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Sea Change?

New Directions in Marine Mammal Research

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On the cover: Marine mammals range in size from more than 30 meters to less than 1 meter, and encompass a large range of morphotypes, which complicates taxonomic identifications using anatomical methods. Figure created by Camilla Speller.

Cumulative Human Impacts on Pinnipeds Over the Last 7,500 Years in Southern South America

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At the southern tip of South America, pinnipeds have been a pivotal resource for human populations for the last 7,500[1] years. For the majority of this time, these marine mammals formed the basis of subsistence for maritime hunter-gatherers (Schiavini 1993), and their bones and hides were also sources of raw materials (Orquera and Piana 2009). Only with the arrival of European and American sealers in the eighteenth century was this relationship seriously affected. Although modern commercial sealing almost led to the extinction of several species of pinnipeds in the South Atlantic, the industrial exploitation of this resource continued in Argentina until it was prohibited in 1949.

Our research program on this topic combines zooarchaeological and stable isotope studies from a historical ecology perspective. We originated this approach, and developed new analytical techniques, to better link archaeological evidence with paleo-ecosystem reconstructions (Zangrando, Panarello et al. 2014). In order to assess the relationship between pinnipeds and hunter-gatherers in Tierra del Fuego, we developed zooarchaeological analyses based on predictions from foraging models. Since information about past abundance or distribution of prey is rare in the southern South Atlantic, zooarchaeological evaluations were based mainly on modern ecological parameters. Current foraging ecology of pinnipeds may be a useful framework for understanding archaeological evidence; however, that framework might present an incomplete picture of the actual range of behaviors and ecological roles that these resources could have provided for human populations in the past. In fact, the historical distribution of pinnipeds in Patagonia and Tierra del Fuego is poorly understood. Moreover, species distributions are likely to have fluctuated throughout time because of different environmental factors, or as a by-product of cumulative human impacts on marine ecosystems. Thus, the range of variation reflected in our knowledge about current pinniped distribution may not sufficiently represent the past. Against this context, an isotopic zooarchaeological approach provides a convenient route to expand our knowledge about human-pinniped relations at long-time scales (Zangrando, Panarello et al. 2014).

Human-Prey Tension during the Holocene

Two species of pinnipeds are abundant in the Fuegian Archipelago: the South American fur seal (*Arctocephalus australis*) and the southern sea lion (*Otaria flavescens*). However, the former dominates zooarchaeological assemblages of the southern coast of Tierra del Fuego (Figure 1), with the sole exception of the Bahía Crossley I site in Isla de los Estados where southern sea lions are more heavily represented (Martinoli 2018). The southern part of Tierra del Fuego was inhabited by two distinctive hunter-gatherer populations. Marine foragers inhabited the archipelago in more southern Tierra del Fuego, while terrestrial hunter-gatherers with high dependence upon coastal resources occupied Península Mitre. First studies on sex, age, and seasonality of death from pinniped remains in the middle Holocene (7,500–5,000

BP) deposits of the Túnel I site located in the Beagle Channel suggested that rookeries were not impacted by human hunting (Schiavini 1993). Marine hunter-gatherers focused on capturing males, concentrating their hunting between autumn and spring. According to current ecological information, mating and breeding take place during summer on outer coasts and islands of the archipelago, away from inner channels. This dynamic in human-prey relations could be used to assert that hunting activities in Beagle Channel did not produce an impact on the population structure of these pinniped resources and, therefore, on their abundance in the environment.

More recent studies based on zooarchaeological evaluations for the complete occupational sequence of the region, however, have shown long-term variation in the composition of faunal assemblages (Zangrando 2009a). Early occupations (ca. 7,500–5,000 BP) are characterized by high frequencies of pinnipeds and limited representation of other vertebrates (e.g., guanacos, birds, and fish), whereas a decrease in the relative importance of pinnipeds and a diversification in subsistence patterns occurred from 5,000 BP onwards, increasing the importance of other resources in zooarchaeological assemblages. This comprehensive human subsistence model raised the following question: If the natural stock of pinnipeds were not affected by hunting activities, why does the abundance of pinnipeds in archaeological settings decrease over time? Two hypothetical explanations were assessed: a) a reduction in resource availability due to increased human predation pressure; and b) variations in foraging habits of pinnipeds that would lead to changes in the degree of predictability or access to the resource. In order to assess these possible explanations, it was imperative to investigate the human-prey relation from a given set of ecological parameters and habitat configurations. Therefore, it was necessary to adopt both regional and supra-regional approaches in these assessments and to integrate zooarchaeological evidence from external coasts and offshore islands of the archipelago.

By expanding the chronological and spatial framework in the zooarchaeological analyses of pinnipeds, we observed more varied exploitation patterns towards the late Holocene in the Beagle Channel and different hunting strategies in the outer sectors of the archipelago (Martinoli 2018). Age categories are more diverse, and the representation of adult females increases after 5,000 BP. Both factors indicate a trend towards a reduction of prey sizes. In more external sectors of the archipelago, pups of both species of pinnipeds (*A. australis* and *O. flavescens*) are proportionally more represented throughout the entire archaeological sequence, suggesting that the breeding areas of pinnipeds were not beyond of the reach of

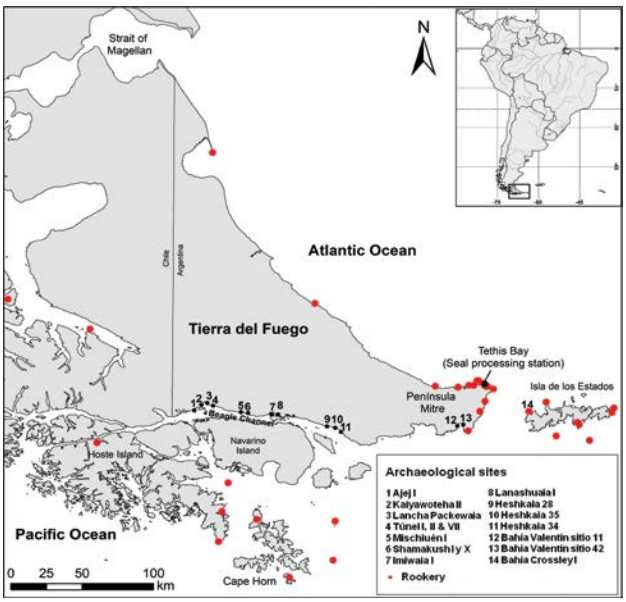

Figure 1. Southern tip of South America with geographical references mentioned in the text and locations of the studied archaeological sites and current rookeries.

hunter-gatherer groups after 5,700 BP. Hence, it is possible that the intensive use of coastal locations off the southeastern coast of Tierra del Fuego and Isla de los Estados, as a result of an overall increase of population density in the southeastern Fuegian archipelago during the late Holocene, might have led to increased human exploitation of pinnipeds. At the same time, hunting pressure generated by terrestrial hunter-gatherer groups from Península Mitre, whose populations neighbor the Beagle Channel, would have enhanced resource competition and affected the abundance of these marine mammals in the channel sectors (Martinoli 2018; Zangrando 2009b). Considering that human predation can depress pinniped metapopulations in several ways (Lyman 2003), the effects of resource depression in southern Tierra del Fuego are uncertain.

Historical Ecology and Stable Isotopes

The use of stable isotopes to qualitatively and quantitatively provide insights into past cultures and their resource use, particularly how humans have impacted landscapes, environments, and ecology, is well established (e.g., Zangrando, Tessone et al. 2014). Stable isotopic analyses of organic materials (e.g., collagen, keratin) are proxies for the general diets of individuals, whereas measurements of biominerals

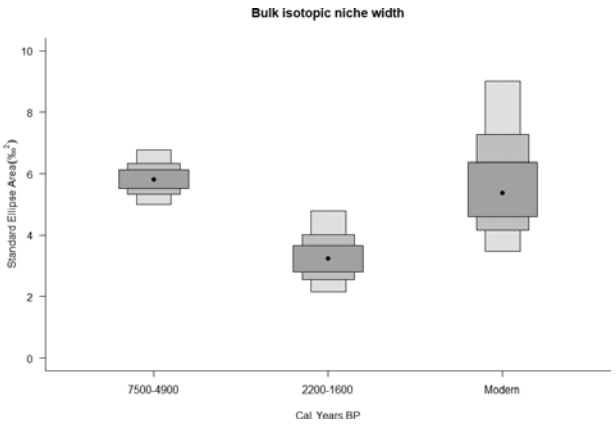

Figure 2. Bulk isotopic niche width between modern and prehistoric fur seals does not significantly differ over time. A Kruskal-Wallis comparison of Standard Ellipse Area using the SIBER model between bulk isotopic values of carbon and nitrogen suggests little temporal difference (SEAc p-value = 0.37; Jackson et al. 2011).

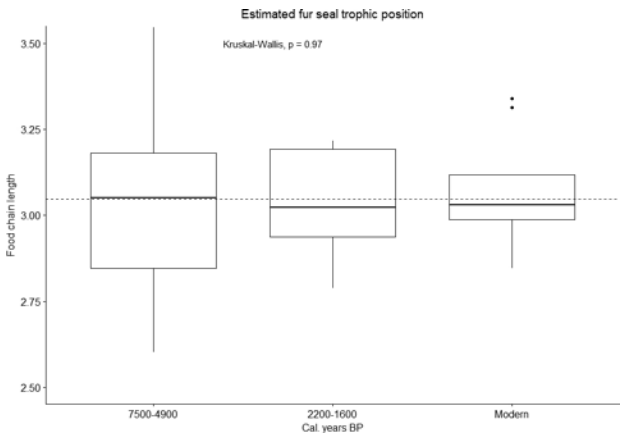

Figure 3. Trophic position of fur seals based on multi-trophic discrimination factor approach using δ^{15}NAAGlu-Phe (see McMahon and McCarthy 2016). Despite several thousand years of difference, there appears to be no change in trophic level between populations of prehistoric fur seals in the Beagle Channel.

in bones and teeth (i.e., apatite) reflect climate and environmental parameters. Collective measurements from past populations, both of humans and the organisms that they associated with, allude to networks of species interactions and relate to the ecological niche space occupied by them.

Isotopic analyses of bulk organic material for carbon and nitrogen isotopes from archaeological specimens are now commonplace (Vales et al. 2017; Zangrando, Panarello et al. 2014). Statistical modeling tools have been developed to better quantify the dietary inputs to the higher consumers. Several software packages and tools are particularly useful to archaeologists. Two of these Bayesian statistical tools are SIBER (Jackson et al. 2011) and FRUITS (Fernandes et al. 2014). Traditional food web models require the presence of all members of the food web to be valid, which can be a problem in archaeological sites in which not all members of the food web are represented or preserved. SIBER is pertinent owing to its ability to model food webs with dietary members missing, as it includes selectable parameters to correct omissions. The program FRUITS provides a relatively easy interface for researchers to quickly and easily model food webs and includes many options for customization to a particular set of samples. These techniques allowed us to infer that pinnipeds from southern and eastern Tierra del Fuego today occupy similar niches to those occupied prehistorically (Figure 2).

In certain situations, bulk isotopic analyses fall short in quantifying diets. In these cases, isotopic analyses of individual compounds, like amino acids from bone collagen, can be applied to individuals of interest at a finer scale, especially when there is reason to believe there may be changes in ecology or climate temporally or spatially (Webb et al. 2016). Compound specific analyses of amino acids in particular relate to the biochemical pathways of formation of proteins (Fogel and Tuross 2003), such as collagen, and have been used to identify relationships between consumers and producers in archaeological contexts. Determining trophic levels of higher organisms is now beginning to be quantified using nitrogen isotopes of two sets of amino acids: ones that retain their isotopic composition as they pass through the food chain (e.g., phenylalanine) and others (e.g., glutamic acid) that increase systematically in the heavier isotope (^{15}N) at each step in the food chain. Research to understand biochemical influences on compound specific nitrogen isotope patterns in marine mammals and fish is ongoing (McMahon and McCarthy 2016). In samples of pinnipeds (n = 378) from coastal Tierra del Fuego, we measured the nitrogen isotopes in collagen from individuals collected from 7,500 to 1,600 cal years BP. Our results showed that food chain length has not appreciably changed over this time interval (Figure 3).

Of particular interest to archaeologists may be the recent development of isotopic fingerprinting, a technique for matching the carbon isotopic composition of essential amino acids in high-trophic-level individuals with potential primary producers at the base of the food web (Larsen et al. 2013). Using Bayesian mixing models, differences in food webs, niche breadth, and ecology can be distinguished with only a

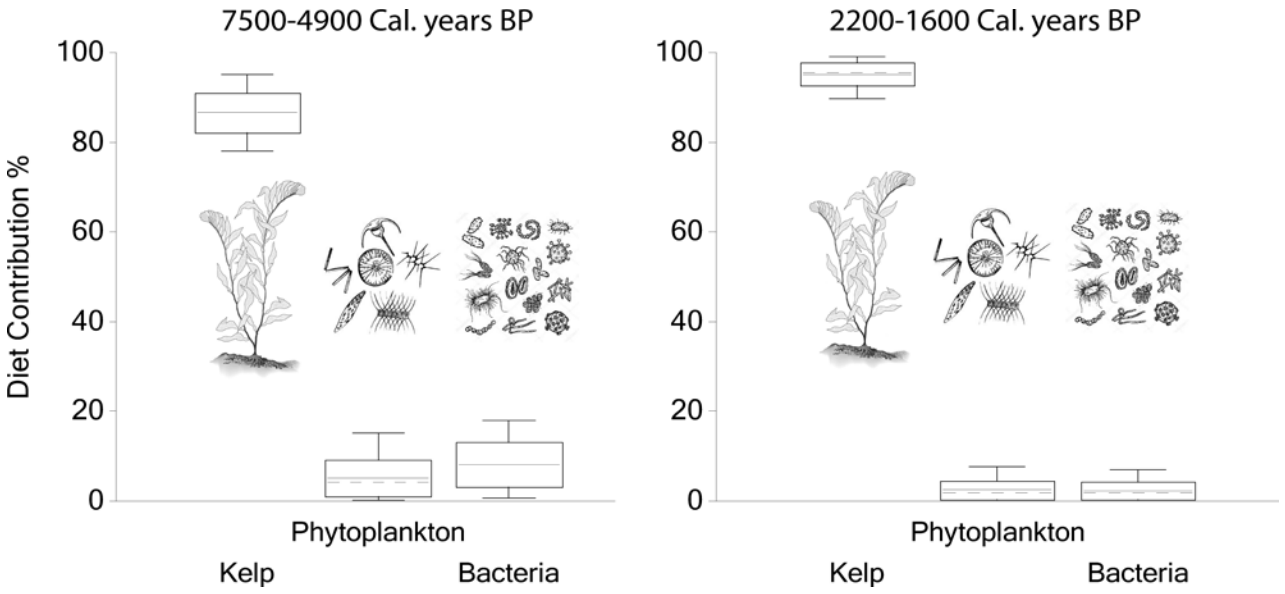

Figure 4. Estimated percentage of primary producer contributions to Beagle Channel fur seals using FRUITS mixing model from carbon essential amino acids (primary producer data from Larsen et al. 2013).

single sample. Using the FRUITS mixing model, we observe no statistical difference between the primary producers that support pinnipeds between the middle and late Holocene (Figure 4).

Best practices for identifying changes in food webs, trophic structure, and ultimately ecology in archaeological contexts rely on using multiple independent methods, such as a combination of bulk isotopic analyses, compound specific analyses of amino acids, and other methods such as ancient DNA or analysis of fatty acids, if available (Traugott et al. 2013). Ideally, a combination of these methods can be aligned to investigate whether changes in resource acquisition are associated with changes in environmental parameters, ecological dynamics, or perhaps human agency.

Human-Pinniped Relations during the Anthropocene

Industrial pinniped exploitation was introduced into southern South America by Europeans at the end of the eighteenth century and significantly changed the scale of pinniped exploitation, reducing their populations and habitat. Motivated by a growing demand for oil from sea mammal blubber, and the overexploitation of cetaceans and pinnipeds that occurred in the northern hemisphere, the sealing companies turned their attention to the South Atlantic (Caviglia 2012). Towards the beginning of the nineteenth century, intense sealing was carried out for decades in the Patagonian and Fuegian coasts resulting in a drastic reduction of the pinniped populations. The period of greatest activity of sealing in the southern South Atlantic was recorded between 1819 and 1831 with an impact normally assumed for the subsistence of the hunter-gatherer populations of the region (but see Tafuri et al. 2017).

More recently, in Argentine territory, several rookeries were exploited at a commercial scale (Baylis et al. 2015). During the first half of the twentieth century, the Argentine government regulated the industrial exploitation of sea lions (*O. flavescens*) by requiring government permission to hunt them (Figure 5). By the mid-1940s, three concessions were still operational in Tierra del Fuego, all of them on the coast of Península Mitre. By the end of this decade, massive pinniped population reductions were reported. Sealing was then prohibited throughout Argentine territory (Carrara 1952).

One of these seal processing stations was located in Thetis Bay, whose facilities are partially preserved. Zooarchaeological studies on pinniped bone accumulations in association with those facilities show that hunting focused on *O. flavescens* and impacted both males and females from pups to adults. A minimum number of 5,400 individuals were estimated from bone accumulations situated along 200 m of coastline (Vázquez and Santiago 2014).

Figure 5. Killing practices at the sealing station of Thetis Bay. Source: http://www.histarmar.com.ar

Conclusion: Cumulative Human Impacts on Pinnipeds

Archaeological and historical information indicates that human exploitation from both hunter-gatherer and industrial economies led to significant reduction of pinniped populations in the southern tip of South America. Stable isotope studies, however, show that this cumulative human impact did not necessarily imply a change of the isotopic niche width of these marine mammals over time.

Today, pinnipeds are fully protected under a number of laws and statutes, including international treaties such as CITES (Hutton and Dickson 2000). South American pinnipeds are considered species of least concern under the IUCN red list (IUCN 2018); however, pinnipeds off the coast of southern South America still face a number of threats. Rules and regulations are not always well enforced off these waters, as illegal fisheries operate nearby, and seals and sea lions may be affected by the actions of fishermen trying to catch organisms that are essential to pinniped diets. Understanding the nuances of past pinniped exploitation and its effect on variation in ecological parameters informs us that the long-term sustainability of pinnipeds in this region depends on careful management of marine resources. In this article, we illustrate how the construction of zooarchaeological and biomolecular datasets contribute century-to-millennial historical perspectives that can be actively incorporated into conservation biology agendas. Isotopic zooarchaeology has a unique opportunity to provide this framework. Biomolecular approaches to archaeological materials such as those shown here can be applied in many regional contexts, and can help us understand how ecosystems react to human influences.

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Notes

[1] Ages are expressed in calibrated years BP.