a range of 4.5‰ and varied similarly between different age categories. We observed significant variation between means of age using Kruskal–Wallis tests ( $p = .0051$ ). The two age groups with the most variable means included juveniles, who had more negative  $\delta^{13}\text{C}$  values, and adults, who were most positive in  $\delta^{13}\text{C}$  ( $p = .0076$ ). Like nitrogen, we observed no significant differences between mean values of  $\delta^{13}\text{C}$  between males or females using a Kruskal–Wallis comparison ( $p = .91$ ) and Kendall rank correlation highlighted no differences ( $p = .95$ ).



**Fig. 3.** Carbon and nitrogen isotopic space of all organisms (see Table 1) organized by species for over the entire time period, from Northrippian to modern. Ellipses represent 95% confidence intervals. More negative  $\delta^{13}\text{C}$  values indicate offshore dominated influence while more positive indicate nearshore influence.  $\delta^{15}\text{N}$  largely indicates trophic level for these organisms. Overlapping ellipses in both carbon and nitrogen space indicate little separation between secondary consumers, while primary consumers show little overlap. Individuals are not diet corrected.

#### 4.4. SIBER, FRUITS – food web/trophic dynamics

Using the SIBER Bayesian analysis package in R, we calculated several metrics to quantify the isotopic niche sizes of otariids (Figs. 6 and 7, Table 5). The two different species show different patterns, with both species having small areas in the early prehistoric, sea lions having much greater ellipse areas than fur seals in the late prehistoric, and both species having nearly equivalent areas in the historic/modern time period.

We calculated the ellipse areas and convex hull areas of total community size from the same time periods using data from the wider

food web (Table 2) based on the ellipse areas calculated from nitrogen and carbon isotope values (Fig. A2). Different time periods show significant differences in the standard ellipse and convex hull areas. The community from the earliest time period had the highest convex hull area while the modern period had the most potential variation in area. Uncertainty in convex hull area shows significant overlap between these two time periods. The community between 3000 and 500 cal yr BP has fewer unique organisms present, and the resulting calculation is a very low value convex hull area likely underestimating a realistic estimate of community size (Fig. A2).

**Table 3**

Summary of statistical tests to determine significance of different variables on carbon and nitrogen isotopic ratios of otariids (*A. australis* n = 201, *O. flavescens* n = 126).

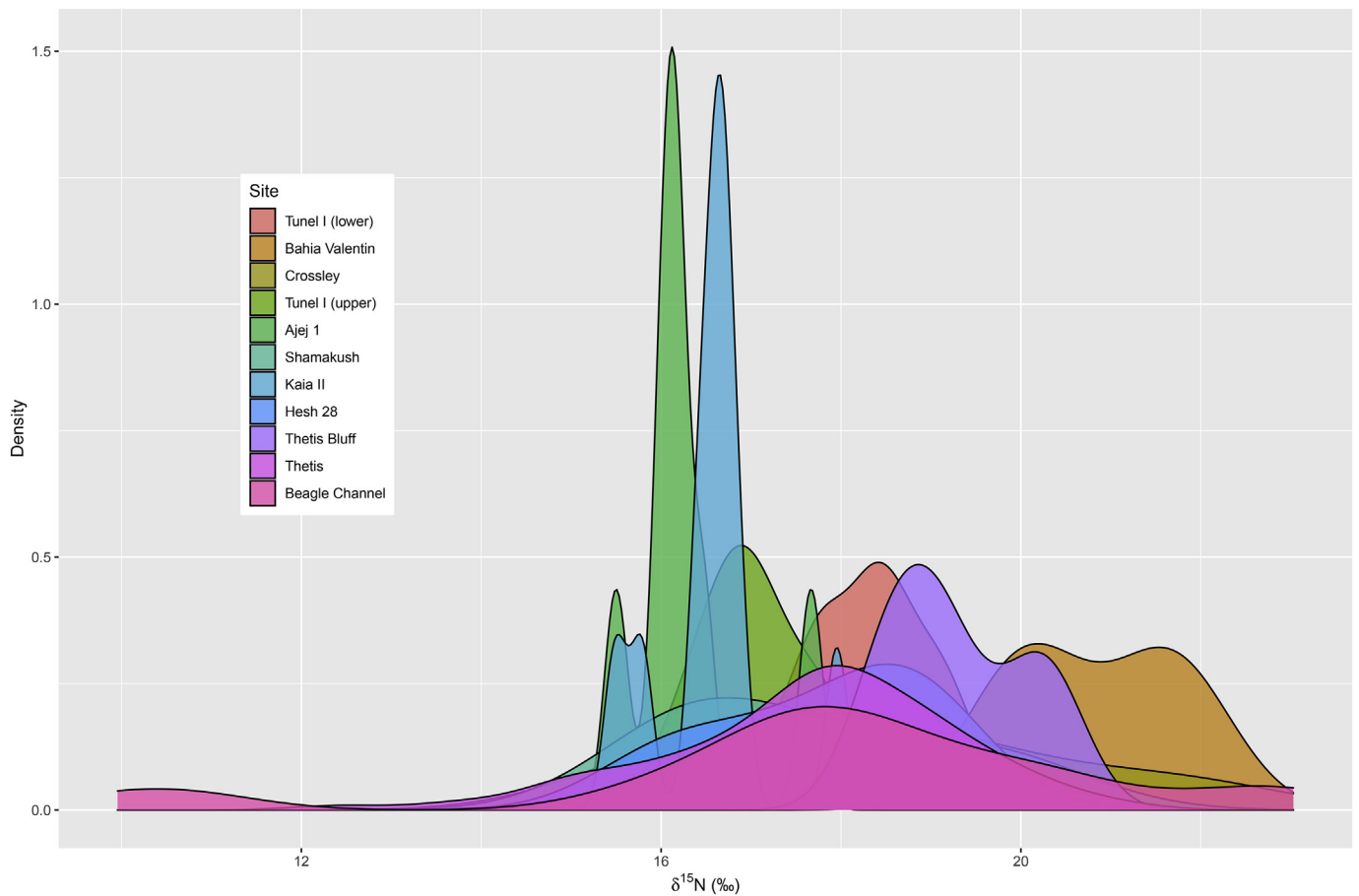
	$\delta^{13}\text{C}$					
	Kruskal–Wallis test		Kendall rank correlation			
	p-Value	Significance (< 0.05)	p-Value	Significance (< 0.05)	$\tau$	Correlation strength
Age of individual	.07	not significant	.03	*	0.12	*
Sex	.95	not significant	.95	not significant	0.00	not correlated
Species ( <i>O. flavescens</i> vs. <i>A. australis</i> )	< .001	*	< .001	*	0.29	**
Mean age of archaeological site	< .001	*	< .001	*	0.29	**
Longitude of archaeological site	< .001	*	< .001	*	-0.33	***

	$\delta^{15}\text{N}$					
	Kruskal–Wallis test		Kendall rank correlation			
	p-Value	Significance (< 0.05)	p-Value	Significance (< 0.05)	$\tau$	Correlation strength
Age of individual	.12	not significant	1.00	not significant	< 0.001	not correlated
Sex	.05	*	.05	*	0.12	*
Species ( <i>O. flavescens</i> vs. <i>A. australis</i> )	.25	not significant	.25	not significant	0.05	not correlated
Mean age of archaeological site	< .001	*	.00	*	0.13	*
Longitude of archaeological site	< .001	*	.46	not significant	0.03	not correlated

Carbon isotopic ratios significantly varied or correlated between species and between mean age and longitude of archaeological sites while nitrogen isotopic values significantly varied or correlated between different sexes and mean age of archaeological sites.

Significance for the Kruskal–Wallis tests and Kendall rank correlations are marked with an asterisk. The level of correlation strength (defined by tau) of the Kendall rank correlation is indicated by the number asterisks, with more asterisks indicating stronger correlation.



**Fig. 4.** Density plot of nitrogen isotopic values in otariids divided by archaeological site. Sites are ordered by mean radiocarbon age with more recent sites in the foreground. While some sites show dense clustering of sampled individuals, this may be an artifact of small sample sizes for these sites. Overall, there is significant overlap in  $\delta^{15}\text{N}$  between sites.

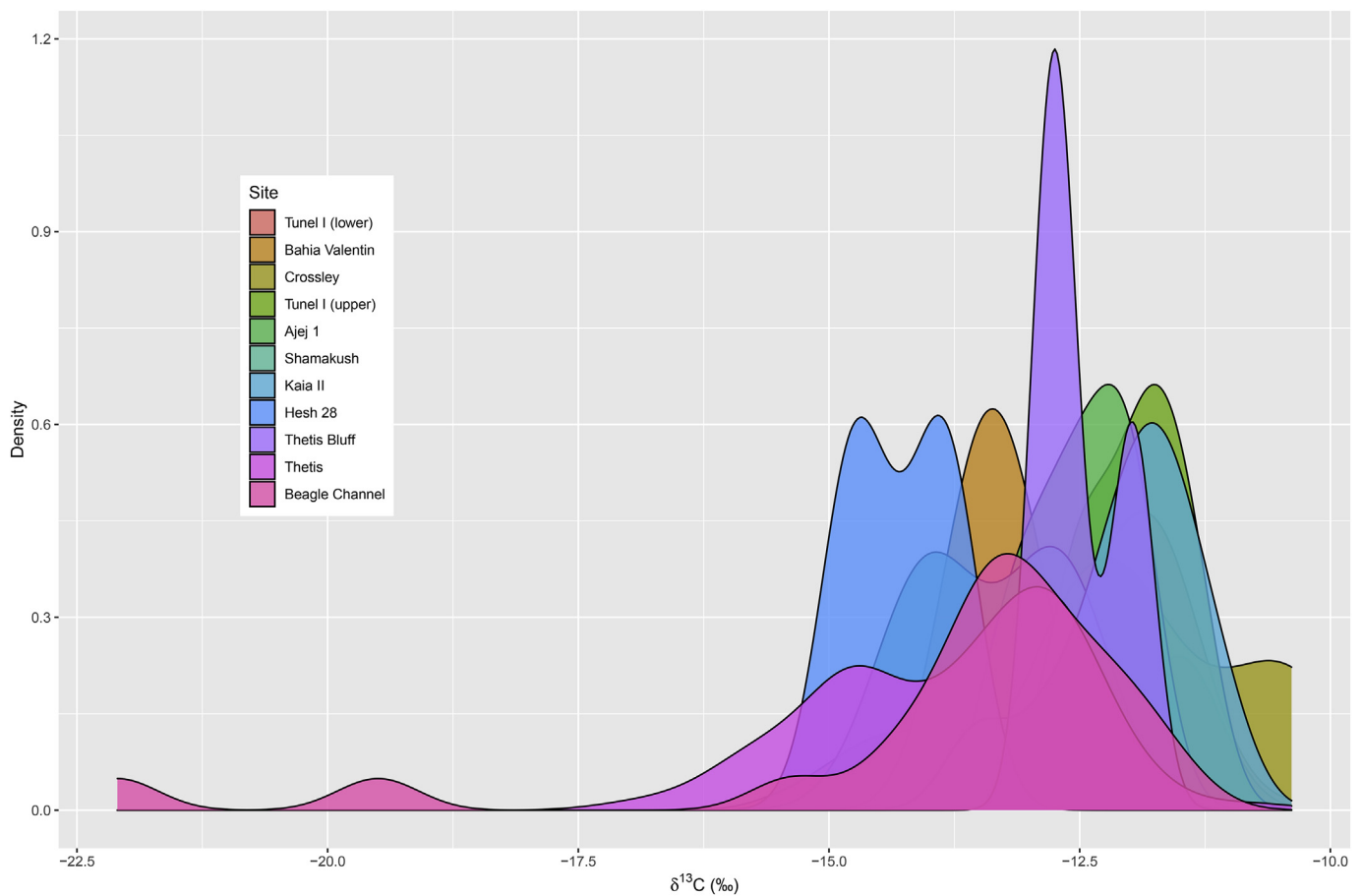


Fig. 5. Density plot of carbon isotopic values in otariids. Sites are ordered by mean radiocarbon age with more recent sites in the foreground. More recent sites show large ranges in  $\delta^{13}\text{C}$  values and significant overlap is observed in all sites over time.

**Table 4**  
Average stable isotope ratios by ontogenetic age class of fur seals (*A. australis*) from Tunel 1.

Sex	Age class	$\delta^{15}\text{N}$ (‰)			$\delta^{13}\text{C}$ (‰)			C:N ratio		n
		Mean	SD	Range	Mean	SD	Range		SD	
NA	pup	18.2	1.0	2.4	-12.5	1.4	3.4	3.3	0.1	5
NA	juvenile	18.1	0.8	4.1	-13.1	1.2	4.1	3.2	0.1	38
F	sub-adult	17.5	1.1	2.3	-11.8	0.3	0.6	3.5	0.3	3
M	sub-adult	18.4	0.9	3.4	-12.7	1.0	3.8	3.3	0.1	38
F	adult	17.9	0.3	1.0	-12.5	0.8	2.3	3.2	0.1	10
M	adult	18.4	0.8	4.1	-12.5	1.0	4.2	3.3	0.2	54

Few differences were observed between individuals of different age classes. The only statistically significant difference was observed between juveniles and adult fur seals in  $\delta^{13}\text{C}$  values (Wilcoxon,  $p = .0076$ ).

**5. Discussion**

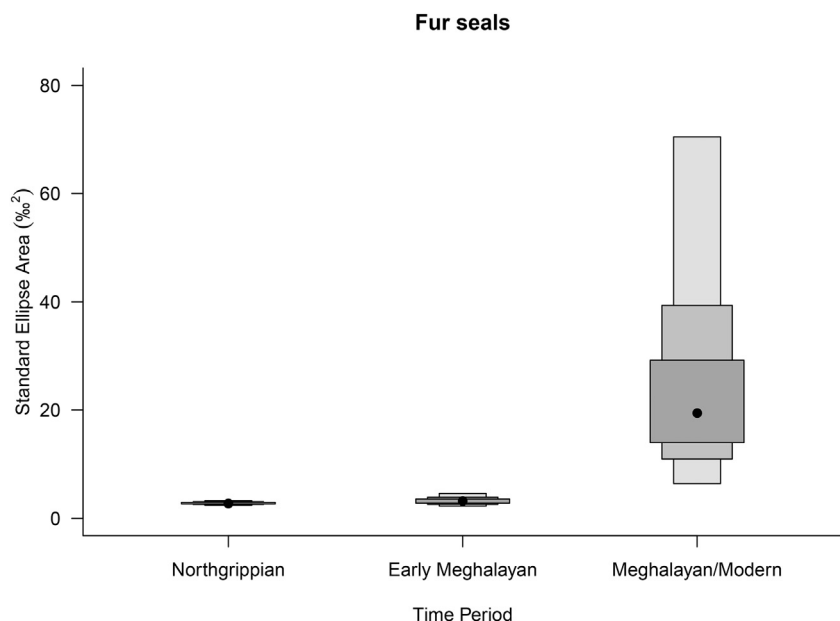
Both species of otariids as well as many other organisms found in coastal Tierra del Fuego have similar isotopic niche spaces (Table 2 and Fig. 3). Squid (*L. gahi*) and sardines (clupeidae) are the only groups of organisms that essentially do not overlap with each other in isotopic niche space and are largely separate from other species in nitrogen isotopic space while being roughly similar to each other. We interpret the wide range in  $\delta^{13}\text{C}$  values as a continuous range between offshore (phytoplankton,  $-21\text{‰}$ ) and nearshore (kelp forest,  $-11.7\text{‰}$ ) ecosystems (Riccialdelli et al., 2017). Sardines and squid represent lower trophic level organisms that reflect reliance on carbon routed through different primary producer biochemical pathways.

Otariids are the most diverse in their ranges for  $\delta^{13}\text{C}$ . Sea lions, *O. flavescens*, clearly show reliance on both offshore and nearshore primary producers, while fur seals, *A. australis*, have  $\delta^{13}\text{C}$  more biased toward nearshore ecosystems, though still derive carbon from a mix of offshore and nearshore sources (Table 2). Patagonian grenadier (*M. magellanicus*) also have intermediate  $\delta^{13}\text{C}$  values indicative of their being reliant on a mix of nearshore and offshore carbon. On the other hand, Imperial Shag (*P. atriceps*) has  $\delta^{13}\text{C}$  values that indicate a firmer reliance on nearshore carbon. Despite differences in carbon sources, representing different primary producers, all four of these species have a similar trophic level, as indicated by their overlapping nitrogen isotopic values (Table 2 and Fig. 3). These findings are consistent with modern day observations of these species (Bas et al., 2018).

The abundance of fur seal remains at the oldest site, Túnel I, (Table 2 and Fig. 2), provides enough samples to characterize the population and ontogeny in a middle Holocene population of fur seals. The presence of more males than females suggests that this locality was not directly adjacent to a breeding colony (Schiavini, 1993), as females are more often associated with rookeries while males are observed to travel more broadly (Carrara, 1952; Siielefeld et al., 1978; de Lima et al., 2019). This observation is supported by the abundance of older individuals as well. Fewer pups and yearlings are observed in the data set (Schiavini, 1993). While some might argue that these individuals may have been selected preferentially by humans evidence points to butchering of larger animals before transport, allowing them to be transported to shore (Cárdenas-Alayza et al., 2017; Martinoli and Vázquez, 2017).

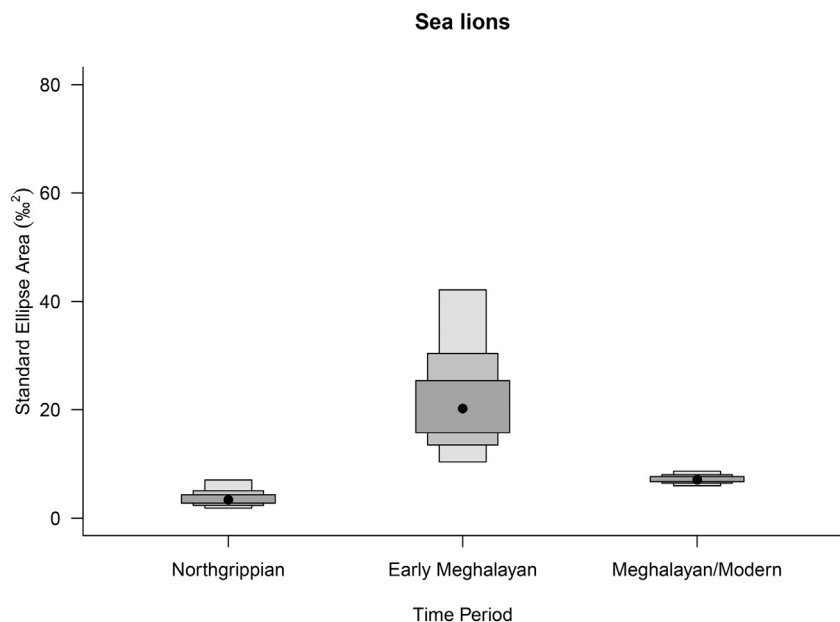
Isotopically, we observe several differences between age class and sex (Fig. 3). Pups reflect the diets of their mothers, while yearlings and





juveniles, restricted in hunting ability and prey sources, show lower  $\delta^{15}\text{N}$  values than adults that can forage for larger, more difficult to hunt prey from a broader array of sources.  $\delta^{13}\text{C}$  values are represented in a continuous range between offshore (phytoplankton,  $-21\text{‰}$ ) and nearshore (kelp forest,  $-11.7\text{‰}$ ) sources in adults, where they are unrestricted in hunting habitat (Riccialdelli et al., 2017). Yearling and juvenile  $\delta^{13}\text{C}$  values tend to cluster in groups associated with either nearshore or offshore diets, indicating that these individuals foraged in one or the other habitat rather than in both habitats as adults. Ultimately, we observe ontogenetic variation within a single community several thousand years ago that is not unlike modern communities.

Primary producers, including the two most significant contributors in the Fuegian marine ecosystem, phytoplankton and kelp (Riccialdelli et al., 2017), will vary in biomass production from nutrient and energy supplies. Changes in climate affect the base of the food web, which can result in a potential baseline shift, in which isotopic values at the lower trophic levels are offset and are reflected in higher trophic levels (Casey and Post, 2011; Bas et al., 2018). The results from our study indicate



**Fig. 6.** Standard Ellipse Areas for southern fur seals (*A. australis*) ( $n = 204$ ) and generated through SIBER using  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$ . Samples were divided into three time periods by mean ages of sites, Northgrippian (6200–5820 Cal yr BP), Early Meghalayan (2150–625 Cal yr BP), and Meghalayan/Modern (150–50 years BP) to ensure adequate sampling size for modeling. Boxes represent confidence intervals of 50, 75 and 95% while points represent the means. Red Xs represent the estimated SEAc metric, a correction for potential biases due to sample size (Jackson et al., 2011).

**Table 5**  
Niche area calculations for the two species of otariids.

	Early prehistoric	Late prehistoric	Historic/Modern
Sea lion (n)	(10)	(9)	(107)
Convex Hull Area (% <sup>2</sup> )	5.9	32.1	55.0
SEA (% <sup>2</sup> )	3.6	18.4	7.2
SEAc (% <sup>2</sup> )	4.0	21.0	7.3
Fur seal (n)	(165)	(32)	(4)
Convex Hull Area (% <sup>2</sup> )	14.4	11.4	5.0
SEA (% <sup>2</sup> )	2.8	3.3	6.3
SEAc (% <sup>2</sup> )	2.8	3.4	9.4

While convex hull area is very sensitive to smaller sample sizes, SEA and SEAc are less so. Sea lions (*O. flavescens*) show increases in niche area sizes within the Northgrippian, and decrease from the transition from Meghalayan to modern. Niche areas in fur seals (*A. australis*) generally increase over time.

**Fig. 7.** Standard Ellipse Areas for southern sea lions (*O. flavescens*) ( $n = 126$ ) as generated through SIBER using  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$ . Samples were divided into three time periods by mean ages of sites, Northgrippian (6200–5820 Cal yr BP), Early Meghalayan (2150–625 Cal yr BP), and Meghalayan/Modern (150–50 years BP) to ensure adequate sampling size for modeling for both species. Boxes represent confidence intervals of 50, 75 and 95% while points represent the means. Red Xs represent the estimated SEAc metric, a correction for potential biases due to sample size (Jackson et al., 2011).

that changes in isotopic values can be explained by 1) a shift in baseline, 2) a change in food chain length or 3) shifts in competition between populations or species. The lack of directional change in nitrogen values suggests scenario 2 is unlikely. Scenario 3 seems to be a likely explanation as we see significant dynamics in the otariid species' isotopic niche areas. Scenario 1 represents a complex dilemma related to changes in productivity and geographic space that cannot be explained by data in this study alone.

Environmental change has long been regarded as a driver of ecological change (Prevosti and Forasiepi, 2018). Climate change events have had notable effects on food webs throughout the Holocene in various parts of the world, especially in high latitude regions. In the Southern Hemisphere notable changes are seen in the Ross Sea and the Antarctic Peninsula (Koch et al., 2019) though near the coast of South America sea surface temperatures have remained at a relatively stable warm state except for a minor cooling event  $\sim 5$  cal kyr BP and more recent cooling in the last 1000 years (Caniupán et al., 2014; Bas et al., 2018). Several papers have advanced the idea that environmental baseline shifts are the proximate cause for variation in carbon and nitrogen isotopic values in higher trophic level organisms in the prehistoric time period (7500–2500 cal yr BP). Saporiti et al. (2014) found a steady depletion in  $\delta^{18}\text{O}$  values from Beagle Channel limpets until the Little Ice Age (500 cal yr BP), a period associated with higher primary productivity. Changes in the sub-Antarctic marine food web of Tierra del Fuego, with dynamics in the presence or absence of fish species, such as snoek (Bas et al., 2018). Isotopic values returned to those previously observed shortly thereafter owing to lower productivity with the termination of this climatic event, from  $\sim 0.1\text{‰}$  to  $0.25\text{‰}$ . These observations are consistent with  $\delta^{15}\text{N}$  obtained from pinnipeds in our study which shifted from  $18.2\text{‰}$  to  $17.8\text{‰}$  (Table 1 and Fig. 4).

While one could speculate about pinnipeds in a similar fashion, the  $\delta^{15}\text{N}$  values measured in pinnipeds are complicated by the more varied prey sources, including prey from both the coast and open ocean. Changes in productivity could be attenuated or routed directly through the length of the food web and reflected in high trophic level organisms. The large ranges in both carbon and nitrogen values in measured otariids support this, where there could be significant individual specialization. The former case cannot be discounted as spikes in productivity could be mediated in intermediate trophic levels through resource partitioning via shifts in species interactions, for example. Using more advanced types of analyses like compound specific stable isotope analysis may elucidate the long term ecological patterns of South American otariids (Nielsen et al., 2018).

In southern South America marine ecosystems, it has been suggested that changes in sea level and sea surface temperature have been linked to changes in productivity in the Holocene (Saporiti et al., 2013; Caniupán et al., 2014). However, our results suggest that these changes have not appeared to affect trophic level, with apparent little change over time in  $\delta^{15}\text{N}$  values ( $0.4\text{‰}$ , Table 2, Figs. 4, 7 and 8). The more apparent and significant changes occur in carbon isotopic niche space, which is more closely associated with habitat regime. Significant changes in productivity could appear as a change in trophic level, as a more complex food web would offer more opportunity for a longer food chain length (Young et al., 2013). Higher productivity may very well shorten food chain length as predators take advantage of a more readily available basal resource (Doi and Hillebrand, 2019). In any case a lack of change in either direction of trophic level indicates potential productivity changes were not significant for otariids. A more likely explanation for dynamic changes in isotopic niches of otariids is direct human activities forcing changes in otariid habitat. The observation of decreasing  $\delta^{13}\text{C}$  values in the prehistoric time period agrees with our

hypothesis that seals are foraging more offshore, even when considering potential climatic effects. It should be noted however that this decreasing trend of mean values of archaeological sites is most notable in the latest 2500 years (Fig. 8a).

Variation in both carbon and nitrogen isotopic values in the historic and modern time periods likely reflect ecological trends influenced by human activities, e.g. hunting, rather than climate or changes in productivity. Due to industrial hunting and habitat encroachment, a competitive release where niches that were human-impacted previously were liberated and available for otariid foraging. A significant population bottleneck introduced by industrial sealers in the 19th and 20th centuries may have allowed for subsequent increased dispersal after hunting was banned. A lack of interspecific and intraspecific competition likely allowed otariids to forage in previously crowded environments, despite less coastal habitat. With less intraspecific and interspecific competition between pinnipeds, individuals could forage in larger niche spaces. This interpretation appears to confirm our second hypothesis that niche size increased over time, though we were not expecting such large variations within the modern population. Regardless, the historic and modern populations represent the most dynamic in isotopic niche space values, coincident with greater human influence on the Fuegian marine ecosystem.

## 6. Conclusions

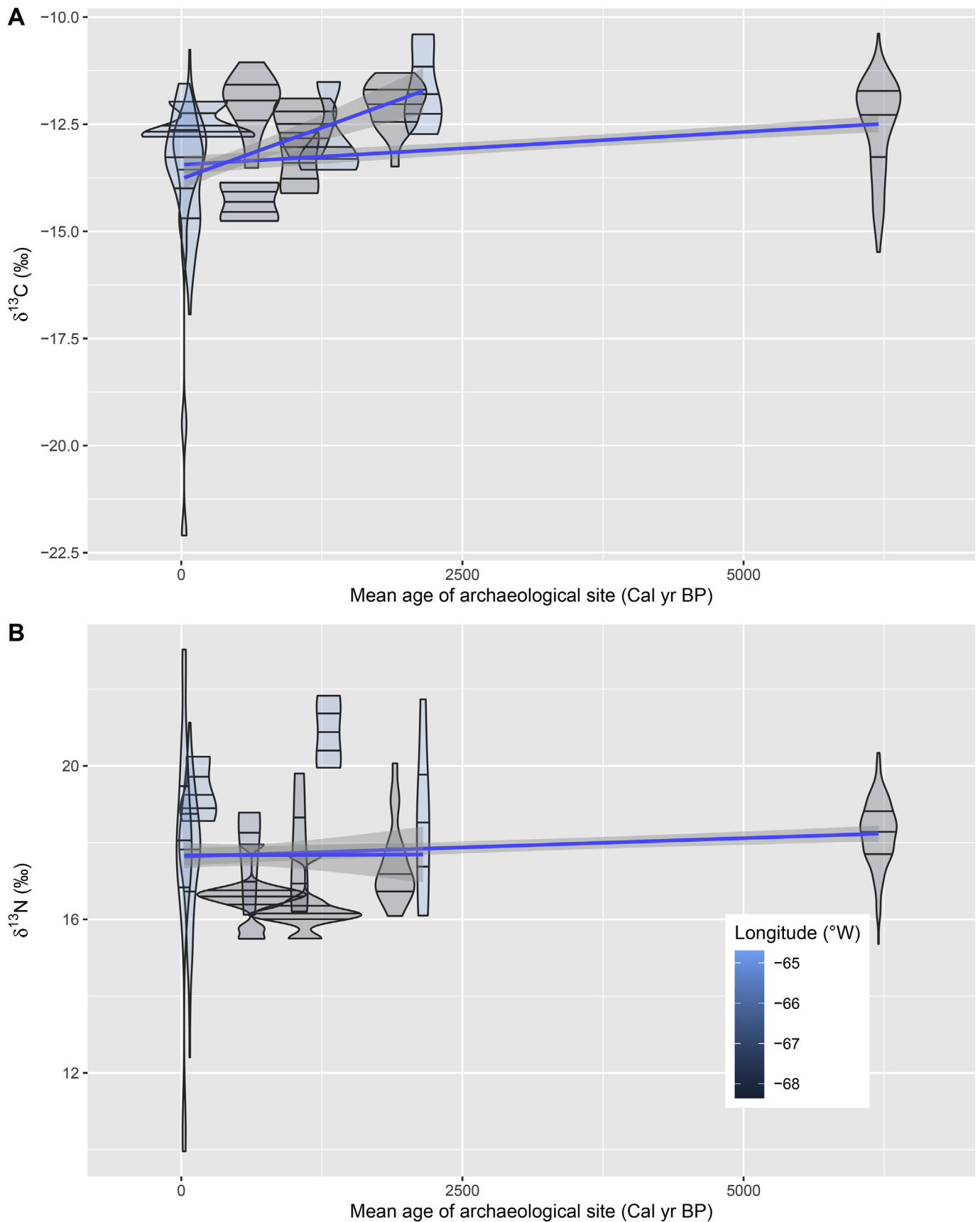
In contrast with some previous findings from archaeological, historic, and modern ecological analyses, we find little evidence of climatic variation affecting higher trophic level organisms from the middle Holocene to the near present. In this region and during the last 7500 years, climatic variation pales in comparison to direct human influences on the marine ecosystems in the Fuegian archipelago. In contrast to our expectation that otariids would increase their trophic level over time, we see little evidence of that change. However, the range of dietary sources and habitats in which otariids forage increases dramatically as time progresses toward the present. This observation is congruent with our hypothesis that human impacts, in both hunter-gatherer and industrial societies, have altered species interactions in coastal Tierra del Fuego. The processes of human hunting of pinnipeds, through prehistory to historical time periods, and habitat encroachment, which continues from prehistory to the present day, have resulted in significant variations in the diets of pinnipeds, most significantly within the past several hundred years.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

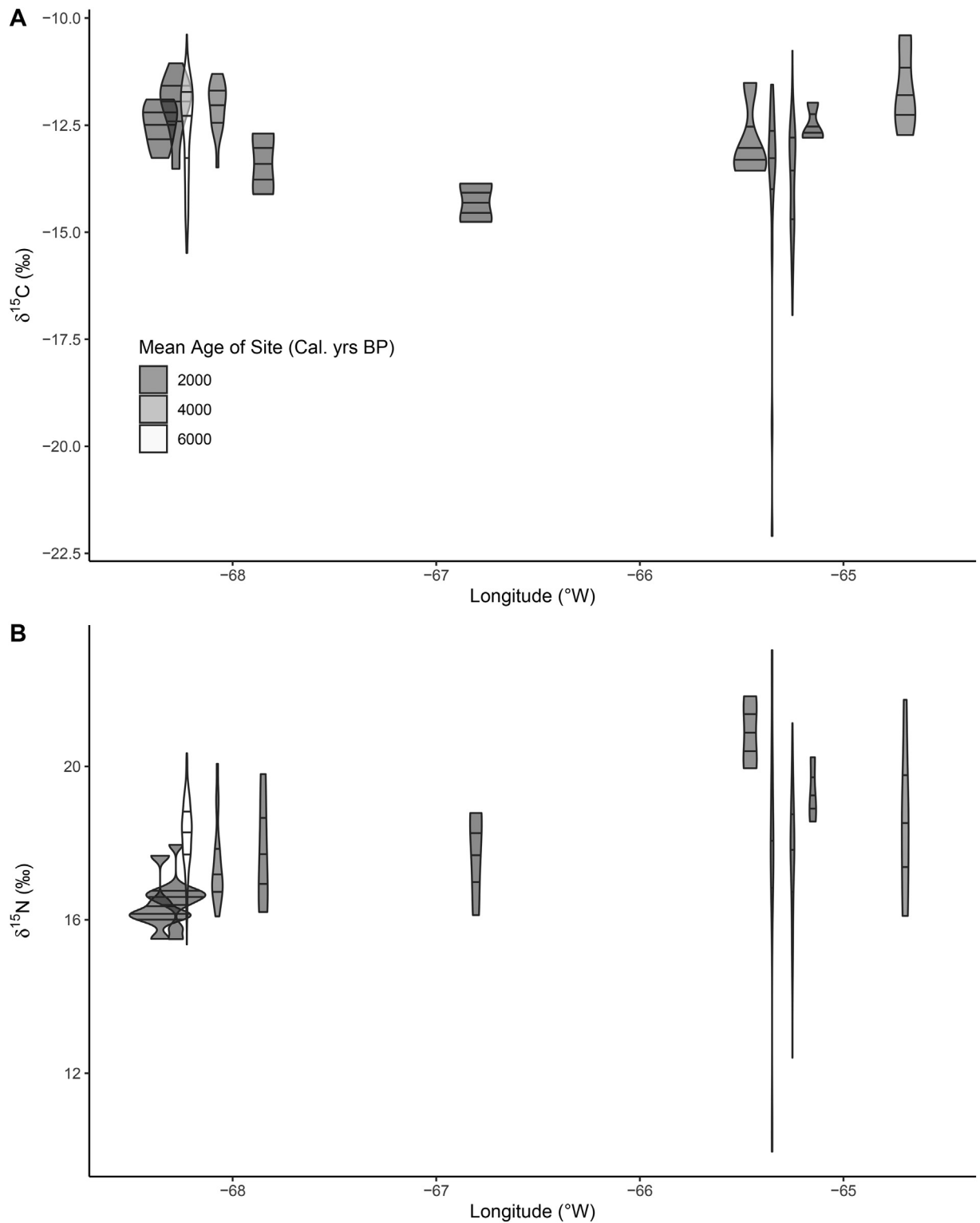
## Acknowledgements

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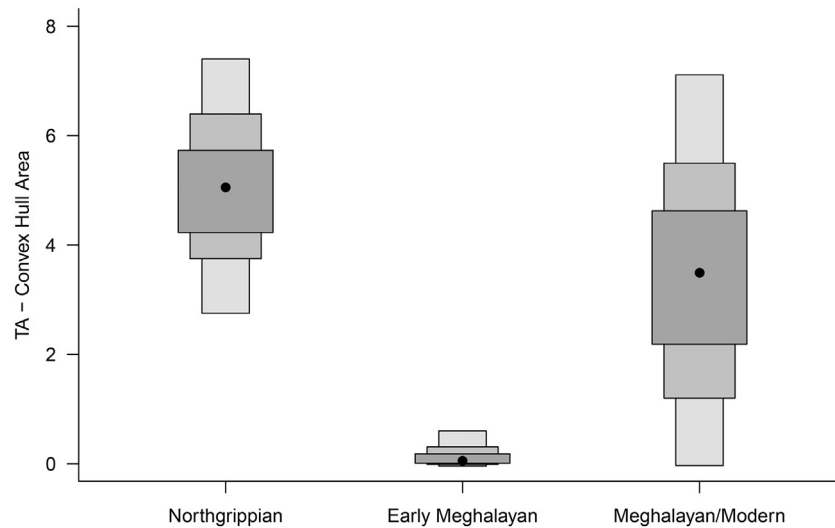


**Fig. 8.** Overlain violin plots of (A) carbon and (B) nitrogen isotopic ratios of otariids organized by mean year of site age. Longitude is represented by colour with lighter blue farther east and black/grey farther west. 25th, 50th and 75th percentile lines are represented on each violin. Linear regression model of means between each site indicate a weak correlation between site age and  $\delta^{13}\text{C}$  values ( $r^2 = 0.11$  for all sites and  $r^2 = 0.2$  for sites less than 2500 yr BP). There was no correlation between site age and  $\delta^{13}\text{N}$  values ( $r^2 = 0.03$  for all sites and  $r^2 = -0.006$  for sites less than 2500 yr BP). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Appendix



**Fig. A1.** Stable isotopic values of (a) carbon and (b) nitrogen in otriids organized by longitude. Kendall rank correlation and linear regression show a significant relationship ( $p < .001$ ) and a weak negative correlation between longitude and  $\delta^{15}\text{C}$  ( $r^2 = 0.15$ ) of otriids while  $\delta^{15}\text{N}$  and longitude show no significant relationship.



**Fig. A2.** Convex hull areas, an indicator of community size, of all archaeological sites (7500–4800 cal yr BP, 3000–500 cal yr BP) compared to all modern sites (120–70 cal yr BP, historic and post-industrial). While average convex hull area is less in the modern community, there is much higher variation in modern carbon-nitrogen isotopic space. Hull area is also much smaller in the intermediate time span, perhaps suggesting less dynamic isotopic niches during this time. Convex hull area is susceptible to small sample size so standard ellipse area (SEA) measurements may more accurately quantify niche size between groups (see Table 5).

**Table A1**  
All bulk  $\delta^{15}\text{N}$  and  $\delta^{13}\text{C}$  measurements of otariids.

Sample ID	$\delta^{15}\text{N}$ (‰)	$\delta^{13}\text{C}$ (‰)	C:N ratio	Species	Sex	Age Class	Site	Latitude (°S)	Longitude (°W)	Site age
MD-AA-LJ	10.8	-19.5	3.1	Aa	NA	juvenile	Beagle Channel	-54.64	-65.25	Modern
MD-Aa-bCap-2	19.4	-13.4	3.1	Aa	NA	NA	Beagle Channel	-54.64	-65.25	Modern
Mod-A1315-cran	18.4	-12.9	3.1	Aa	NA	NA	Beagle Channel	-54.64	-65.25	Modern
Md-A4-RNP-2858	15.7	-15.4	3.3	Aa	NA	NA	Beagle Channel	-54.64	-65.25	Modern
MD-OF-FLA2	16.4	-13.3	3.1	Of	F	adult	Beagle Channel	-54.64	-65.25	Modern
MD-OF-L2	20.8	-12.0	3.2	Of	NA	sub-adult	Beagle Channel	-54.64	-65.25	Modern
MD-OF-L1	16.9	-12.4	3.4	Of	NA	sub-adult	Beagle Channel	-54.64	-65.25	Modern
MD-OF-R	18.6	-12.0	3.4	Of	NA	sub-adult	Beagle Channel	-54.64	-65.25	Modern
MD-OF-L3	17.5	-13.2	3.7	Of	NA	sub-adult	Beagle Channel	-54.64	-65.25	Modern
MD-OF-L4	17.4	-14.1	3.7	Of	NA	sub-adult	Beagle Channel	-54.64	-65.25	Modern
Md-OF-FLA1	19.9	-14.4	3.1	Of	F	adult	Beagle Channel	-54.64	-65.25	Modern
Md-Of-MLA	17.4	-11.6	3.3	Of	M	adult	Beagle Channel	-54.64	-65.25	Modern
MD-OF-MRA	18.5	-13.2	3.4	Of	M	adult	Beagle Channel	-54.64	-65.25	Modern
MD-OF-FRA	17.7	-12.8	3.5	Of	F	adult	Beagle Channel	-54.64	-65.25	Modern
MD-OF-LJ	20.1	-13.6	3.4	Of	NA	juvenile	Beagle Channel	-54.64	-65.25	Modern
Md-OF-LSA	17.6	-12.8	3.1	Of	NA	sub-adult	Beagle Channel	-54.64	-65.25	Modern
Md-Of-Cran	10.0	-22.1	3.3	Of	NA	NA	Beagle Channel	-54.64	-65.25	Modern
MD-Of-scap-M7	22.5	-13.7	3.3	Of	NA	NA	Beagle Channel	-54.64	-65.25	Modern
Md-Of-Seap-1	18.5	-13.5	3.3	Of	NA	NA	Beagle Channel	-54.64	-65.25	Modern
Md-Of-Pelvis-9anos	23.0	-12.4	3.5	Of	NA	adult	Beagle Channel	-54.64	-65.25	Modern
T-27	18.0	-12.7	3.1	Of	NA	NA	Thetis	-54.64	-65.25	1940-1950 AD
T-27	18.4	-12.7	3.1	Of	NA	NA	Thetis	-54.64	-65.25	1940-1950 AD
T-6	18.2	-13.1	3.1	Of	NA	NA	Thetis	-54.64	-65.25	1940-1950 AD
T-6	18.6	-13.1	3.1	Of	NA	NA	Thetis	-54.64	-65.25	1940-1950 AD
T-69	18.9	-12.4	3.1	Of	NA	NA	Thetis	-54.64	-65.25	1940-1950 AD
T-74	17.9	-14.5	3.1	Of	NA	NA	Thetis	-54.64	-65.25	1940-1950 AD
T-78	18.9	-11.9	3.2	Of	NA	NA	Thetis	-54.64	-65.25	1940-1950 AD
T-18	19.6	-12.6	3.2	Of	NA	NA	Thetis	-54.64	-65.25	1940-1950 AD
T-18	20.0	-12.6	3.2	Of	NA	NA	Thetis	-54.64	-65.25	1940-1950 AD
T-24	19.5	-12.9	3.2	Of	NA	NA	Thetis	-54.64	-65.25	1940-1950 AD
T-24	19.9	-12.9	3.2	Of	NA	NA	Thetis	-54.64	-65.25	1940-1950 AD
T-79	18.0	-12.6	3.2	Of	NA	NA	Thetis	-54.64	-65.25	1940-1950 AD
T-87	18.1	-10.8	3.2	Of	NA	NA	Thetis	-54.64	-65.25	1940-1950 AD
T-81	18.9	-12.9	3.2	Of	NA	NA	Thetis	-54.64	-65.25	1940-1950 AD
T-86	19.5	-12.4	3.2	Of	NA	NA	Thetis	-54.64	-65.25	1940-1950 AD
T-29	18.6	-12.8	3.2	Of	NA	NA	Thetis	-54.64	-65.25	1940-1950 AD
T-29	19.1	-12.8	3.2	Of	NA	NA	Thetis	-54.64	-65.25	1940-1950 AD
T-82	17.9	-12.8	3.3	Of	NA	NA	Thetis	-54.64	-65.25	1940-1950 AD
T-26	17.1	-13.7	3.3	Of	NA	NA	Thetis	-54.64	-65.25	1940-1950 AD
T-26	17.5	-13.7	3.3	Of	NA	NA	Thetis	-54.64	-65.25	1940-1950 AD
T-102	16.1	-12.0	3.3	Of	NA	NA	Thetis	-54.64	-65.25	1940-1950 AD
T-41	17.5	-12.7	3.3	Of	NA	NA	Thetis	-54.64	-65.25	1940-1950 AD
T-83	18.7	-12.4	3.3	Of	NA	NA	Thetis	-54.64	-65.25	1940-1950 AD
T-47	16.8	-12.9	3.3	Of	NA	NA	Thetis	-54.64	-65.25	1940-1950 AD

(continued on next page)

Table A1 (continued)

Sample ID	$\delta^{15}\text{N}$ (‰)	$\delta^{13}\text{C}$ (‰)	C:N ratio	Species	Sex	Age Class	Site	Latitude (°S)	Longitude (°W)	Site age
T-7	16.8	-13.4	3.4	Of	NA	NA	Thetis	-54.64	-65.25	1940-1950 AD
T-7	17.3	-13.4	3.4	Of	NA	NA	Thetis	-54.64	-65.25	1940-1950 AD
T-fem-9	17.2	-13.0	3.4	Of	NA	NA	Thetis	-54.64	-65.25	1940-1950 AD
T-43	18.3	-12.4	3.4	Of	NA	NA	Thetis	-54.64	-65.25	1940-1950 AD
T-fem-14	15.5	-13.3	3.4	Of	NA	NA	Thetis	-54.64	-65.25	1940-1950 AD
T-fem-8	17.7	-12.6	3.4	Of	NA	NA	Thetis	-54.64	-65.25	1940-1950 AD
T-15	19.9	-13.3	3.4	Of	NA	NA	Thetis	-54.64	-65.25	1940-1950 AD
T-15	20.3	-13.3	3.4	Of	NA	NA	Thetis	-54.64	-65.25	1940-1950 AD
T-fem-7	19.6	-12.3	3.4	Of	NA	NA	Thetis	-54.64	-65.25	1940-1950 AD
T-fem-21	18.6	-12.8	3.4	Of	NA	NA	Thetis	-54.64	-65.25	1940-1950 AD
T-fem-15	16.6	-13.2	3.4	Of	NA	NA	Thetis	-54.64	-65.25	1940-1950 AD
T-fem-20	15.0	-14.1	3.4	Of	NA	NA	Thetis	-54.64	-65.25	1940-1950 AD
T-fem-19	18.5	-13.1	3.4	Of	NA	NA	Thetis	-54.64	-65.25	1940-1950 AD
T-12	18.7	-13.7	3.4	Of	NA	NA	Thetis	-54.64	-65.25	1940-1950 AD
T-12	19.1	-13.7	3.4	Of	NA	NA	Thetis	-54.64	-65.25	1940-1950 AD
T-63	21.1	-12.1	3.4	Of	NA	NA	Thetis	-54.64	-65.25	1940-1950 AD
T-fem-12	20.2	-11.6	3.4	Of	NA	NA	Thetis	-54.64	-65.25	1940-1950 AD
T-97	17.9	-12.8	3.4	Of	NA	NA	Thetis	-54.64	-65.25	1940-1950 AD
T-94	17.0	-12.9	3.5	Of	NA	NA	Thetis	-54.64	-65.25	1940-1950 AD
T-48	18.1	-13.2	3.5	Of	NA	NA	Thetis	-54.64	-65.25	1940-1950 AD
T-fem-13	17.6	-14.2	3.5	Of	NA	NA	Thetis	-54.64	-65.25	1940-1950 AD
T-54	17.2	-15.2	3.5	Of	NA	NA	Thetis	-54.64	-65.25	1940-1950 AD
T-fem-17	19.1	-13.2	3.5	Of	NA	NA	Thetis	-54.64	-65.25	1940-1950 AD
T-fem-5	19.4	-12.9	3.5	Of	NA	NA	Thetis	-54.64	-65.25	1940-1950 AD
T-84	14.9	-12.7	3.5	Of	NA	NA	Thetis	-54.64	-65.25	1940-1950 AD
T-fem-2	17.9	-12.7	3.5	Of	NA	NA	Thetis	-54.64	-65.25	1940-1950 AD
T-fem-16	20.6	-12.5	3.5	Of	NA	NA	Thetis	-54.64	-65.25	1940-1950 AD
T-25	18.6	-13.8	3.5	Of	NA	NA	Thetis	-54.64	-65.25	1940-1950 AD
T-25	19.1	-13.8	3.5	Of	NA	NA	Thetis	-54.64	-65.25	1940-1950 AD
T-90	14.9	-13.4	3.5	Of	NA	NA	Thetis	-54.64	-65.25	1940-1950 AD
T-fem-6	15.4	-13.2	3.5	Of	NA	NA	Thetis	-54.64	-65.25	1940-1950 AD
T-98	13.6	-14.2	3.5	Of	NA	NA	Thetis	-54.64	-65.25	1940-1950 AD
T-71	19.4	-14.9	3.6	Of	NA	NA	Thetis	-54.64	-65.25	1940-1950 AD
T-103-01	15.2	-13.6	3.6	Of	NA	NA	Thetis	-54.64	-65.25	1940-1950 AD
T-17	17.7	-14.8	3.6	Of	NA	NA	Thetis	-54.64	-65.25	1940-1950 AD
T-17	18.2	-14.8	3.6	Of	NA	NA	Thetis	-54.64	-65.25	1940-1950 AD
T-fem-18	15.9	-13.6	3.7	Of	NA	NA	Thetis	-54.64	-65.25	1940-1950 AD
T-95	18.0	-13.8	3.7	Of	NA	NA	Thetis	-54.64	-65.25	1940-1950 AD
T-49	17.2	-14.4	3.7	Of	NA	NA	Thetis	-54.64	-65.25	1940-1950 AD
T-75	16.8	-14.4	3.7	Of	NA	NA	Thetis	-54.64	-65.25	1940-1950 AD
T-67	18.9	-15.7	3.8	Of	NA	NA	Thetis	-54.64	-65.25	1940-1950 AD
T-99	14.7	-14.6	3.8	Of	NA	NA	Thetis	-54.64	-65.25	1940-1950 AD
T-96	17.8	-13.8	3.8	Of	NA	NA	Thetis	-54.64	-65.25	1940-1950 AD
T-13	17.5	-14.8	3.8	Of	NA	NA	Thetis	-54.64	-65.25	1940-1950 AD
T-13	18.1	-14.8	3.8	Of	NA	NA	Thetis	-54.64	-65.25	1940-1950 AD
T-51	18.5	-13.2	3.8	Of	NA	NA	Thetis	-54.64	-65.25	1940-1950 AD
T-11	17.3	-14.8	3.8	Of	NA	NA	Thetis	-54.64	-65.25	1940-1950 AD
T-11	17.8	-14.8	3.8	Of	NA	NA	Thetis	-54.64	-65.25	1940-1950 AD
T-16	17.8	-15.8	3.9	Of	NA	NA	Thetis	-54.64	-65.25	1940-1950 AD
T-16	18.3	-15.8	3.9	Of	NA	NA	Thetis	-54.64	-65.25	1940-1950 AD
T-52	17.4	-16.4	3.9	Of	NA	NA	Thetis	-54.64	-65.25	1940-1950 AD
T-101-Real	18.0	-14.7	3.9	Of	NA	NA	Thetis	-54.64	-65.25	1940-1950 AD
T-22	12.4	-15.6	3.9	Of	NA	NA	Thetis	-54.64	-65.25	1940-1950 AD
T-37	17.6	-14.8	3.9	Of	NA	NA	Thetis	-54.64	-65.25	1940-1950 AD
T-10	16.0	-15.0	3.9	Of	NA	NA	Thetis	-54.64	-65.25	1940-1950 AD
T-10	16.6	-15.0	3.9	Of	NA	NA	Thetis	-54.64	-65.25	1940-1950 AD
T-4	15.4	-15.6	3.9	Of	NA	NA	Thetis	-54.64	-65.25	1940-1950 AD
T-4	16.0	-15.6	3.9	Of	NA	NA	Thetis	-54.64	-65.25	1940-1950 AD
T-2	16.4	-16.9	3.9	Of	NA	NA	Thetis	-54.64	-65.25	1940-1950 AD
T-93	18.8	-14.9	3.9	Of	NA	NA	Thetis	-54.64	-65.25	1940-1950 AD
T-77	17.7	-16.0	3.9	Of	NA	NA	Thetis	-54.64	-65.25	1940-1950 AD
T-91	14.1	-15.3	3.9	Of	NA	NA	Thetis	-54.64	-65.25	1940-1950 AD
T-46	17.7	-14.6	3.9	Of	NA	NA	Thetis	-54.64	-65.25	1940-1950 AD
T-66	15.9	-14.8	3.9	Of	NA	NA	Thetis	-54.64	-65.25	1940-1950 AD
T-50	16.4	-16.0	4.0	Of	NA	NA	Thetis	-54.64	-65.25	1940-1950 AD
T-23	16.3	-14.7	4.0	Of	NA	NA	Thetis	-54.64	-65.25	1940-1950 AD
T-23	16.9	-14.7	4.0	Of	NA	NA	Thetis	-54.64	-65.25	1940-1950 AD
TH-3	19.1	-12.8	3.3	NA	NA	adult	Thetis Bluff	-54.64	-65.25	Historic
TB-2	20.2	-12.0	3.1	NA	NA	juvenile	Thetis Bluff	-54.64	-65.25	Historic
TB-1	18.6	-12.7	3.2	NA	NA	juvenile	Thetis Bluff	-54.64	-65.25	Historic
SH 1765	16.6	-13.9	3.2	Aa	NA	sub-adult	Shamakush	-54.85	-67.85	1100-1000 BP
SH 1655	19.8	-12.7	3.3	Aa	NA	sub-adult	Shamakush	-54.85	-67.85	1100-1000 BP
SH 1751	16.2	-14.1	3.4	Aa	NA	sub-adult	Shamakush	-54.85	-67.85	1100-1000 BP
SH 1511	18.1	-12.7	3.5	Aa	NA	sub-adult	Shamakush	-54.85	-67.85	1100-1000 BP

(continued on next page)

Table A1 (continued)

Sample ID	$\delta^{15}\text{N}$ (‰)	$\delta^{13}\text{C}$ (‰)	C:N ratio	Species	Sex	Age Class	Site	Latitude (°S)	Longitude (°W)	Site age
2705	16.5	-11.9	3.4	NA	M	juvenile	Ajeje 1	-54.84	-68.36	1400-800 BP
2020	16.1	-12.6	3.9	NA	M	juvenile	Ajeje 1	-54.84	-68.36	1400-800 BP
1031	17.7	-13.3	3.5	NA	M	sub-adult	Ajeje 1	-54.84	-68.36	1400-800 BP
2174	16.2	-12.0	3.4	NA	M	NA	Ajeje 1	-54.84	-68.36	1400-800 BP
3084	15.5	-12.9	3.5	NA	M	NA	Ajeje 1	-54.84	-68.36	1400-800 BP
1405	16.0	-12.4	3.5	NA	NA	NA	Ajeje 1	-54.84	-68.36	1400-800 BP
2629	16.2	-12.2	3.5	NA	M	NA	Ajeje 1	-54.84	-68.36	1400-800 BP
13,225	20.2	-13.0	3.5	Aa	NA	pup	Bahia Valentin	-54.89	-65.46	1500-1120 BP
11,275	20.0	-11.5	3.9	Of	F	juvenile	Bahia Valentin	-54.89	-65.46	1500-1120 BP
10,246	21.8	-13.6	3.6	Of	NA	pup	Bahia Valentin	-54.89	-65.46	1500-1120 BP
10,246	21.5	-13.4	3.7	Of	NA	pup	Bahia Valentin	-54.89	-65.46	1500-1120 BP
35,880	17.0	-11.8	3.2	Aa	M	adult	Tunel I (upper)	-54.82	-68.15	2200-1600 BP
42,527	16.8	-12.6	3.2	Aa	F	adult	Tunel I (upper)	-54.82	-68.15	2200-1600 BP
40,194	19.0	-11.4	3.3	Aa	F	adult	Tunel I (upper)	-54.82	-68.15	2200-1600 BP
35,229	17.2	-11.8	3.2	Aa	NA	juvenile	Tunel I (upper)	-54.82	-68.15	2200-1600 BP
42,460	16.1	-12.3	3.2	Aa	NA	pup	Tunel I (upper)	-54.82	-68.15	2200-1600 BP
36,597	20.1	-12.5	3.2	Aa	NA	pup	Tunel I (upper)	-54.82	-68.15	2200-1600 BP
42,742	17.7	-11.7	3.2	Aa	NA	pup	Tunel I (upper)	-54.82	-68.15	2200-1600 BP
37,702	19.2	-12.7	3.2	Aa	NA	pup	Tunel I (upper)	-54.82	-68.15	2200-1600 BP
37,371	16.7	-11.9	3.1	Aa	NA	sub-adult	Tunel I (upper)	-54.82	-68.15	2200-1600 BP
42,614	17.7	-11.5	3.2	Aa	NA	sub-adult	Tunel I (upper)	-54.82	-68.15	2200-1600 BP
136,325	16.3	-12.3	3.2	Aa	NA	sub-adult	Tunel I (upper)	-54.82	-68.15	2200-1600 BP
42,439	17.8	-11.3	3.2	Aa	NA	sub-adult	Tunel I (upper)	-54.82	-68.15	2200-1600 BP
42,416	17.0	-11.6	3.2	Aa	M	sub-adult	Tunel I (upper)	-54.82	-68.15	2200-1600 BP
40,878	18.1	-11.8	3.2	Aa	NA	sub-adult	Tunel I (upper)	-54.82	-68.15	2200-1600 BP
35,210	17.2	-12.5	3.4	Aa	NA	sub-adult	Tunel I (upper)	-54.82	-68.15	2200-1600 BP
42,421	17.0	-11.4	3.4	Aa	NA	sub-adult	Tunel I (upper)	-54.82	-68.15	2200-1600 BP
37,401	16.7	-11.9	3.4	Aa	NA	sub-adult	Tunel I (upper)	-54.82	-68.15	2200-1600 BP
37,605	16.8	-12.2	3.5	Aa	NA	sub-adult	Tunel I (upper)	-54.82	-68.15	2200-1600 BP
32,730	16.5	-13.5	3.9	Of	NA	adult	Tunel I (upper)	-54.82	-68.15	2200-1600 BP
BCI VI 80	18.3	-10.4	3.4	Aa	M	adult	Crossley	-54.81	-64.70	3000-1300 BP
BCI 458	16.1	-12.3	3.7	Aa	F	adult	Crossley	-54.81	-64.70	3000-1300 BP
BCI VI 1045	21.7	-12.1	3.8	Aa	NA	pup	Crossley	-54.81	-64.70	3000-1300 BP
II 879	16.4	-12.7	3.4	Aa	NA	sub-adult	Crossley	-54.81	-64.70	3000-1300 BP
BCI 968	19.7	-10.6	3.5	Of	M	adult	Crossley	-54.81	-64.70	3000-1300 BP
11,870	18.5	-11.9	3.6	Of	M	sub-adult	Crossley	-54.81	-64.70	3000-1300 BP
H28-25B1	17.5	-14.8	3.3	NA	NA	NA	Hesh 28	-54.96	-66.81	660-550 BP
H28-9908-F40	18.8	-13.9	3.3	NA	NA	NA	Hesh 28	-54.96	-66.81	660-550 BP
7571	16.1	-14.7	3.3	Of	M	adult	Hesh 28	-54.96	-66.81	660-550 BP
9908	18.8	-13.9	3.3	Of	M	adult	Hesh 28	-54.96	-66.81	660-550 BP
K 9729	18.0	-11.4	3.2	Aa	M	adult	Kaia II	-54.80	-68.28	690-560 BP
K 8470	16.6	-12.8	3.3	Aa	M	adult	Kaia II	-54.80	-68.28	690-560 BP
K 8676	16.4	-13.5	3.5	Aa	F	adult	Kaia II	-54.80	-68.28	690-560 BP
K 8725	15.8	-12.2	3.7	Aa	M	adult	Kaia II	-54.80	-68.28	690-560 BP
K 7756	16.7	-11.8	3.6	Aa	M	sub-adult	Kaia II	-54.80	-68.28	690-560 BP
K 7756	16.9	-11.1	3.8	Aa	M	sub-adult	Kaia II	-54.80	-68.28	690-560 BP
K 8388	16.5	-11.9	3.6	NA	NA	juvenile	Kaia II	-54.80	-68.28	690-560 BP
K 8598	15.5	-12.3	3.8	NA	NA	juvenile	Kaia II	-54.80	-68.28	690-560 BP
K 9037	16.7	-11.8	3.4	Of	F	NA	Kaia II	-54.80	-68.28	690-560 BP
K 8872	16.7	-11.5	3.5	Of	F	NA	Kaia II	-54.80	-68.28	690-560 BP
3 Amigos 1	11.6	-17.4	3.2	NA	NA	adult	3 Amigos	-54.64	-65.25	7500-200 BP
3 Amigos 4	19.2	-13.7	3.1	NA	NA	pup	3 Amigos	-54.64	-65.25	7500-200 BP
3 Amigos 2	18.8	-13.0	3.1	NA	NA	juvenile	3 Amigos	-54.64	-65.25	7500-200 BP
3 Amigos 3	7.0	-19.9	3.5	NA	NA	juvenile	3 Amigos	-54.64	-65.25	7500-200 BP
3 Amigos 6	22.4	-12.2	3.2	Of	NA	juvenile	3 Amigos	-54.64	-65.25	7500-200 BP
3 Amigos 5	9.7	-20.5	3.1	Of	NA	pup	3 Amigos	-54.64	-65.25	7500-200 BP
34,326	18.2	-13.2	3.1	Aa	F	adult	Tunel I (lower)	-54.82	-68.15	7500-4900 BP
34,466	19.3	-13.4	3.1	Aa	M	adult	Tunel I (lower)	-54.82	-68.15	7500-4900 BP
34,248	17.9	-13.8	3.1	Aa	F	adult	Tunel I (lower)	-54.82	-68.15	7500-4900 BP
33,630	17.8	-14.6	3.1	Aa	M	adult	Tunel I (lower)	-54.82	-68.15	7500-4900 BP
32,090	20.0	-14.6	3.1	Aa	M	adult	Tunel I (lower)	-54.82	-68.15	7500-4900 BP
34,537	18.5	-12.6	3.1	Aa	M	adult	Tunel I (lower)	-54.82	-68.15	7500-4900 BP
33,854	18.8	-12.5	3.2	Aa	M	adult	Tunel I (lower)	-54.82	-68.15	7500-4900 BP
34,222	17.9	-12.3	3.2	Aa	M	adult	Tunel I (lower)	-54.82	-68.15	7500-4900 BP
34,138	17.9	-12.3	3.2	Aa	F	adult	Tunel I (lower)	-54.82	-68.15	7500-4900 BP
31,109	18.3	-13.5	3.2	Aa	M	adult	Tunel I (lower)	-54.82	-68.15	7500-4900 BP
30,510	18.5	-14.5	3.2	Aa	M	adult	Tunel I (lower)	-54.82	-68.15	7500-4900 BP
34,111	17.8	-14.5	3.2	Aa	M	adult	Tunel I (lower)	-54.82	-68.15	7500-4900 BP
33,100	18.6	-13.1	3.2	Aa	M	adult	Tunel I (lower)	-54.82	-68.15	7500-4900 BP
31,178	18.2	-13.4	3.2	Aa	F	adult	Tunel I (lower)	-54.82	-68.15	7500-4900 BP
34,467	18.2	-11.6	3.2	Aa	M	adult	Tunel I (lower)	-54.82	-68.15	7500-4900 BP
34,212	18.3	-14.0	3.2	Aa	M	adult	Tunel I (lower)	-54.82	-68.15	7500-4900 BP
31,454	20.3	-12.4	3.2	Aa	M	adult	Tunel I (lower)	-54.82	-68.15	7500-4900 BP
31,794	18.3	-14.5	3.2	Aa	M	adult	Tunel I (lower)	-54.82	-68.15	7500-4900 BP

(continued on next page)

Table A1 (continued)

Sample ID	$\delta^{15}\text{N}$ (‰)	$\delta^{13}\text{C}$ (‰)	C:N ratio	Species	Sex	Age Class	Site	Latitude (°S)	Longitude (°W)	Site age
32,102	17.9	-12.8	3.2	Aa	F	adult	Tunnel I (lower)	-54.82	-68.15	7500-4900 BP
31,289	17.6	-12.2	3.2	Aa	F	adult	Tunnel I (lower)	-54.82	-68.15	7500-4900 BP
33,454	19.4	-13.9	3.2	Aa	M	adult	Tunnel I (lower)	-54.82	-68.15	7500-4900 BP
30,486	18.7	-12.0	3.2	Aa	M	adult	Tunnel I (lower)	-54.82	-68.15	7500-4900 BP
33,045	17.7	-13.9	3.2	Aa	M	adult	Tunnel I (lower)	-54.82	-68.15	7500-4900 BP
30,441	17.4	-11.6	3.2	Aa	M	adult	Tunnel I (lower)	-54.82	-68.15	7500-4900 BP
30,439	18.3	-11.8	3.2	Aa	M	adult	Tunnel I (lower)	-54.82	-68.15	7500-4900 BP
32,428	18.4	-12.1	3.2	Aa	F	adult	Tunnel I (lower)	-54.82	-68.15	7500-4900 BP
31,236	20.0	-12.6	3.2	Aa	M	adult	Tunnel I (lower)	-54.82	-68.15	7500-4900 BP
33,781	18.8	-11.9	3.2	Aa	M	adult	Tunnel I (lower)	-54.82	-68.15	7500-4900 BP
31,820	17.9	-11.7	3.2	Aa	M	adult	Tunnel I (lower)	-54.82	-68.15	7500-4900 BP
34,152	17.7	-12.2	3.3	Aa	M	adult	Tunnel I (lower)	-54.82	-68.15	7500-4900 BP
30,166	19.2	-11.7	3.3	Aa	M	adult	Tunnel I (lower)	-54.82	-68.15	7500-4900 BP
32,308	18.1	-11.9	3.3	Aa	M	adult	Tunnel I (lower)	-54.82	-68.15	7500-4900 BP
33,624	19.0	-11.9	3.3	Aa	M	adult	Tunnel I (lower)	-54.82	-68.15	7500-4900 BP
30,634	18.9	-11.7	3.3	Aa	M	adult	Tunnel I (lower)	-54.82	-68.15	7500-4900 BP
33,775	16.2	-13.4	3.3	Aa	M	adult	Tunnel I (lower)	-54.82	-68.15	7500-4900 BP
32,124	18.1	-12.7	3.3	Aa	M	adult	Tunnel I (lower)	-54.82	-68.15	7500-4900 BP
33,835	19.1	-11.9	3.3	Aa	M	adult	Tunnel I (lower)	-54.82	-68.15	7500-4900 BP
30,697	19.4	-11.4	3.3	Aa	M	adult	Tunnel I (lower)	-54.82	-68.15	7500-4900 BP
32,461	19.1	-11.5	3.3	Aa	M	adult	Tunnel I (lower)	-54.82	-68.15	7500-4900 BP
31,837	18.8	-11.4	3.3	Aa	M	adult	Tunnel I (lower)	-54.82	-68.15	7500-4900 BP
33,490	18.3	-12.4	3.3	Aa	M	adult	Tunnel I (lower)	-54.82	-68.15	7500-4900 BP
33,777	16.3	-12.3	3.3	Aa	M	adult	Tunnel I (lower)	-54.82	-68.15	7500-4900 BP
31,923	17.5	-11.8	3.3	Aa	M	adult	Tunnel I (lower)	-54.82	-68.15	7500-4900 BP
31,792	19.2	-12.0	3.3	Aa	M	adult	Tunnel I (lower)	-54.82	-68.15	7500-4900 BP
32,245	18.9	-11.4	3.3	Aa	M	adult	Tunnel I (lower)	-54.82	-68.15	7500-4900 BP
32,351	18.0	-11.5	3.3	Aa	F	adult	Tunnel I (lower)	-54.82	-68.15	7500-4900 BP
31,872	19.2	-11.8	3.3	Aa	M	adult	Tunnel I (lower)	-54.82	-68.15	7500-4900 BP
33,050	18.3	-11.7	3.3	Aa	M	adult	Tunnel I (lower)	-54.82	-68.15	7500-4900 BP
31,107	17.4	-11.8	3.3	Aa	F	adult	Tunnel I (lower)	-54.82	-68.15	7500-4900 BP
30,472	17.6	-11.5	3.4	Aa	M	adult	Tunnel I (lower)	-54.82	-68.15	7500-4900 BP
30,139	18.7	-11.7	3.4	Aa	M	adult	Tunnel I (lower)	-54.82	-68.15	7500-4900 BP
30,169	18.7	-11.3	3.4	Aa	M	adult	Tunnel I (lower)	-54.82	-68.15	7500-4900 BP
33,422	17.8	-11.9	3.4	Aa	M	adult	Tunnel I (lower)	-54.82	-68.15	7500-4900 BP
34,220	19.0	-11.9	3.4	Aa	M	adult	Tunnel I (lower)	-54.82	-68.15	7500-4900 BP
32,813	18.0	-11.5	3.4	Aa	F	adult	Tunnel I (lower)	-54.82	-68.15	7500-4900 BP
32,946	18.7	-11.9	3.4	Aa	M	adult	Tunnel I (lower)	-54.82	-68.15	7500-4900 BP
32,495	18.5	-11.7	3.4	Aa	M	adult	Tunnel I (lower)	-54.82	-68.15	7500-4900 BP
31,578	18.1	-12.4	3.5	Aa	M	adult	Tunnel I (lower)	-54.82	-68.15	7500-4900 BP
32,385	18.3	-11.7	3.5	Aa	M	adult	Tunnel I (lower)	-54.82	-68.15	7500-4900 BP
32,288	18.2	-15.5	3.6	Aa	M	adult	Tunnel I (lower)	-54.82	-68.15	7500-4900 BP
32,288	17.7	-12.5	3.6	Aa	M	adult	Tunnel I (lower)	-54.82	-68.15	7500-4900 BP
33,936	18.3	-12.5	3.6	Aa	M	adult	Tunnel I (lower)	-54.82	-68.15	7500-4900 BP
33,045	17.0	-13.5	3.8	Aa	M	adult	Tunnel I (lower)	-54.82	-68.15	7500-4900 BP
33,936	17.3	-12.3	4.0	Aa	M	adult	Tunnel I (lower)	-54.82	-68.15	7500-4900 BP
34,495	19.1	-14.4	3.1	Aa	M	juvenile	Tunnel I (lower)	-54.82	-68.15	7500-4900 BP
34,614	17.6	-12.5	3.1	Aa	M	juvenile	Tunnel I (lower)	-54.82	-68.15	7500-4900 BP
32,040	17.5	-14.8	3.1	Aa	M	juvenile	Tunnel I (lower)	-54.82	-68.15	7500-4900 BP
33,786	16.7	-15.0	3.1	Aa	M	juvenile	Tunnel I (lower)	-54.82	-68.15	7500-4900 BP
34,434	18.7	-13.1	3.1	Aa	M	juvenile	Tunnel I (lower)	-54.82	-68.15	7500-4900 BP
32,846	18.5	-13.7	3.1	Aa	F	juvenile	Tunnel I (lower)	-54.82	-68.15	7500-4900 BP
32,075	17.2	-14.2	3.1	Aa	F	juvenile	Tunnel I (lower)	-54.82	-68.15	7500-4900 BP
30,765	20.2	-13.6	3.1	Aa	M	juvenile	Tunnel I (lower)	-54.82	-68.15	7500-4900 BP
34,509	19.4	-13.1	3.1	Aa	M	juvenile	Tunnel I (lower)	-54.82	-68.15	7500-4900 BP
34,392	17.5	-13.9	3.1	Aa	M	juvenile	Tunnel I (lower)	-54.82	-68.15	7500-4900 BP
33,795	18.3	-13.6	3.2	Aa	M	juvenile	Tunnel I (lower)	-54.82	-68.15	7500-4900 BP
33,745	17.2	-13.5	3.2	Aa	M	juvenile	Tunnel I (lower)	-54.82	-68.15	7500-4900 BP
34,041	18.5	-13.3	3.2	Aa	M	juvenile	Tunnel I (lower)	-54.82	-68.15	7500-4900 BP
34,080	18.2	-14.5	3.2	Aa	M	juvenile	Tunnel I (lower)	-54.82	-68.15	7500-4900 BP
33,629	19.1	-14.2	3.2	Aa	M	juvenile	Tunnel I (lower)	-54.82	-68.15	7500-4900 BP
33,518	18.4	-14.0	3.2	Aa	M	juvenile	Tunnel I (lower)	-54.82	-68.15	7500-4900 BP
33,565	18.2	-15.1	3.2	Aa	M	juvenile	Tunnel I (lower)	-54.82	-68.15	7500-4900 BP
34,038	18.5	-15.2	3.2	Aa	F	juvenile	Tunnel I (lower)	-54.82	-68.15	7500-4900 BP
31,379	17.9	-11.8	3.2	Aa	M	juvenile	Tunnel I (lower)	-54.82	-68.15	7500-4900 BP
33,155	18.7	-12.0	3.2	Aa	F	juvenile	Tunnel I (lower)	-54.82	-68.15	7500-4900 BP
32,359	17.2	-14.3	3.2	Aa	M	juvenile	Tunnel I (lower)	-54.82	-68.15	7500-4900 BP
33,785	16.1	-12.6	3.2	Aa	M	juvenile	Tunnel I (lower)	-54.82	-68.15	7500-4900 BP
30,794	17.7	-11.8	3.2	Aa	M	juvenile	Tunnel I (lower)	-54.82	-68.15	7500-4900 BP
33,160	16.9	-12.2	3.2	Aa	M	juvenile	Tunnel I (lower)	-54.82	-68.15	7500-4900 BP
34,747	18.4	-11.9	3.2	Aa	M	juvenile	Tunnel I (lower)	-54.82	-68.15	7500-4900 BP
33,522	18.6	-12.5	3.3	Aa	M	juvenile	Tunnel I (lower)	-54.82	-68.15	7500-4900 BP
31,865	18.1	-11.6	3.3	Aa	M	juvenile	Tunnel I (lower)	-54.82	-68.15	7500-4900 BP
34,525	18.2	-11.4	3.3	Aa	M	juvenile	Tunnel I (lower)	-54.82	-68.15	7500-4900 BP

(continued on next page)



Table A1 (continued)

Sample ID	$\delta^{15}\text{N}$ (‰)	$\delta^{13}\text{C}$ (‰)	C:N ratio	Species	Sex	Age Class	Site	Latitude (°S)	Longitude (°W)	Site age
33,392	19.0	-11.7	3.3	Aa	M	juvenile	Tunel I (lower)	-54.82	-68.15	7500-4900 BP
34,499	18.9	-11.9	3.3	Aa	M	juvenile	Tunel I (lower)	-54.82	-68.15	7500-4900 BP
33,719	17.9	-11.3	3.3	Aa	M	juvenile	Tunel I (lower)	-54.82	-68.15	7500-4900 BP
33,478	16.8	-13.3	3.3	Aa	F	juvenile	Tunel I (lower)	-54.82	-68.15	7500-4900 BP
33,172	17.8	-12.4	3.3	Aa	M	juvenile	Tunel I (lower)	-54.82	-68.15	7500-4900 BP
31,819	18.0	-12.1	3.4	Aa	M	juvenile	Tunel I (lower)	-54.82	-68.15	7500-4900 BP
33,311	16.8	-11.9	3.4	Aa	M	juvenile	Tunel I (lower)	-54.82	-68.15	7500-4900 BP
31,930	17.8	-15.4	3.4	Aa	M	juvenile	Tunel I (lower)	-54.82	-68.15	7500-4900 BP
34,302	17.6	-12.8	3.4	Aa	F	juvenile	Tunel I (lower)	-54.82	-68.15	7500-4900 BP
34,228	18.9	-12.1	3.5	Aa	M	juvenile	Tunel I (lower)	-54.82	-68.15	7500-4900 BP
33,553	18.9	-14.9	3.3	Aa	M	pup	Tunel I (lower)	-54.82	-68.15	7500-4900 BP
33,342	18.3	-11.5	3.3	Aa	M	pup	Tunel I (lower)	-54.82	-68.15	7500-4900 BP
33,547	18.8	-11.6	3.3	Aa	F	pup	Tunel I (lower)	-54.82	-68.15	7500-4900 BP
32,815	16.5	-12.5	3.4	Aa	M	pup	Tunel I (lower)	-54.82	-68.15	7500-4900 BP
32,462	18.6	-11.8	3.4	Aa	F	pup	Tunel I (lower)	-54.82	-68.15	7500-4900 BP
34,217	18.6	-14.0	3.1	Aa	M	sub-adult	Tunel I (lower)	-54.82	-68.15	7500-4900 BP
30,862	19.6	-12.2	3.1	Aa	M	sub-adult	Tunel I (lower)	-54.82	-68.15	7500-4900 BP
34,443	19.3	-13.8	3.1	Aa	M	sub-adult	Tunel I (lower)	-54.82	-68.15	7500-4900 BP
30,980	19.5	-14.0	3.1	Aa	M	sub-adult	Tunel I (lower)	-54.82	-68.15	7500-4900 BP
34,681	19.0	-13.5	3.1	Aa	M	sub-adult	Tunel I (lower)	-54.82	-68.15	7500-4900 BP
34,355	18.5	-13.3	3.1	Aa	M	sub-adult	Tunel I (lower)	-54.82	-68.15	7500-4900 BP
34,324	19.6	-12.5	3.1	Aa	M	sub-adult	Tunel I (lower)	-54.82	-68.15	7500-4900 BP
32,609	18.9	-11.3	3.2	Aa	M	sub-adult	Tunel I (lower)	-54.82	-68.15	7500-4900 BP
34,376	17.2	-12.2	3.2	Aa	M	sub-adult	Tunel I (lower)	-54.82	-68.15	7500-4900 BP
34,057	17.0	-14.7	3.2	Aa	M	sub-adult	Tunel I (lower)	-54.82	-68.15	7500-4900 BP
31,974	18.3	-12.8	3.2	Aa	M	sub-adult	Tunel I (lower)	-54.82	-68.15	7500-4900 BP
34,027	16.9	-14.8	3.2	Aa	M	sub-adult	Tunel I (lower)	-54.82	-68.15	7500-4900 BP
34,627	19.1	-14.2	3.2	Aa	M	sub-adult	Tunel I (lower)	-54.82	-68.15	7500-4900 BP
31,450	18.5	-13.3	3.2	Aa	M	sub-adult	Tunel I (lower)	-54.82	-68.15	7500-4900 BP
31,851	18.4	-12.8	3.2	Aa	M	sub-adult	Tunel I (lower)	-54.82	-68.15	7500-4900 BP
34,672	19.3	-11.5	3.2	Aa	M	sub-adult	Tunel I (lower)	-54.82	-68.15	7500-4900 BP
32,840	18.2	-13.2	3.2	Aa	M	sub-adult	Tunel I (lower)	-54.82	-68.15	7500-4900 BP
32,483	17.2	-12.2	3.2	Aa	M	sub-adult	Tunel I (lower)	-54.82	-68.15	7500-4900 BP
34,496	19.1	-11.0	3.2	Aa	M	sub-adult	Tunel I (lower)	-54.82	-68.15	7500-4900 BP
34,616	18.7	-11.8	3.2	Aa	M	sub-adult	Tunel I (lower)	-54.82	-68.15	7500-4900 BP
34,059	18.5	-14.6	3.2	Aa	M	sub-adult	Tunel I (lower)	-54.82	-68.15	7500-4900 BP
32,527	17.9	-13.0	3.3	Aa	M	sub-adult	Tunel I (lower)	-54.82	-68.15	7500-4900 BP
33,705	17.3	-11.5	3.3	Aa	M	sub-adult	Tunel I (lower)	-54.82	-68.15	7500-4900 BP
31,118	18.7	-11.6	3.3	Aa	M	sub-adult	Tunel I (lower)	-54.82	-68.15	7500-4900 BP
32,005	16.6	-12.8	3.3	Aa	M	sub-adult	Tunel I (lower)	-54.82	-68.15	7500-4900 BP
33,104	19.1	-12.0	3.3	Aa	M	sub-adult	Tunel I (lower)	-54.82	-68.15	7500-4900 BP
34,429	17.2	-12.6	3.3	Aa	M	sub-adult	Tunel I (lower)	-54.82	-68.15	7500-4900 BP
33,388	17.9	-12.7	3.3	Aa	M	sub-adult	Tunel I (lower)	-54.82	-68.15	7500-4900 BP
33,184	18.5	-12.0	3.3	Aa	M	sub-adult	Tunel I (lower)	-54.82	-68.15	7500-4900 BP
33,461	19.4	-11.4	3.3	Aa	M	sub-adult	Tunel I (lower)	-54.82	-68.15	7500-4900 BP
33,307	18.5	-11.5	3.3	Aa	F	sub-adult	Tunel I (lower)	-54.82	-68.15	7500-4900 BP
31,463	17.6	-12.6	3.3	Aa	M	sub-adult	Tunel I (lower)	-54.82	-68.15	7500-4900 BP
33,512	20.0	-11.5	3.3	Aa	M	sub-adult	Tunel I (lower)	-54.82	-68.15	7500-4900 BP
32,499	17.6	-11.9	3.4	Aa	F	sub-adult	Tunel I (lower)	-54.82	-68.15	7500-4900 BP
32,467	19.2	-12.5	3.4	Aa	M	sub-adult	Tunel I (lower)	-54.82	-68.15	7500-4900 BP
33,610	17.7	-11.7	3.4	Aa	M	sub-adult	Tunel I (lower)	-54.82	-68.15	7500-4900 BP
33,421	17.7	-12.0	3.5	Aa	M	sub-adult	Tunel I (lower)	-54.82	-68.15	7500-4900 BP
33,904	17.5	-12.2	3.6	Aa	M	sub-adult	Tunel I (lower)	-54.82	-68.15	7500-4900 BP
33,436	17.7	-12.3	3.6	Aa	M	sub-adult	Tunel I (lower)	-54.82	-68.15	7500-4900 BP
32,491	18.5	-13.6	3.8	Aa	M	sub-adult	Tunel I (lower)	-54.82	-68.15	7500-4900 BP
32,816	16.2	-12.0	3.9	Aa	F	sub-adult	Tunel I (lower)	-54.82	-68.15	7500-4900 BP
33,882	19.2	-11.8	3.2	Aa	M	NA	Tunel I (lower)	-54.82	-68.15	7500-4900 BP
33,461	18.7	-11.8	3.2	Aa	M	NA	Tunel I (lower)	-54.82	-68.15	7500-4900 BP
33,684	19.1	-11.8	3.2	Aa	NA	NA	Tunel I (lower)	-54.82	-68.15	7500-4900 BP
32,424	18.0	-11.7	3.3	Aa	M	NA	Tunel I (lower)	-54.82	-68.15	7500-4900 BP
33,175	17.9	-11.9	3.3	Aa	M	NA	Tunel I (lower)	-54.82	-68.15	7500-4900 BP
33,652	18.6	-12.4	3.3	Aa	M	NA	Tunel I (lower)	-54.82	-68.15	7500-4900 BP
33,378	18.3	-11.8	3.3	Aa	M	NA	Tunel I (lower)	-54.82	-68.15	7500-4900 BP
32,382	18.4	-11.6	3.3	Aa	M	NA	Tunel I (lower)	-54.82	-68.15	7500-4900 BP
32,442	18.0	-12.6	3.3	Aa	F	NA	Tunel I (lower)	-54.82	-68.15	7500-4900 BP
33,632	19.3	-11.3	3.4	Aa	M	NA	Tunel I (lower)	-54.82	-68.15	7500-4900 BP
32,430	18.7	-12.2	3.4	Aa	M	NA	Tunel I (lower)	-54.82	-68.15	7500-4900 BP
32,350	17.6	-12.2	3.4	Aa	M	NA	Tunel I (lower)	-54.82	-68.15	7500-4900 BP
32,255	18.4	-12.1	3.4	Aa	M	NA	Tunel I (lower)	-54.82	-68.15	7500-4900 BP
XX287	16.2	-12.8	3.5	Aa	M	NA	Tunel I (lower)	-54.82	-68.15	7500-4900 BP
33,666	17.6	-11.9	3.6	Aa	M	NA	Tunel I (lower)	-54.82	-68.15	7500-4900 BP
33,666	17.9	-12.2	3.7	Aa	M	NA	Tunel I (lower)	-54.82	-68.15	7500-4900 BP
30,422	17.7	-11.6	3.3	NA	NA	NA	Tunel I (lower)	-54.82	-68.15	7500-4900 BP
34,437	17.1	-13.3	3.3	NA	NA	NA	Tunel I (lower)	-54.82	-68.15	7500-4900 BP

(continued on next page)

Table A1 (continued)

Sample ID	$\delta^{15}\text{N}$ (‰)	$\delta^{13}\text{C}$ (‰)	C:N ratio	Species	Sex	Age Class	Site	Latitude (°S)	Longitude (°W)	Site age
32,816	15.4	-14.5	3.3	NA	NA	NA	Tunel I (lower)	-54.82	-68.15	7500–4900 BP
33,571	18.5	-11.2	3.4	NA	NA	NA	Tunel I (lower)	-54.82	-68.15	7500–4900 BP
34,544	18.2	-11.5	3.4	NA	NA	NA	Tunel I (lower)	-54.82	-68.15	7500–4900 BP
34,751	18.6	-11.2	3.2	Of	NA	NA	Tunel I (lower)	-54.82	-68.15	7500–4900 BP
33,551	18.8	-11.1	3.2	Of	NA	NA	Tunel I (lower)	-54.82	-68.15	7500–4900 BP
30,459	19.6	-10.4	3.2	Of	NA	NA	Tunel I (lower)	-54.82	-68.15	7500–4900 BP
33,458	18.2	-11.8	3.3	Of	NA	NA	Tunel I (lower)	-54.82	-68.15	7500–4900 BP
33,459	19.1	-11.0	3.3	Of	NA	NA	Tunel I (lower)	-54.82	-68.15	7500–4900 BP
34,227	17.7	-12.3	3.5	Of	NA	NA	Tunel I (lower)	-54.82	-68.15	7500–4900 BP
33,717	18.4	-10.8	3.5	Of	NA	NA	Tunel I (lower)	-54.82	-68.15	7500–4900 BP

Table A2

Average stable isotope ratios of nitrogen and carbon of *A. australis* organized by archaeological site.

Site	Cal years BP (approximate ranges)	$\delta^{15}\text{N}$ (‰)			$\delta^{13}\text{C}$ (‰)			C:N ratio		n
		Mean	SD	Range	Mean	SD	Range	SD		
Tunel I 2nd Component	7500–4900	18.2	0.8	4.3	-12.6	1.1	4.5	3.3	0.2	164
Bahia Valentin	5700–4800	20.2			-13.0			3.5		1
Bahia Crossley	3000–1300	18.1	2.6	5.6	-11.9	1.0	2.3	3.6	0.2	4
Tunel I C1	2200–1600	17.5	1.0	4.0	-12.0	0.5	1.4	3.2	0.1	18
Shamakush	1100–1000	17.7	1.6	3.6	-13.4	0.8	1.4	3.3	0.1	4
Kaiawoteha	690–560	16.7	0.7	2.2	-12.1	0.9	2.5	3.5	0.2	6
Peninsula Mitre	Post-industrial (not dated)	16.1	3.8	8.5	-15.3	3.0	6.6	3.2	0.1	4

Table A3

Average stable isotope ratios of nitrogen and carbon of *O. flavescens* organized by archaeological site.

Site	Cal years BP (approximate ranges)	$\delta^{15}\text{N}$ (‰)			$\delta^{13}\text{C}$ (‰)			C:N ratio		n
		Mean	SD	Range	Mean	SD	Range	SD		
Tunel I 2nd Component	7500–4900	18.6	0.6	1.8	-11.2	0.6	2.0	3.3	0.1	7
Bahia Valentin	5700–4800	21.1	1.0	1.9	-12.8	1.1	2.0	3.7	0.1	3
Bahia Crossley	3000–1300	19.1	0.8	1.2	-11.2	0.9	1.3	3.6	0.1	2
Tunel I C1	2200–1600	16.5			-13.5			3.9		1
Kaiawoteha	690–560	16.7	0.0	0.0	-11.6	0.2	0.0	3.5	0.0	2
Heshkaia	660–550	17.5	1.9	2.7	-14.3	0.6	0.8	3.3	0.0	2
Tres Amigos	Prehistoric (not dated)	16.1	8.9	12.7	-16.3	5.8	8.2	3.2	0.1	2
Bahia Thetis	120–70	17.7	1.6	8.7	-13.7	1.2	6.2	3.5	0.3	90
Peninsula Mitre	Post-industrial (not dated)	18.3	3.0	13.1	-13.6	2.4	10.5	3.4	0.2	16

Table A4

Average stable isotope ratios of nitrogen and carbon of unknown otariids organized by archaeological site.

Site	Cal years BP (approximate ranges)	$\delta^{15}\text{N}$ (‰)			$\delta^{13}\text{C}$ (‰)			C:N ratio		n
		Mean	SD	Range	Mean	SD	Range	SD		
Tunel I 2nd component	7500–4900	17.4	1.3	3.2	-12.4	1.4	3.3	3.3	0.1	5
Ajej	1400–800	16.3	0.7	0.7	-12.5	0.5	0.5	3.5	0.2	7
Kaiawoteha	690–560	16.0	0.7	1.0	-12.1	0.3	0.4	3.7	0.1	2
Heshkaia	660–550	18.1	0.9	1.3	-14.3	0.6	0.9	3.3	0.0	2
Tres Amigos	Prehistoric (not dated)	14.1	5.9	12.2	-16.0	3.2	6.8	3.2	0.2	4
Thetis Bluff	Historic (not dated)	19.3	0.9	1.7	-12.5	0.5	0.8	3.2	0.1	3
Bahia Thetis	120–70	17.6			-14.8			3.9		1

## References

- Ambrose, S.H., 1990. Preparation and characterization of bone and tooth collagen for isotopic analysis. *J. Archaeol. Sci.* 17, 431–451.
- Barnosky, A.D., Hadly, E.a., Bascompte, J., Berlow, E.L., Brown, J.H., Fortelius, M., Getz, W.M., Harte, J., Hastings, A., Marquet, P.a., Martinez, N.D., Mooers, A., Roopnarine, P., Vermeij, G., Williams, J.W., Gillespie, R., Kitzes, J., Marshall, C., Matzke, N., Mindell, D.P., Revilla, E., Smith, A.B., 2012. Approaching a state shift in Earth's biosphere. *Nature* 486, 52–58. <https://doi.org/10.1038/nature11018>.
- Bas, M., Briz i Godino, I., Álvarez, M., Vales, D.G., Crespo, E.A., Cardona, L., 2018. Back to the future? Late Holocene marine food web structure in a warm climatic phase as a predictor of trophodynamics in a warmer South-Western Atlantic Ocean. *Glob. Chang. Biol.* <https://doi.org/10.1111/gcb.14523>.
- Bastida, R., Rodríguez, D., 2003. *Mamíferos marinos de Patagonia y Antártida*.
- Bastos, R.F., Corrêa, F., Winemiller, K.O., Garcia, A.M., 2017. Are you what you eat? Effects of trophic discrimination factors on estimates of food assimilation and trophic position with a new estimation method. *Ecol. Indic.* 75, 234–241. <https://doi.org/10.1016/j.ecolind.2017.05.011>.

- 1016/j.ecolind.2016.12.007.
- Baylis, A.M.M., Tierney, M., Orben, R.A., Staniland, I.J., Brickle, P., 2018. Geographic variation in the foraging behaviour of South American fur seals. *Mar. Ecol. Prog. Ser.* 596, 233–245.
- Boecklen, W.J., Yarnes, C.T., Cook, B.A., James, A.C., 2011. On the use of stable isotopes in trophic ecology. *Annu. Rev. Ecol. Evol. Syst.* 42, 411–440. <https://doi.org/10.1146/annurev-ecolsys-102209-144726>.
- Borrero, L.A., 2010. Historia Evolutiva y Subsistencia de Cazadores-Recolectores Marítimos de Tierra del Fuego. *J. Island Coast. Archaeol.* 5, 296–298. <https://doi.org/10.1080/15564894.2010.496303>.
- Campagna, C., Werner, R., Karesch, W., Marín, M.R., Koontz, F., Cook, R., Koontz, C., 2001. Movements and location at sea of South American sea lions (*Otaria flavescens*). *J. Zool.* 255, 205–220. <https://doi.org/10.1017/S0952836901001285>.
- Cane, K.N., Arnould, J.P.Y., Nicholas, K.R., 2005. Characterisation of proteins in the milk of fur seals. *Comp. Biochem. Physiol. B Biochem. Mol. Biol.* 141, 111–120. <https://doi.org/10.1016/j.cbpc.2005.02.003>.
- Caniupán, M., Lamy, F., Lange, C.B., Kaiser, J., Kilian, R., Arz, H.W., León, T., Mollenhauer, G., Sandoval, S., De Pol-Holz, R., Pantoja, S., Wellner, J., Tiedemann, R., 2014. Holocene Sea-surface temperature variability in the Chilean fjord region. *Q. Res. U. S.* 82, 342–353. <https://doi.org/10.1016/j.yqres.2014.07.009>.
- Cárdenas-Alayza, S., Crespo, E., Oliveira, L.R., 2017. *Otaria byronia*. In: The IUCN Red List of Threatened Species 2016 8235.
- Carrara, I., 1952. Lobos marinos, pingüinos y guaneras de la costa del litoral marítimo e islotes adyacentes de la República de la Argentina. 16 p. Ministerio de Educación Nacional de la Plata. Facultad de Ciencias Veterinarias (Publicación Especial) Enero.
- Casey, M.M., Post, D.M., 2011. The problem of isotopic baseline: reconstructing the diet and trophic position of fossil animals. *Earth Sci. Rev.* <https://doi.org/10.1016/j.earscirev.2011.02.001>.
- Casper, R.M., Gales, N.J., Hindell, M.A., Robinson, S.M., 2006. Diet estimation based on an integrated mixed prey feeding experiment using *Arctocephalus* seals. *J. Exp. Mar. Biol. Ecol.* 328, 228–239. <https://doi.org/10.1016/j.jembe.2005.07.009>.
- Core Team, R., 2018. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria.
- Crespo, E.A., Pedraza, S.N., 2000. Food Habits of the South American Sea Lion, *Otaria flavescens*, off Patagonia, Argentina.
- De Carvalho, M.S., Rossi-santos, M.R., Santos-neto, E., Baracho, C.G., 2018. Advances in Marine Vertebrate Research in Latin America. Vol. 22. pp. 197–220. <https://doi.org/10.1007/978-3-319-56985-7>.
- de Lima, R.C., Franco-Trecu, V., Vales, D.G., Inchausti, P., Secchi, E.R., Botta, S., 2019. Individual foraging specialization and sexual niche segregation in south American fur seals. *Mar. Biol.* 166, 1–12. <https://doi.org/10.1007/s00227-019-3480-x>.
- Doi, H., Hillebrand, H., 2019. Historical contingency and productivity effects on food-chain length. *Commun. Biol.* 2, 40. <https://doi.org/10.1038/s42003-019-0287-8>.
- Drago, M., Cardona, L., Crespo, E.A., Aguilar, A., 2009. Ontogenetic dietary changes in South American sea lions. *J. Zool.* 279, 251–261. <https://doi.org/10.1111/j.1469-7998.2009.00613.x>.
- Drago, M., Cardona, L., Franco-Trecu, V., Crespo, E.A., Vales, D.G., Borella, F., Zenteno, L., Gonzáles, E.M., Inchausti, P., 2017. Isotopic niche partitioning between two apex predators over time. *J. Anim. Ecol.* 86, 766–780. <https://doi.org/10.1111/1365-2656.12666>.
- Fernandes, R., Millard, A.R., Brabec, M., Nadeau, M.J., Grootes, P., 2014. Food reconstruction using isotopic transferred signals (FRUITS): a bayesian model for diet reconstruction. *PLoS One* 9. <https://doi.org/10.1371/journal.pone.0087436>.
- Fernández, M., Ponce, J.F., Zangrando, F.J., Borromei, A.M., Musotto, L.L., Alunni, D., Vázquez, M., 2018. Relationships between terrestrial animal exploitation, marine hunter-gatherers and palaeoenvironmental conditions during the Middle-Late Holocene in the Beagle Channel region (Tierra del Fuego). *Quat. Int.* <https://doi.org/10.1016/j.quaint.2018.05.032>.
- Franco-Trecu, V., Auriolos-Gamboá, D., Inchausti, P., 2014. Individual trophic specialization and niche segregation explain the contrasting population trends of two sympatric otariids. *Mar. Biol.* 161, 609–618. <https://doi.org/10.1007/s00227-013-2363-9>.
- Friedlander, A.M., Ballesteros, E., Bell, T.W., Giddens, J., Henning, B., Hüne, M., Muñoz, A., Salinas-de-León, P., Sala, E., 2018. Marine biodiversity at the end of the world: Cape Horn and Diego Ramírez islands. *PLoS One* 13, e0189930.
- Garzón, J.E.C., Martínez, A.M., Barrera, F., Pfaff, F., Koch, B.P., Freije, R.H., Gómez, E.A., Lara, R.J., 2016. The Pacific-Atlantic connection: biogeochemical signals in the southern end of the Argentine shelf. *J. Mar. Syst.* 163, 95–101. <https://doi.org/10.1016/j.jmarsys.2016.07.008>.
- Grandi, M.F., Dans, S.L., Crespo, E.A., 2015. The recovery process of a population is not always the same: the case of *Otaria flavescens*. *Mar. Biol. Res.* 11, 225–235. <https://doi.org/10.1080/17451000.2014.932912>.
- Heusser, C., 1989. Late Quaternary vegetation and climate of southern Tierra del Fuego. *Quat. Res.* 31, 396–406.
- Heusser, C.J., 1998. Deglacial palaeoclimate of the American sector of the Southern Ocean: Late Glacial-Holocene records from the latitude of Canal Beagle (55°S), Argentine Tierra del Fuego. *Palaeogeogr. Palaeoclimatol. Palaeoecol.* 141, 277–301. [https://doi.org/10.1016/S0031-0182\(98\)00053-4](https://doi.org/10.1016/S0031-0182(98)00053-4).
- Horwitz, V.D., 1993. Maritime settlement patterns: the case from Isla de los Estados (Staten Island). In: *Explotación de Recursos Faunísticos en sistemas Adaptativos Americanos, Arqueología Contemporánea* Buenos Aires. Vol. 4. pp. 149–161.
- Hunt, G.L., Drinkwater, K.F., Arrigo, K., Berge, J., Daly, K.L., Danielson, S., Daase, M., Hop, H., Isla, E., Karnovsky, N., Laidre, K., Mueter, F.J., Murphy, E.J., Renaud, P.E., Smith, W.O., Trathan, P., Turner, J., Wolf-Gladrow, D., 2016. Advection in polar and sub-polar environments: impacts on high latitude marine ecosystems. *Prog. Oceanogr.* 149, 40–81. <https://doi.org/10.1016/j.poccean.2016.10.004>.
- Jackson, A.L., Inger, R., Parnell, A.C., Bearhop, S., 2011. Comparing isotopic niche widths among and within communities: SIBER – Stable Isotope Bayesian Ellipses in R. *J. Anim. Ecol.* 80, 595–602. <https://doi.org/10.1111/j.1365-2656.2011.01806.x>.
- Jarić, I., Knežević-Jarić, J., Gessner, J., 2015. Global effort allocation in marine mammal research indicates geographical, taxonomic and extinction risk-related biases. *Mammal Rev.* 45, 54–62. <https://doi.org/10.1111/mam.12032>.
- Koch, P.L., Hall, B.L., de Bruyn, M., Hoelzel, A.R., Baroni, C., Salvatore, M.C., 2019. Mummified and skeletal southern elephant seals (*Mirounga leonina*) from the Victoria Land Coast, Ross Sea, Antarctica. *Mar. Mamm. Sci.* 1–23. <https://doi.org/10.1111/mms.12581>.
- Kovacs, K.M., Aguilar, A., Auriolos, D., Burkanov, V., Campagna, C., Gales, N., Gelatt, T., Goldsworthy, S.D., Goodman, S.J., Hofmeyr, G.J.G., Härkönen, T., Lowry, L., Lydersen, C., Schipper, J., Sipilä, T., Southwell, C., Stuart, S., Thompson, D., Trillmich, F., 2012. Global threats to pinnipeds. *Mar. Mamm. Sci.* 28, 414–436. <https://doi.org/10.1111/j.1748-7692.2011.00479.x>.
- Lothrop, S.K., 1928. The Indians of Tierra del Fuego. *Ams Press Inc.*
- Martinoli, M.P., 2015. Procesamiento y consumo de pinnípedos: el caso de las ocupaciones canoeras tempranas del sitio Imiwaia I (Tierra del Fuego, República Argentina). *Intersec. Antropol.* 16, 367–381.
- Martinoli, M., 2018. Modalidades de explotación, procesamiento y consumo de pinnípedos en la margen meridional de Tierra del Fuego.
- Martinoli, M.P., Vázquez, M., 2017. In: Mondini, M., Muñoz, A.S., Fernández, P.M. (Eds.), *Pinniped Capture and Processing: A Comparative Analysis from Beagle Channel (Tierra del Fuego, Argentina) BT - Zooarchaeology in the Neotropics: Environmental Diversity and Human-Animal Interactions*. Springer International Publishing, Cham, pp. 7–23. [https://doi.org/10.1007/978-3-319-57328-1\\_2](https://doi.org/10.1007/978-3-319-57328-1_2).
- Newsome, S.D., Clementz, M.T., Koch, P.L., 2010. Using stable isotope biogeochemistry to study marine mammal ecology. *Mar. Mammal Sci.* 26, 509–572.
- Nielsen, J.M., Clare, E.L., Hayden, B., Brett, M.T., Kratina, P., 2018. Diet tracing in ecology: method comparison and selection. *Methods Ecol. Evol.* 9, 278–291. <https://doi.org/10.1111/2041-210X.12869>.
- Nye, J.W., Zangrando, A.F.J., Martinoli, M.P., Vázquez, M.M., Fogel, M.L., 2018. Cumulative human impacts on pinnipeds over the last 7,500 years in Southern South America. *SA Archaeol. Rec.* 47.
- Orquera, L.A., Piana, E.L., 1996. El sitio Shamakush 1 (Tierra del Fuego, República Argentina). *Relac. Soc. Argent. Antropol.* 21.
- Orquera, L.A., Piana, E.L., 1999. Arqueología de la región del canal beagle.
- Orquera, L.A., Piana, E.L., 2009. Sea nomads of the beagle channel in southernmost South America: over six thousand years of coastal adaptation and stability. *J. Island Coast. Archaeol.* 4, 61–81. <https://doi.org/10.1080/15564890902789882>.
- Orquera, L.A., Legoupil, D., Piana, E.L., 2011. Littoral adaptation at the southern end of South America. *Quat. Int.* 239, 61–69. <https://doi.org/10.1016/j.quaint.2011.02.032>.
- Piana, E.L., Vázquez, M., Cerraso, A., 2007. Kaiyawoteha. In: Informe de excavación. Informe Técnico para la Dirección de Ciencia y Tecnología de Tierra del Fuego, Ushuaia.
- Piana, E.L., Vázquez, M., Álvarez, M., 2008. Nuevos resultados del estudio del sitio Alej I: UN aporte a la variabilidad de estrategias de los canoeros fueguinos. *Runa Arch. Para Cienc. Hombre* 29, 101–122.
- Prevosti, F.J., Forasiepi, A.M., 2018. Evolution and biological context of South American mammalian carnivores during the cenozoic and the biological context. In: Prevosti, F.J., Forasiepi, A.M. (Eds.), *Springer Geology*. Springer International Publishing, Cham, pp. 155–196. [https://doi.org/10.1007/978-3-319-03701-1\\_6](https://doi.org/10.1007/978-3-319-03701-1_6).
- Ricciardelli, L., Newsome, S.D., Fogel, M.L., Fernández, D.A., 2017. Trophic interactions and food web structure of a subantarctic marine food web in the Beagle Channel: Bahía Lapataia, Argentina. *Polar Biol.* 40, 807–821. <https://doi.org/10.1007/s00300-016-2007-x>.
- Riet-Sapirza, F.G., Costa, D.P., Franco-Trecu, V., Marín, Y., Chocca, J., González, B., Beathgate, G., Louise Chilvers, B., Hückstadt, L.A., 2013. Foraging behavior of lactating South American sea lions (*Otaria flavescens*) and spatial-temporal resource overlap with the Uruguayan fisheries. *Deep-Sea Res. II Top. Stud. Oceanogr.* 88–89, 106–119. <https://doi.org/10.1016/j.dsr2.2012.09.005>.
- Romero, M.A., Grandi, M.F., Koen-Alonso, M., Svendsen, G., Ocampo Reinaldo, M., García, N.A., Dans, S.L., González, R., Crespo, E.A., 2017. Analysing the natural population growth of a large marine mammal after a depletive harvest. *Sci. Rep.* 7, 1–16. <https://doi.org/10.1038/s41598-017-05577-6>.
- Romiguier, J., Gayral, P., Ballenghien, M., Bernard, A., Cahais, V., Chenail, A., Chiari, Y., Dernet, R., Duret, L., Faivre, N., Loire, E., Lourenco, J.M., Nabholz, B., Roux, C., Tsagkogeorga, G., Weber, A.A.-T., Weinert, L.A., Belkhir, K., Bierne, N., Glemis, S., Galtier, N., 2014. Comparative population genomics in animals uncovers the determinants of genetic diversity. *Nature* 515, 261–263.
- Saporiti, F., Bala, L.O., Crespo, E.A., Gómez Otero, J., Zangrando, A.F.J., Aguilar, A., Cardona, L., 2013. Changing patterns of marine resource exploitation by hunter-gatherers throughout the late Holocene of Argentina are uncorrelated to sea surface temperature. *Quat. Int.* 299, 108–115. <https://doi.org/10.1016/j.quaint.2013.03.026>.
- Saporiti, F., Bala, L.O., Otero, J.G., Crespo, E.A., Piana, E.L., Aguilar, A., Cardona, L., 2014. Paleoindian pinniped exploitation in South America was driven by oceanic productivity. *Quat. Int.* 352, 85–91. <https://doi.org/10.1016/j.quaint.2014.05.015>.
- Schiavini, A., 1993. Los lobos marinos como recurso para cazadores-recolectores marinos: El caso de tierra del Fuego. *Lat. Am. Antiq.* 4, 346–366.
- Schlacher, T.a., Connolly, R.M., 2014. Effects of acid treatment on carbon and nitrogen stable isotope ratios in ecological samples: a review and synthesis. *Methods Ecol. Evol.* 5, 541–550. <https://doi.org/10.1111/2041-210X.12183>.
- Sealy, J., Johnson, M., Richards, M., Nehlich, O., 2014. Comparison of two methods of extracting bone collagen for stable carbon and nitrogen isotope analysis: comparing

- whole bone demineralization with gelatinization and ultrafiltration. *J. Archaeol. Sci.* 47, 64–69. <https://doi.org/10.1016/j.jas.2014.04.011>.
- Siielefeld, W., Venegas, C., Atalah, A., Torres, J., 1978. Prospección de otáridos en las costas de Magallanes. *Anales del instituto de la Patagonia*.
- Tafari, M.A., Zangrando, A.F.J., Tessone, A., Kochi, S., Moggi Cecchi, J., Di Vincenzo, F., Profico, A., Manzi, G., 2017. Dietary resilience among hunter-gatherers of Tierra del Fuego: Isotopic evidence in a diachronic perspective. *PLoS One* 12, e0175594.
- Tivoli, A.M., Zangrando, A.F., 2011. Subsistence variations and landscape use among maritime hunter-gatherers. A zooarchaeological analysis from the Beagle Channel (Tierra del Fuego, Argentina). *J. Archaeol. Sci.* 38, 1148–1156. <https://doi.org/10.1016/j.jas.2010.12.018>.
- Vales, D., Cardona, L., García, N., Zenteno, L., Crespo, E., 2015. Ontogenetic dietary changes in male south American fur seals *Arctocephalus australis* in Patagonia. *Mar. Ecol. Prog. Ser.* 525, 245–260. <https://doi.org/10.3354/meps11214>.
- Vales, D.G., Cardona, L., Zangrando, A.F., Borella, F., Saporiti, F., Goodall, R.N.P., de Oliveira, L.R., Crespo, E.A., 2016. Holocene changes in the trophic ecology of an apex marine predator in the South Atlantic Ocean. *Oecologia*. <https://doi.org/10.1007/s00442-016-3781-4>.
- van Klinken, G.J., 1999. Bone collagen quality indicators for palaeodietary and radiocarbon measurements. *J. Archaeol. Sci.* 26, 687–695. <https://doi.org/10.1006/jasc.1998.0385>.
- Vaz-Ferreira, R., 1978. South American sea lion. *Mamm. Seas Rep.* 1, 9.
- Vázquez, M., 2019. Distribución del registro arqueológico en la costa norte de Península Mitre, Tierra del Fuego. In: Otero, J.G., Svoboda, A., Banegas, A. (Eds.), *Arqueología de La Patagonia: El Pasado En Las Arenas*. CONICET-IDEAus, Puerto Madryn, Argentina, pp. 181–192.
- Young, H.S., Mccauley, D.J., Dunbar, R.B., Hutson, M.S., Ter-Kuile, A.M., Dirzo, R., 2013. The roles of productivity and ecosystem size in determining food chain length in tropical terrestrial ecosystems. *Ecology* 94, 692–701. <https://doi.org/10.1890/12-0729.1>.
- Zangrando, A.F., 2009. Historia evolutiva y subsistencia de cazadores-recolectores marítimos de Tierra del Fuego. *Sociedad Argentina de Antropología*.
- Zangrando, A.F., 2010. Coastal archaeology and hunter-gatherers in southeastern Tierra del Fuego. *J. Island Coas. Archaeol.* 5, 288–291.
- Zangrando, A.F., Panarello, H., Piana, E.L., 2014. Zooarchaeological and stable isotopic assessments on pinniped-human relations in the Beagle Channel (Tierra del Fuego, southern South America). *Int. J. Osteoarchaeol.* 24, 231–244. <https://doi.org/10.1002/oa.2352>.
- Zangrando, A.F.J., Ponce, J.F., Martinoli, M.P., Montes, A., Piana, E., Vanella, F., 2016. Palaeogeographic changes drove prehistoric fishing practices in the Cambaceres Bay (Tierra del Fuego, Argentina) during the middle and late Holocene. *Environ. Archaeol.* 4103 <https://doi.org/10.1080/14614103.2015.1130888>.
- Zangrando, A.F., Bjerck, H.B., Piana, E.L., Breivik, H.M., Tivoli, A.M., Negre, J., 2018. Spatial patterning and occupation dynamics during the Early Holocene in an archaeological site from the south coast of Tierra del Fuego: Binushmuka I. *estudios atacameños*.
- Zenteno, L., Borella, F., Otero, J.G., Piana, E., Belardi, J.B., Borrero, L.A., Saporiti, F., Cardona, L., Crespo, E., 2015. Shifting niches of marine predators due to human exploitation: the diet of the South American sea lion (*Otaria flavescens*) since the late Holocene as a case study. *Paleobiology* 1–15. <https://doi.org/10.1017/pab.2015.9>.