

INTEGRATED ARCHAEOZOOLOGICAL RESEARCH OF SHELL
MIDDENS: NEW INSIGHTS INTO HUNTER-GATHERER-FISHER
COASTAL EXPLOITATION IN TIERRA DEL FUEGO

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Abstract

Shells of *Nacella magellanica* are abundant in archaeological shell middens distributed along the Beagle Channel. In this study we analyze the oxygen isotopic composition of shells of this species to obtain information on its seasonal exploitation patterns by hunter-gatherer-fisher groups of this region during the 19th century, just before their near extermination by Euro-American settlers. Oxygen isotopic data from shells recovered from Lanashuaia and from some occupations of Túnel VII (both contact sites) indicate that *N. magellanica* was gathered in different seasons. Our data agree with fauna-derived seasonal reconstructions, and their combination provides more detailed economic scenarios. Comprehensive results confirm that in the 19th century, Yamana people constantly occupied the coast of the Beagle Channel by means of short-lived campsites.

Introduction

Archaeological evidence from Isla Grande de Tierra del Fuego (Argentina and Chile) provides exceptional examples of long-term hunter-gatherer-fisher adaptations to high latitude environmental conditions (e.g., Orquera et al. 2011; Orquera and Piana 2009).

This is particularly evident along the coast of the Beagle Channel. Hunter-gatherer groups have occupied the area since about 7.8 ka BP, but the earliest evidence of littoral societies occurs around 6.5 ka BP (Orquera and Piana 2009). The archaeological record suggests relative stability in the resources exploited in the area through the Holocene until the establishment of European and American settlements in the nineteenth century (Estévez and Vila 2007; Orquera and Piana 2009). At this point in time, commercial exploitation adversely affected key resources (e.g., pinnipeds) of the indigenous economies and influenced the spread of infectious diseases, almost extinguishing local peoples within a few decades (Estévez and Vila 2007; Orquera and Piana 2009). At that time the Beagle Channel was occupied by “Canoe Indians” called Yamana or Yaghan, a society described as highly reliant on marine resources, formed by small groups living along coastal areas exploiting a wide range of fauna according to their local availability (Estévez and Vila 2006; Orquera and Piana 1999). Intertidal mollusks (e.g., mussels and limpets) were among the most predictable and abundant resources exploited by Yamana groups (Orquera and Piana 2001, 2002), differing from other prey exploited only occasionally or seasonally (Orquera and Piana 2009). The abundance of intertidal mollusk remains provides unique snapshots of intense Yamana use of intertidal resources, but may also offer insight into settlement and mobility patterns of this coastal society.

Oxygen isotopic composition ($\delta_{18}\text{O}$) of shells of intertidal mollusks is a well-established approach to investigating temporal patterns of mollusk exploitation in archaeological sites (e.g., Colonese et al.

2009; Culleton et al. 2009; Jones et al. 2008; Kennett and Voorhies 1996; Mannino et al. 2007; Quitmyer et al. 1997; Walker and Surge 2006). Shell $\delta_{18}\text{O}$ is a function of the seawater $\delta_{18}\text{O}$ ($\delta_{18}\text{O}_w$) and the temperature at which the carbonate secretion takes place (e.g., Wefer and Berger 1991). Thus, by establishing the seasonal variations of shell $\delta_{18}\text{O}$ relative to seawater temperature, the season in which the mollusk was harvested can be estimated. Such an approach can potentially yield valuable insights into territorial and subsistence strategies adopted by Yamana society during Euro-American pressure on environments and resources.

Yamana groups have been ethnographically described as highly mobile, with a settlement pattern characterized by very short-lived use of sites (Orquera et al. 2011). In this perspective an additional advantage of shell $\delta_{18}\text{O}$ seasonality data is the possibility to evaluate (corroborate, reject) such ethnographic descriptions, which play a crucial role in the interpretation of more recent coastal archaeological records in the Beagle Channel (Orquera et al. 2011).

This article investigates the seasonal exploitation pattern of *Nacella magellanica* (Gmelin 1791, *Gastropoda*, *Patellidae*) by Yamana groups from two sites in the Beagle Channel dated to the time of European and Euro-American contact in the nineteenth century: Lanashuaia and Túnel VII. To address this issue we analyze the oxygen isotope ratio of shells of *N. magellanica*

in modern and archaeological assemblages.

Our main goals include: a) to check if shell $\delta_{18}\text{O}$ of *N. magellanica* can be considered a suitable archive of seasonal temperature changes in the Beagle Channel; b) to evaluate the exploitation pattern of *N. magellanica* (seasonally or year-round); and c) to provide new insights into Yamana coastal mobility and subsistence strategies at the time of their near extinction.

ENVIRONMENTAL AND ARCHAEOLOGICAL SETTING

The study area is located in the southwestern Argentine side of Isla Grande de Tierra del Fuego (Figure 1). The region exhibits a sub-polar oceanic climate (Köppen 1936), dominated by humid and cold westerlies. Mean monthly atmospheric temperature at Ushuaia Bay ranges from about 9°C in summer to 1°C in winter, and annual precipitation is about 530 mm (<http://www.cadic.gov.ar/>). Vegetation cover is mostly comprised of *Nothofagus* forest (e.g., *N. betuloides* and *N. pumilio*) and tundra (Iturraspe and Schroeder 1999; Orquera and Piana 2009; Piqué 1999).

The Beagle Channel separates the Isla Grande de Tierra del Fuego from other southernmost islands (e.g., Navarino, Picton, Lennox, Nueva, Hoste, Londonderry). The Channel is a drowned glacial valley 5 km wide and 180 km long in a western-eastern trend and has an estuarine dynamic, which is partially influenced by river discharges from precipitation and glaciers. Sea surface temperature (SST) in the summer is about 9°C and is about 4°C in the winter, with an average of about 6.5°C. Sea surface salinity (SSS) varies from 27 to 33.5 PSU (Practical Salinity Unit), but lower values have also been reported (e.g., 23 PSU, Obelic et al. 1998). Lower SSS occurs mostly in summer according to the volume of meltwater discharged into the channel which is ice-free throughout the year. Water circulation is also influenced by microtidal oscillations (mean tidal range is 1.1 m) flowing from the east (Atlantic) and west (Pacific), with a semidiurnal regime (e.g., Bujalesky 2007; Isla et al. 1999; Iturraspe et al. 1989; *Servicio de Información Ambiental y Geográfica* - SIAG, CADIC). On a larger scale the surface circulation is controlled by the Antarctic Circumpolar Current (ACC), which generates the Cape Horn Current (CHC) to the west. The CHC descends southwards and passes around the continent through the Drake Passage, joining the Malvinas Current on the Atlantic side of South America, influencing both the eastern and western coasts (Gordillo et al. 2008).

Archaeological evidence from Lanashuaia and Túnel VII provide interesting snapshots of the Yamana society over the course of the eighteenth and nineteenth centuries.

Lanashuaia and Túnel VII are open-air coastal sites located in the northern coast of the Beagle Channel (Figure 1) (Orquera and Piana 1995a, 1995b; Piana et al. 2000). Similar to other recent shell middens in the region, they consist of circular structures comprising a

central area with hearths surrounded by a peripheral deposition of food remains (mainly marine shells) and a different suite of artifacts (Estévez and Vila 2006; Piana et al. 2000). Lanashuaia belongs to a series of several structures distributed linearly over the shore of the inner Cambaceres Bay, and it is possibly related to a collective consumption of a stranded whale (e.g., Álvarez et al. 2009; Piana et al. 2000). The occupation of Lanashuaia was chronologically anchored to the nineteenth century due to the presence of ovicaprine fauna which were first introduced to the area in 1867 (Piana et al.

2000). According to ethnographic sources and previous archaeological evidence (Orquera and Piana 1999), Piana et al. (2000) interpreted Lanashuaia as the result of several short-lived occupation episodes, but recent stratigraphic and refitting analyses suggest a single occupation phase. Refitting studies establish that fragments of bones (marine and terrestrial fauna) and lithic debitage were distributed throughout the whole deposit, suggesting continuity in the archaeological stratigraphic succession.

Túnel VII is an example of a circular hut occupied during different periods. The succession of central hearths surrounded by small postholes and food refuse indicates at least 10 different occupation episodes spanning roughly 80 years (Estévez and Vila 2006; Orquera and Piana 1995a). Occupations of Túnel VII were dated to the eighteenth and nineteenth centuries using different techniques.

Several dendrochronological dates and one ^{14}C age place occupations between about AD 1776–1792 and 1863–1898 (Piana and Orquera 1995). This chronological framework is supported by the presence of glass and ovicaprine remains in the site (Piana and Orquera 1995).

Both sites also depicted an economic system characterized by the exploitation of a broad range of biotic resources, including terrestrial, but predominantly marine mammals, shellfish, fish, and birds (Estévez et al. 2001; Estévez and Vila 2006, and references therein; Piana et al. 2000). Faunal records from Túnel VII have been described previously in part (e.g., Estévez et al. 2001; Estévez and Vila 2006; Juan-Muns 1992; Mameli 2000), but only preliminary data has been reported for Lanashuaia (Piana et al.

2000). A brief description of more recent data provides a more complete picture than previously reported. Quantitative analysis (NISP and MNI) are reported in Figures 2 and 3. At Lanashuaia, fish remains comprise the majority of the vertebrate fauna (ca. 30%), represented by snoek (*Thyrstites atun*), patagonian grenadier (*Macruronus magellanicus*), and sardines (Cupleidae).

Sea birds also occupied a relevant position (ca. 25%), represented by the southern black-backed gull (*Larus dominicanus*), followed by other taxa such as cormorant (*Phalacrocorax* sp.), grey-headed albatross (*Diomedea chrysostoma*), and southern giant petrel (*Macronectes giganteus*) (Mameli 2004; Mameli and Estévez 2004). Marine (pinnipeds and cetaceans) and terrestrial (guanaco) mammals are also significant, and among them pinnipeds probably represent the most reliable and predictable source of protein and fat (Piana et al. 2006). Pinniped (*Arctocephalus australis* and *Otaria flavescens*) and cetacean (*Balaenoptera acutorostrata*) remains account for ca. 20% and 11%, respectively, of the total NISP of the vertebrate fauna, while guanaco (*Lama guanicoe*) composes ca. 14% (Figure 2).

Quantitatively, shellfish are the most abundant faunal remains at Lanashuaia. They are mostly represented by intertidal rocky shore taxa, among which mussels dominate with ca. 80% (e.g., *Mytilus edulis*), followed by limpets (e.g., *Nacella deurata* and *N. magellanica*) and chitons (e.g., *Plaxiphora aurata*), with ca. 13% and 4%, respectively (Figure 3).

MATERIALS AND METHODS

N. magellanica (Gmelin, 1791) is a subantarctic limpet inhabiting intertidal rocky shores of the Beagle Channel (Malanga et al. 2004). It is abundant in archaeological sites of this region (Orquera and Piana 2001, 2002) and occurs with many wellpreserved shells at Lanashuaia and Túnel VII (contrary to *M. edulis*). Seasonal environmental conditions, SST among others, phytoplankton productivity, and deviations in daylight length influence metabolic activity and growth rate of *N. magellanica* (Guzmán and Ríos 1987; Malanga et al. 2005, 2007).

Its metabolism increases progressively from the early spring and throughout the warmer seasons, whereas it is reduced during the winter (e.g., Malanga et al. 2005, 2007).

Using external growth checks, Guzmán and Ríos (1987) proposed maximum and minimum growth rates during spring/summer and in autumn/winter, respectively, for populations of the Strait of Magellan. These authors have also observed a decreasing growth rate with age and estimated longevity up to ca. 40 yrs. Shell sizes also show significant differences according to intertidal environmental conditions. In sheltered biotopes (e.g., from wave actions) shells can reach ca. 50 mm in length, while on exposed shores, shells reach ca. 70 mm (Morriconi 2005). The reproduction has been observed in September, with a peak at the end of spring (November–December) (Malanga et al. 2007, and references therein).

In order to reconstruct seasonal exploitation patterns of *N. magellanica* from Lanashuaia and Túnel VII, modern specimens were collected over the course of several months from 2005 to 2007 in rocky shores of Golondrina Bay (GB) and Ushuaia Bay (UB) for stable isotopes and sclerochronological analysis (ongoing study) (Figure 1). Specimens were collected during fieldwork in different periods over these three years and data were combined to obtain a unique intra-annual record. Medium shells (34–41 mm) were selected for isotopic analysis because they are representative of the average size of archaeological specimens at Lanashuaia (41.9 ± 8 mm) and Túnel VII (32.2 ± 8 mm). Specimens were sectioned along the axis of maximum growth, polished, and cleaned with distilled water. For each month, two to four specimens were used for oxygen isotope analysis to estimate their ultimate growth increment (shell-edge). A single carbonate sample (ca. 150–200 µg) was obtained from the inner layer of the shell-edge by using a manual microdrill with a 0.5 mm bit.

One medium-large shell (M8-19, 45 mm) collected in December 2005 in front of Lanashuaia (Cambaceres Bay) was sampled sequentially along the axis of maximum growth to estimate ontogenic $\delta^{18}\text{O}$ variability.

M8-19 was mounted in epoxy resin and a 2 mm thick section of shell along the axis of maximum growth was prepared over a glass slide. After this process, continuous carbonate microsamples (ca. 30 to 60 µg) were micromilled (from 100 to 500 µm spacing) using a microdrill controlled by computer (MERCHANTEK) at the Institute of Earth Sciences Jaume Almera (ICTJA-CSIC) (Figure 4).

Archaeological specimens from Lanashuaia ($N = 10$) were recovered during archaeological excavation in 2005. Shells from Túnel VII derive from occupation episodes G, H and J, excavated between 1988 and 1993 (Estévez and Vila 1995) and represent the last occupation episodes of Túnel VII. For each occupation episode six shells were analyzed. Archaeological shells were sectioned and three continuous carbonate samples were obtained from the inner layer, starting from the shell-edge, by using a manual microdrill with a 0.5 mm bit. The shell-edge $\delta^{18}\text{O}$ value is representative of the season when mollusks were collected. In the case of harvesting during intermediate seasons (i.e., spring and autumn) the further two samples behind the shell-edge would provide indications of SST trend (cooling or warming). In addition, one shell from Lanashuaia (L1, 42 mm) and one from each occupation episode of Túnel VII was sampled sequentially with the same microdrill (0.5 mm bit) (occupation episodes G: specimen TG, 33 mm; H: specimen TH, 38 mm; and J: specimen TJ, 49 mm). These sequential samples enabled us to evaluate the intra-annual shell $\delta^{18}\text{O}$ variability which is representative of intra-annual SST and $\delta^{18}\text{O}_w$ variations (Figure 4).

Isotopic analyses were performed at the Royal Netherlands Institute for Sea Research (NIOZ) using a Finnigan MAT 253 mass spectrometer with a Kiel IV device from Thermo. Some samples were also analyzed at Vrije University in Amsterdam using a Finnigan MAT 252 equipped with an automated preparation line (Kiel II type). In both laboratories the reproducibility of a routinely analyzed carbonate standard (NBS 19) is better than 0.09‰. The oxygen isotope composition is expressed using the δ (‰) notation. The $\delta^{18}\text{O}$ of shells are related to V-PDB standard (Vienna Pee Dee Belemnite), whereas those of seawater are relative to V-SMOW (Vienna Standard Mean Ocean Water). The inner shell structure of both modern and archaeological specimens was analyzed using X-ray diffraction (XRD). Internal calcite structures for all specimens were intact.

SST and SSS data were not available for the study area at the moment of shell collections.

Therefore we used monthly mean SST records from measurements in Ushuaia Bay (port of Ushuaia) from 1994 to 2001 (data source: *Servicio de Información Ambiental y Geográfica*,

CADIC). We also used monthly mean SSS data generated during monitoring studies of planktons from 1987 to 1989 (G. Lovrich, personal communication) and from Obelich et al. (1998), who compiled the SSS data in Bahía Ushuaia between 1971 and 1987 for the E.U. project “Marine Resources at the Beagle Channel prior to the Industrial Exploitation: an Archaeological Evaluation” CI1*-CT93-0015. ALAMED” (Vila 1999).

RESULTS Intra-annual $\delta_{18}\text{O}$ Variation in Shells of *Nacella magellanica* Monthly mean SST for the years 1994–2001 ranged from $9 \pm 0.4^\circ\text{C}$ in summer to $4.5 \pm 0.4^\circ\text{C}$ in winter, displaying an intra-annual variability of 4.5°C . No substantial variability is observed between monthly mean SST of different years. Mean monthly SSS in the area ranged from ca.

26 to 31 PSU, with substantial differences between SSS1 and SSS2 (Figure 5). SSS1 is rather irregular throughout the year, while SSS2 is consistent with the model of summer meltwater discharged into the channel promoting seasonal trends in SSS (e.g., Iturraspe et al. 1989; Bujalesky 2007). Intra-annual shell-edge $\delta_{18}\text{O}$ exhibits clear seasonal fluctuations, with most positive (e.g., $+1.9 \pm 0.6\text{‰}$) and negative (e.g., $-0.1 \pm 0.5\text{‰}$) average values recorded during colder and warmer months respectively ($\delta_{18}\text{O}_{\text{mean}} = 2\text{‰}$) (Figure 6). The intra-annual mean $\delta_{18}\text{O}$ is $+0.9 \pm 0.7\text{‰}$ and is consistent with average isotopic values (i.e., -0.2‰ to $+1.4\text{‰}$) of other modern mollusk shells from the Beagle Channel (Gordillo et al. 2010; Lomovasky et al. 2002, 2007; Obelich et al. 1998; Panarello 1987).

However temperature is not the only factor controlling shell $\delta_{18}\text{O}$ of *N. magellanica* in the study area. The intra-annual SST range of 4.5°C cannot alone explain the intra-annual mean $\delta_{18}\text{O}$ range of 2‰ ($\delta_{18}\text{O}_{\text{mean}}$), thus variations of $\delta_{18}\text{O}$ should be involved. According to the following paleotemperature equation for biogenic calcite (i.e., *Mytilus edulis*) precipitated at similar SSS and SST of the study area (Wanamaker et al. 2007): $T(^{\circ}\text{C}) = 16.33 - 4.48 * (\delta_{18}\text{O}_{\text{V-PDB}} - \delta_{18}\text{O}_{\text{W(SMOW)})$, we estimate that about 1‰ of the intra-annual mean $\delta_{18}\text{O}$ range ($\delta_{18}\text{O}_{\text{mean}} = 2\text{‰}$) is due to changes in $\delta_{18}\text{O}_{\text{w}}$. The correlation coefficient (R_2) between mean monthly shell-edge $\delta_{18}\text{O}$ and SST is 0.7 (Figure 7), which indicates that SST and $\delta_{18}\text{O}_{\text{w}}$ influence shell $\delta_{18}\text{O}$ values in the same direction because increasing SST is accompanied by decreasing SSS due to enhanced freshwater input and *mutatis mutandis* (i.e., SSS2; Figure 5). Direct $\delta_{18}\text{O}_{\text{w}}$ data are not available for the study area. The only $\delta_{18}\text{O}_{\text{w}}$ record is provided by Obelich et al. (1998), who report one summer (i.e., February) value of -1.6‰ measured at Ushuaia Bay with a SSS around 30 PSU. The above paleotemperature equation enables us to estimate the $\delta_{18}\text{O}_{\text{w}}$ range experienced by *Nacella magellanica* during the study interval. Using mean monthly shell-edge $\delta_{18}\text{O}$ and SSTs we calculated $\delta_{18}\text{O}_{\text{w}}$ values ranging from -0.7‰ to -1.7‰ in winter and summer respectively, with an annual average of -1.2‰ . Estimated summer $\delta_{18}\text{O}_{\text{w}}$ values are in broad agreement with Obelich et al. (1998).

On a global scale, the $\delta_{18}\text{O}_{\text{w}}$ is positively related with the salinity, but hydrological and oceanographic conditions promote regional to local relations (e.g., Rye and Sommer 1980, and references therein). South Atlantic waters at the Drake Passage with surface salinity of ca. 34 PSU exhibit a mean $\delta_{18}\text{O}$ of -0.16‰ (Meredith et al. 1999, source data <http://data.giss.nasa.gov/o18data/>). On the other hand, mean annual $\delta_{18}\text{O}$ of precipitation at Ushuaia (year 2002) is -11‰ ($\pm 1.6\text{‰}$) (IAEA/WMO 2006), which can be roughly assumed as the equivalent of freshwater input in the area with 0 PSU.

Using this relation we estimate that *N.*

magellanica grew in seawater with salinity oscillating from ca. 29 to 32 PSU during the study interval. These values agree with SSS data from the area and confirm that shell $\delta_{18}\text{O}$ of *N. magellanica* is to some extent influenced by ^{18}O -depleted freshwater input, but less than other large intertidal and shallow subtidal mollusks from the area, which are also abundant in archaeological sites in the region (i.e., *M. edulis*; Obelich et al. 1998).

Monthly $\delta_{18}\text{O}$ variability ranges from 0.2‰ to 1.1‰ and could be related to different factors such as intra-specific variability in growth rate (e.g., Mannino et al. 2008), different food quality and quantity (e.g., Schöne et al. 2007), different individual times of aerial exposure during low tide (e.g., Goodwin et al. 2001), and local variations of $\delta_{18}\text{O}_{\text{w}}$. Limpets may be subject to shell erosion by contact with the substrate (e.g., Day et al. 2000) and this process could also be involved in monthly $\delta_{18}\text{O}$ variability.

In essence, our results suggest that shell erosion, if occurring in *N. magellanica*, has not significantly affected seasonal $\delta_{18}\text{O}$ trends.

In agreement with monthly shell-edge data, ontogenic $\delta_{18}\text{O}$ values of the modern specimen from Lanashuaia (M8-19) display a cyclical trend (Figure 8). The $\delta_{18}\text{O}$ profile of M8-19 ranges from -0.8 to $+1.5$ and represents the last two and a half years of shell growth. Consequently our results disagree with age estimations proposed by Guzmán and Ríos (1987). Indeed their size/age model would provide an age of ca. 8 years to M8-19.

Although M8-19 was gathered in December (spring), the shell-edge $\delta_{18}\text{O}$ signal is compatible with a winter value. This discrepancy probably results from the analytic failure of the shell-edge samples, a problem that occurred with other samples of this shell because carbonate powder quantity was insufficient to provide reliable results. Using distances between the three positive $\delta_{18}\text{O}$ peaks (coldest SSTs), we estimate growth rates for the last two years of 4.5 and 5.4 mm, respectively. The earliest $\delta_{18}\text{O}$ trend towards high values encompasses 5 mm of the shell.

These data suggest that M8-19 grew faster in its youngest stage, decreasing growth rate with longevity. Isotopic data suggest that M8-19 experienced different seasonal growth rates. Faster growth occurred during increasing $\delta_{18}\text{O}$ between samples 2 and 11 and samples 30 and 38, and during decreasing $\delta_{18}\text{O}$ recorded between samples 17 and 28. Between these $\delta_{18}\text{O}$ trends the growth is reduced (samples 13–17; Figure 8).

Seasonal Exploitation Pattern of *N. magellanica*

To determine the seasonal connotation of shell-edge $\delta_{18}\text{O}$ values of archaeological specimens, the intra-annual $\delta_{18}\text{O}$ amplitude should be estimated. Thus, one archaeological shell from Lanashuaia (specimen L1) and one from each analyzed layer of Túnel VII (specimens TG, TH, TJ) were sampled sequentially to establish the potential intra-annual $\delta_{18}\text{O}$ range (Table 1; Figure 9). Archaeological shells exhibit different $\delta_{18}\text{O}$ magnitudes and time spans (1–3 years). They also display noticeable variability in growth rate which could explain the monthly variability of modern specimens.

The $\delta_{18}\text{O}$ amplitude of L1 can be compared with M8-19 because both were collected in the same area. On the other hand, shells from Túnel VII can be compared with monthly shell-edge $\delta_{18}\text{O}$ because of similar environmental conditions among these areas.

$\delta_{18}\text{O}$ values of specimen L1 range from -0.8 to $+2.2$ and represent about one year of growth. L1 displays larger $\delta_{18}\text{O}$ amplitude ($\delta_{18}\text{O} = 2.9$) when compared with M8-19 (horizontal lines in L1) due to higher values during the coldest months (by 0.7). Shells from Túnel VII (TG, TH, TJ) show lower $\delta_{18}\text{O}$ amplitudes compared to L1, and their $\delta_{18}\text{O}$ values fall into the range measured in modern specimens (horizontal lines). Specimen TG provides the largest $\delta_{18}\text{O}$ range, from -0.3 to $+1.9$ ($\delta_{18}\text{O} = 2.2$), which represents three years of growth. Specimens TH and TJ show similar $\delta_{18}\text{O}$ range, from $+0.4$ to $+2.1$ ($\delta_{18}\text{O} = 1.6$) and from $+0.3$ to $+2.1$ ($\delta_{18}\text{O} = 1.8$), respectively.

Their $\delta_{18}\text{O}$ profiles represent about one year of growth and exhibit highest $\delta_{18}\text{O}$ values during warmer months than specimen TG (by ca. 0.7), and also in relation to mean monthly shell-edges collected in summer (by ca. 0.5).

For each layer we compared the above sequential data with $\delta_{18}\text{O}$ values of those shells used for seasonal determinations (three sequential samples; Table 2). Sequential data are represented into quartiles, from which archaeological shell-edge $\delta_{18}\text{O}$ are compared (Figure 10). Quartile distribution organizes $\delta_{18}\text{O}$ values into four different groups of equal parts consisting of one fourth of the data set. For instance, lowest $\delta_{18}\text{O}$ values corresponding to warmer months are grouped in the lower quartile (lowest 25% of data). Highest $\delta_{18}\text{O}$ values associated to colder months are grouped into the upper quartile (upper 25%). Intermediate $\delta_{18}\text{O}$ values (i.e., spring and autumn) are grouped into the interquartile range (>25% and <75%), with the 50% of the $\delta_{18}\text{O}$ data set. This approach allows seasonal discriminations devoid of subjective attributions of shell-edge $\delta_{18}\text{O}$ to specific seasons (Colonese et al. 2009; Mannino et al. 2007).

Shell-edge $\delta_{18}\text{O}$ values from Lanashuaia are distributed mostly into the interquartile ($+0.5$ to $+1.3$) and in the lowermost part of the upper quartile ($+1.4$). These data can be associated with collections in autumn–beginning of winter, although one shell provided values consistent with spring gathering. Specimens from Túnel VII exhibit different shell-edge $\delta_{18}\text{O}$ distributions. Shells from layer G are commonly distributed into the upper

quartile (+1.7_to+2.0_) and in the uppermost part of the interquartile range (+0.9_ to +1.2_), suggesting autumn winter exploitations. Shell-edge δ_{18O} values from layer H are mainly centered in the interquartile range (+0.8_ to +1.6_) with one specimen in the upper quartile (+2.7_).

These δ_{18O} data denote mainly spring collections, with some specimens probably collected also in winter. Finally, shell-edge δ_{18O} from layer J are distributed mostly in the lower interquartile range (+0.5_ to +1.0_), with one shell falling in the lower quartile (+0.4_), and another one in the upper quartile (+1.5_). These results are indicative of prevalent autumn gathering, with some specimens possibly collected at the end of summer and also in winter.

DISCUSSION

Our results indicate that shell δ_{18O} of *N. magellanica* tracks seasonal fluctuations of SST and δ_{18Ow} in the study area. Because both parameters influence shell δ_{18O} in the same direction, shell-edge δ_{18O} can be used to reconstruct seasonal exploitation patterns in archaeological sites. Medium shells (e.g., 33–41 mm length), the most frequent at Lanashuaia and Túnel VII, have annual growth rates that ensure sufficient seasonal isotopic resolution. Nevertheless, specific environmental conditions of the study area might influence quantitative relations among shell δ_{18O} and SST, for example the extent to which freshwater input (δ_{18Ow} variability) influences the correlation of Figure 7, and the effect of lower temperatures and their seasonal amplitude on species-specific physiology (e.g., reducing growth rate, Malanga et al. 2005, 2007).

The archaeological δ_{18O} profile from Lanashuaia (L1) shows highest δ_{18O} values in coldest months compared to a modern specimen collected in the area (M8-19). Also, shells from occupation H (TH) and J (TJ) of Túnel VII are ^{18}O -enriched during warmer months in relation to modern specimens collected in summer, but also to the specimen from layer G (TG). Overall, these differences (ranging from 0.7_ in L1 to 0.4_ in TJ) fall into the monthly δ_{18O} variability observed in modern specimens (from 0.2_ to 1.1_) and could reflect the inherent δ_{18O} variability of *N. magellanica* shells in the area.

Alternatively, these data could imply lower SST and/or higher δ_{18Ow} compared to the present day. For instance, assuming constant δ_{18Ow} in equation 1 (i.e., -1.2_), shell ^{18}O -enrichments from 0.7_ to 0.4_ would correspond to a decrease in SST from about 3.1°C and 1.8°C respectively. To some extent these results agree with data from Obelic et al. (1998), which estimated lower mean annual SST at the end of the nineteenth century by using shell δ_{18O} values of *M. edulis* from the same sites. However, shifts in δ_{18Ow} can also promote shell ^{18}O -enrichments without necessarily involving variations in SST. For instance, a persistent period of reduced river discharge might favor the circulation of seawater with higher δ_{18O} . Using equation 1 on shell δ_{18O} differences observed in TH and TJ compared to modern counterparts in summer (at a constant temperature of 9°C), it is possible to estimate summer increases of δ_{18Ow} by +0.5_ and +0.4_ for layers H and J, respectively. Assuming similar SSS/ δ_{18Ow} relation of present day, we calculate for these episodes an increase in SSS of ca. 1 PSU. These results seem to be supported by historical pluviometric data from southern Patagonia (i.e., Punta Arenas), which report lower precipitation over the region at the end of the nineteenth century (Santana et al. 2006, and references therein). The salinity influences seem to be less compelling for L1 (Lanashuaia) because this shell provides a winter ^{18}O -enrichment which would already correspond with a period of higher SSS. In conclusion, these data might indicate lowest summer SST and/or lowest river discharges during the last occupations of Túnel VII (episodes H and J), with respect to modern conditions. Alternatively, the data from L1 seems to be more compatible with lower winter SST. The discrepancy among winter (L1) vs. summer (TH and TJ) conditions complicate interpretations and require further studies.

Archaeological shell-edge δ_{18O} values depict different seasons of *N. magellanica* exploitations by Yamana groups during the occupation of Lanashuaia and some of Túnel VII. Gathering at Lanashuaia occurred mainly in autumn and in the beginning of winter, which agrees well with fauna-derived seasonal data. According to Piana et al. (2000), the presence of guanaco could be indicative of hunting in winter because guanacos tend to spend the winter season in coastal regions (e.g., Montes et al. 2000). In addition, if we take into account those bones with fusion temporarily delimited (i.e., Mengoni Goñalons 1999) and the

reproduction period of this species (December to March), it seems reasonable to propose that some of the guanacos were hunted in months prior to November through February. That would mean that those animals were probably obtained during winter. Piana et al. (2000) also proposed that pinnipeds were exploited in winter on the basis of teeth growth patterns. However these authors also suggested summer and spring faunal exploitations due to the occurrence of some specific bird taxa (*Spheniscus magellanicus* and *Chloephaga* sp.). These taxa are only sporadically represented in the site (Mameli 2004; Mameli and Estévez 2004), thus their occurrence might not be significant in seasonal terms.

During the more recent occupations of Túnel VII (i.e., G, H, J), exploitation of *N. magellanica* occurred mainly in autumn/winter (G), spring (H), and autumn (J).

Previous seasonal data are available for occupations H and J. Mameli (2004) associates the occupation H to spring-summer due to the presence of a juvenile individual of cormorant (Mameli 2004). This agrees with our isotopic data elucidating spring collections. Our results also agree with a seasonal interpretation of occupation J, associated with summer and autumn due to a large concentration of Clupeidae remains, a migratory fish appearing in the channel between December and April (Fiore and Zangrando 2006, and references therein; Juan-Muns 1992).

In conclusion, at Lanashuaia and Túnel VII (i.e., layers G, H, and J) *N. magellanica* was exploited periodically and not yearround.

However, these occupations represent distinct moments of gathering (i.e., autumn, winter, spring), supporting yearround coastal occupation, high mobility, and reliance on marine resources, as emphasized in previous research on the subject (e.g., Estévez et al. 2001; Estévez and Vila 2006, 2007; Orquera and Piana 2009). On a regional scale, short-term site occupation coupled with the exploitation of a wide range of resources might reflect economic strategies operated to maximize benefits from local resources (e.g., Estévez et al. 2001; Orquera and Piana 2009). At a local scale (intra-site economy) quantitative and qualitative trends in faunal assemblages, which document intense exploitation of some resources rather than others, suggest a collective effort to obtain high returns and reduce the acquisition cost of local resources (Table 3). For instance, at both Lanashuaia and Túnel VII cetacean remains were abundant at the base of the deposit which seems to suggest preferential, and likely occasional consumption of such animals over others (Estévez and Vila 2006; Piana et al. 2000). In particular, the data from Lanashuaia suggest the possibility of an occupation that began with the collective exploitation of a whale carcass lasting until the depletion of local resources. However, other mechanisms influencing qualitative faunal remains may also be involved, such as the differing importance of some species due to social and ideological factors (Fiore and Zangrando 2006; Mameli and Estévez 2004). At Lanashuaia, further research is required to evaluate if such economic strategies have been adopted by Fuegian groups in response to changes in resource availability, demographic growth, and technological development (see Ocampo and Rivas 2000), or triggered by European and American exploitations of marine resources in the Beagle Channel (Estévez et al. 2001; Estévez and Vila 2007; Vila and Estévez 2010).

CONCLUSIONS

Archaeological evidence from the Beagle Channel provides interesting examples of long-term human adaptation to high latitude environmental conditions, notably depicted by faunal remains from archaeological sites.

The shells of *N. magellanica* are abundant in archaeological shell middens distributed along the Beagle Channel and this study demonstrates that oxygen isotopic composition of its shell may provide suitable information on seasonal exploitation patterns by hunter-gatherer-fisher groups in this region.

Oxygen isotopic data from shells recovered from ethnographic sites (i.e., Lanashuaia and Túnel VII) indicate that *N. magellanica* was gathered on a periodic basis. A more exhaustive economic scenario emerges when shell isotopic data are compared with fauna-derived seasonal reconstructions.

Comprehensive results suggest that in the nineteenth century, Yamana consistently occupied the coast of the Beagle Channel by means of short-term campsites, in substantial agreement with ethnographic records (e.g., Orquera et al. 2011). However, new perspectives on the Yamana subsistence economy might emerge by increasing and extending seasonal studies and improving chronological control stratigraphically.

Combining these data with ethnographic sources, we will surely improve our understanding of Yamana responses to abrupt and short-term social changes, a frequent phenomenon in human history.

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Samples	$\delta^{18}\text{O}\text{‰}$ (V-PDB)				
	M8-19	L1	TG	TH	TJ
1*	ND	+0.9	+0.9	+1.0	+0.5
2	+1.5	+1.5	+0.3	+1.7	+0.4
3	ND	ND	+1.0	+1.1	+1.3
4	+0.8	+0.5	+1.7	+1.4	+2.1
5	ND	+1.4	+1.1	+1.0	+1.8
6	+0.5	+0.7	+0.4	+0.4	+2.0
7	ND	+0.2	-0.3	+0.9	+2.1
8	+0.5	+0.2	-0.1	+0.5	+1.8
9	+0.2	-0.8	+0.4	+0.9	+1.6
10	+0.1	+0.6	+0.7	+0.9	+1.1
11	+0.0	+0.3	+0.9	+0.8	+0.9
12	ND	+0.0	+1.9	+1.3	+0.4
13	+0.6	+0.4	+1.9	+1.1	+0.4
14	+1.1	+0.6	+1.9	+1.4	+0.7
15	+1.4	+0.5	+0.9	+1.8	+0.3
16	+1.1	+1.3	+0.7	+2.1	+0.9
17	-0.1	+2.2	+0.0		+0.3
18	+0.0	+1.3	+0.5		
19	ND	+1.8	+0.7		
20	+0.0	+1.9	+1.2		
21	+0.3	+2.0	+0.4		
22	+0.1	+2.1			
23	+0.5	+1.6			
24	+0.4				
25	+0.6				
26	+1.0				
27	+1.0				
Max	+1.5	+2.2	+1.9	+2.1	+2.1
Min	-0.8	-0.8	-0.3	+0.4	+0.3
Mean	+0.5	+1.0	+0.8	+1.1	+1.1
$\Delta\delta^{18}\text{O}\text{‰}$	2.2	2.9	2.2	1.6	1.8

Table 1 - Sequential $\delta^{18}\text{O}$ values of modern (M8-19) and archaeological shells from Lanashuaia (L1) and Tunel VII (TG, TH, TJ); *shell-edge, ND = No data.

Site	Layer	Shell length (mm)	$\delta^{18}\text{O}\text{‰}$ (V-PDB)		
			1st sample (shell-edge)	2nd sample	3rd sample
Lanashuaia		47.5	+1.3	+0.0	+0.4
		47.5	+0.5	-0.6	+0.0
		45	+1.4	+1.3	+0.9
		40	+0.7	+0.6	-0.2
		49	+0.9	+1.2	+1.2
		42.5	+1.3	+0.0	+0.3
		30	+1.0	+1.2	+1.4
		43	+1.4	+1.4	+0.2
		42*	+0.9	+1.5	<i>ND</i>
		39.5	+0.8	<i>ND</i>	<i>ND</i>
Tunel VII	G	38.5	+1.7	+1.4	+0.3
		33*	+0.9	+0.3	+1.0
		30	+1.2	+0.8	+0.5
		32	+1.2	+0.6	+0.6
		36	+2.0	+0.6	+1.0
	H	37.5	+1.7	+2.0	+0.8
		35	+0.8	+1.3	+2.0
		30	+0.9	+0.1	+1.9
		38*	+1.0	+1.7	+1.1
		35.5	+1.6	+0.4	+1.2
	J	38.5	+2.7	+1.3	+0.1
		37	+0.8	+2.2	+1.8
		49*	+0.5	+0.4	+1.3
		35.5	+0.7	+0.3	<i>ND</i>
		40	+1.0	+0.5	+0.7
	44.5	+0.4	+1.3	<i>ND</i>	
	30	+0.8	+1.3	+1.0	
	31.5	+1.5	+1.7	+1.1	

Table 2 - Seasonal $\delta^{18}\text{O}$ values of shells from Lanashuaia and from occupation of Tunel VII (G, H, J); *shells analyzed sequentially, *ND* = No data.

Taxa	Lanashuaia		Tunel VII (G)		Tunel VII (H)		Tunel VII (J)	
	N	%	N	%	N	%	N	%
Fish	5	2	6		4		6	6
	2	9		0	9	3	0	.
	1	.		.		.		7
Birds		9		9		5		
	4			6	7	5	5	6
	3		4	0	8	5	6	3
Cetaceans	5	2	2	.	2	.	8	.
		5	2	9		1		3
	1	1					1	1
Pinnipeds	8	0		4		1	0	.
	5	.	3	.	2	.		1
		6	0	3	1	5		
Guanaco (<i>Lama guanicoe</i>)	3	2		3			2	2
	5	0	2	2	5		5	8
	5	.	2	.	5	3	7	.
Total NISP		4	5	5	4	9		6
	2			1	1	0	3	0
	4	1	1	.	3	.		.
Total NISP	4	4	0	4		9		3
	1				1		8	
	7		6		4		9	
	4		9		1		8	
	0		3		9			

Table 3 - NISP and % of all identified vertebrate taxa remains from Lanashuaia and Tunel VII (occupations G, H, J) (Juan-Muns 1992; Mameli 2004; Estévez, unpublished data).

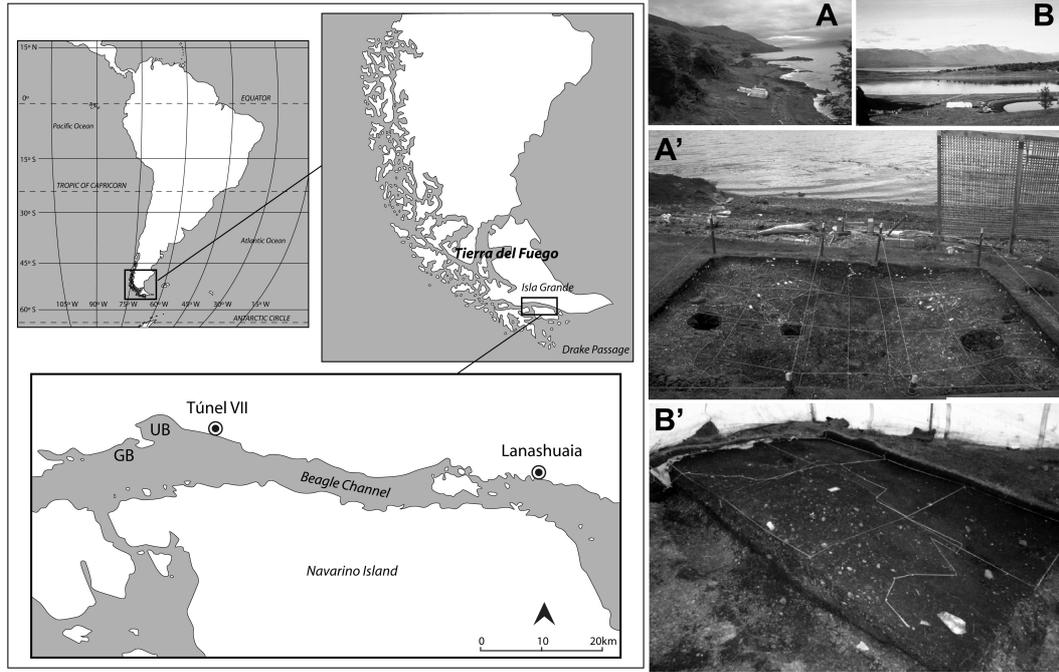


Figure 1 – Map showing the Isla Grande de Tierra del Fuego in South America and the Beagle Channel, with geographical locations of Túnel VII (A and A') and Lanashuaia (B and B') sites. Also shown are sample locations of living *Nacella magellanica* for oxygen isotope analysis: (GB) Golondrina Bay and (UB) Ushuaia Bay are represented.

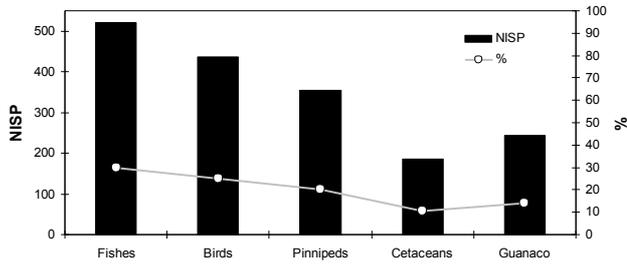


Figure 2 – Relative taxonomic abundance of vertebrate fauna remains at Lanashuaia.

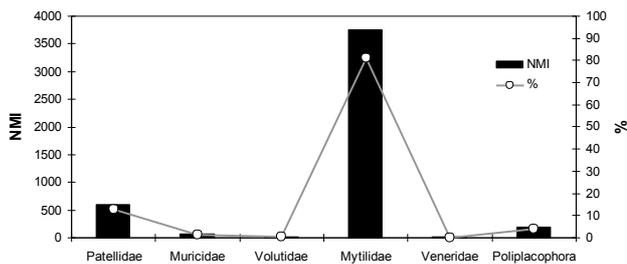


Figure 3 – Relative taxonomic abundance of shellfish remains at Lanashuaia.

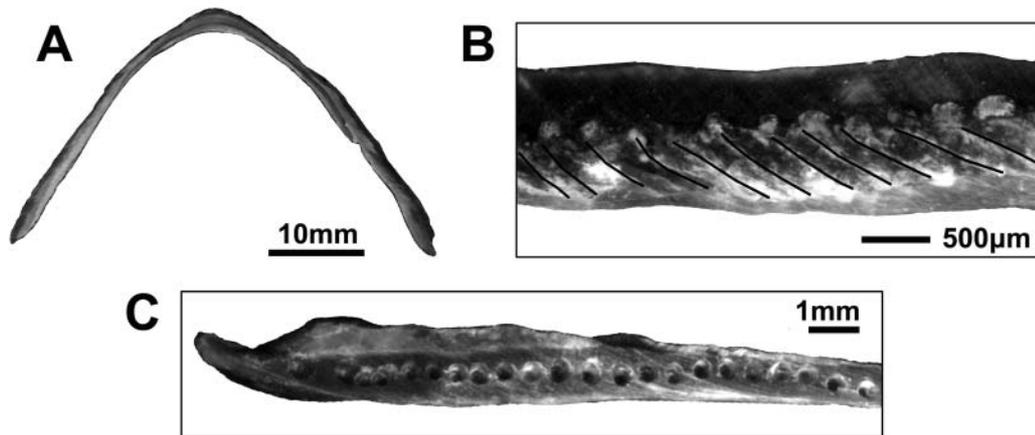


Figure 4 – A) *Nacella magellanica* (M8-19); B) sequential inner shell carbonate samples of M8-19 by means of computer-monitored micromill and C) sequential inner shell carbonate samples of archaeological specimen L1 from Lanashuaia using a manual micro-drill.

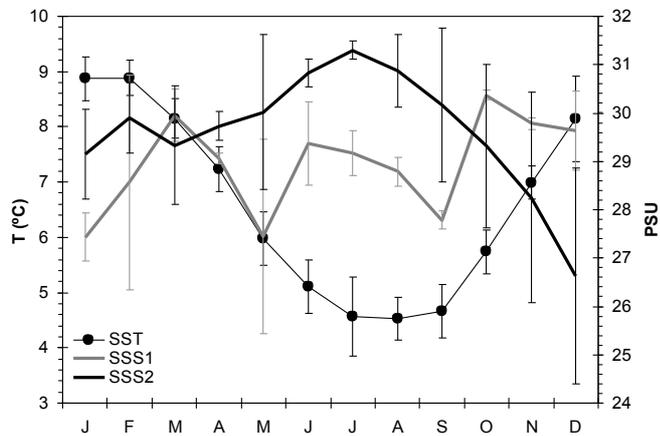


Figure 5 – Sea surface temperature (SST) and salinity (SSS) from the Beagle Channel. SSTs result from measurements in Ushuaia Bay (port of Ushuaia) during 1994 - 2001. SSS1 refers to the interval from 1987 to 1989 (Lovrich, *personal communication*), and SSS2 to the period between 1971 and 1987 Obelic et al. (1998).

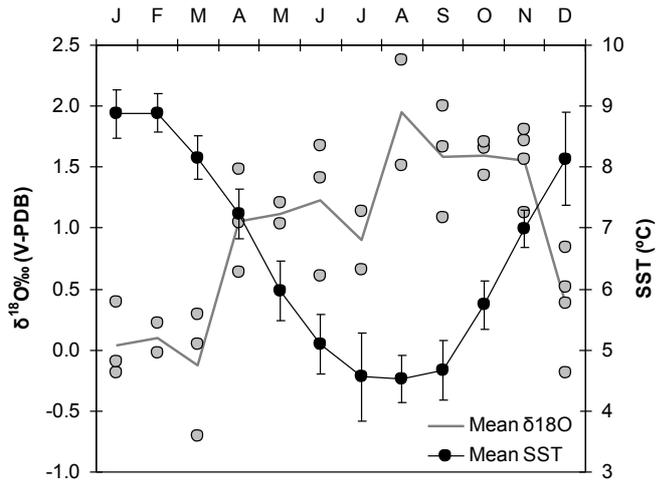


Figure 6 – Intra-annual variation of monthly shell-edge $\delta^{18}\text{O}$ values of *N. magellanica* and monthly mean SST data.

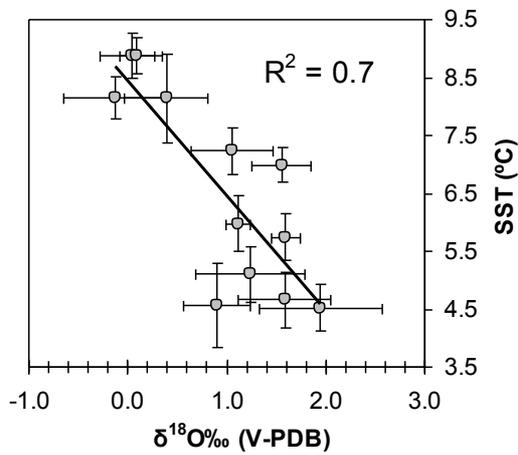


Figure 7 – Monthly mean shell-edge $\delta^{18}\text{O}$ values vs. monthly mean SST data. The correlation coefficient (R^2) is 0.7, which indicates a substantial $\delta^{18}\text{O}$ dependence on SST.

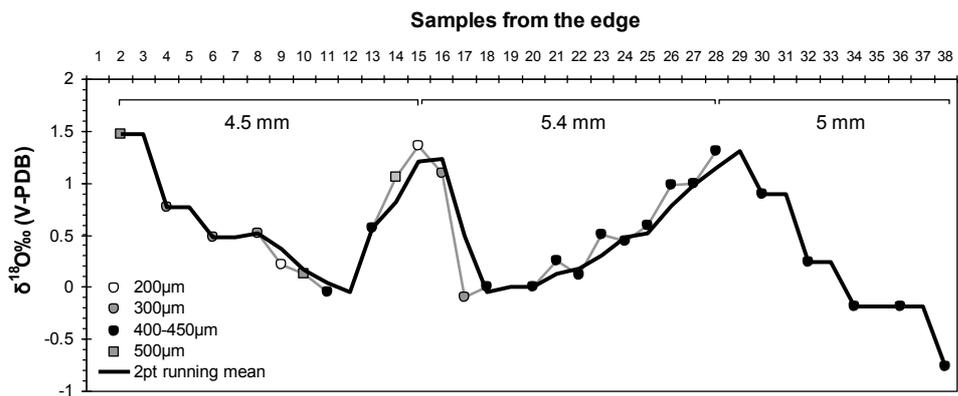


Figure 8 – Ontogenic $\delta^{18}\text{O}$ values and 2-point running mean of the modern specimen M8-19. Estimated annual growth rates and sample diameters are also reported. Note the cyclical $\delta^{18}\text{O}$ pattern recording mainly seasonal SST fluctuations.

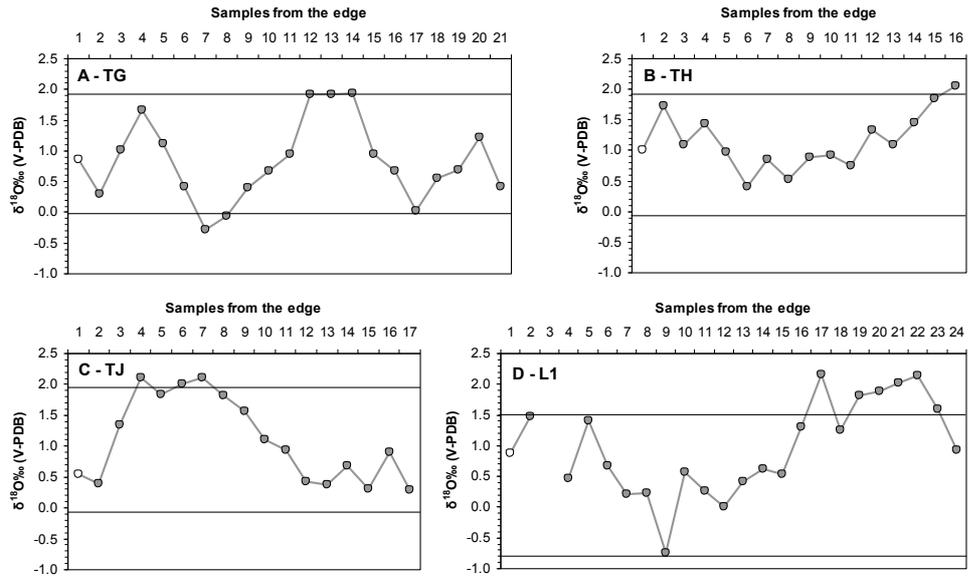


Figure 9 - Ontogenic $\delta^{18}\text{O}$ values of archaeological shells from Túnel VII occupation phase G (A), H (B), J (C) and Lanashuaia (D). Horizontal lines in TG, TH, TJ (Túnel VII) represent the annual range of mean monthly shell-edge $\delta^{18}\text{O}$ values. Horizontal lines in L1 (Lanashuaia) represent the ontogenic annual $\delta^{18}\text{O}$ range of M8-19.

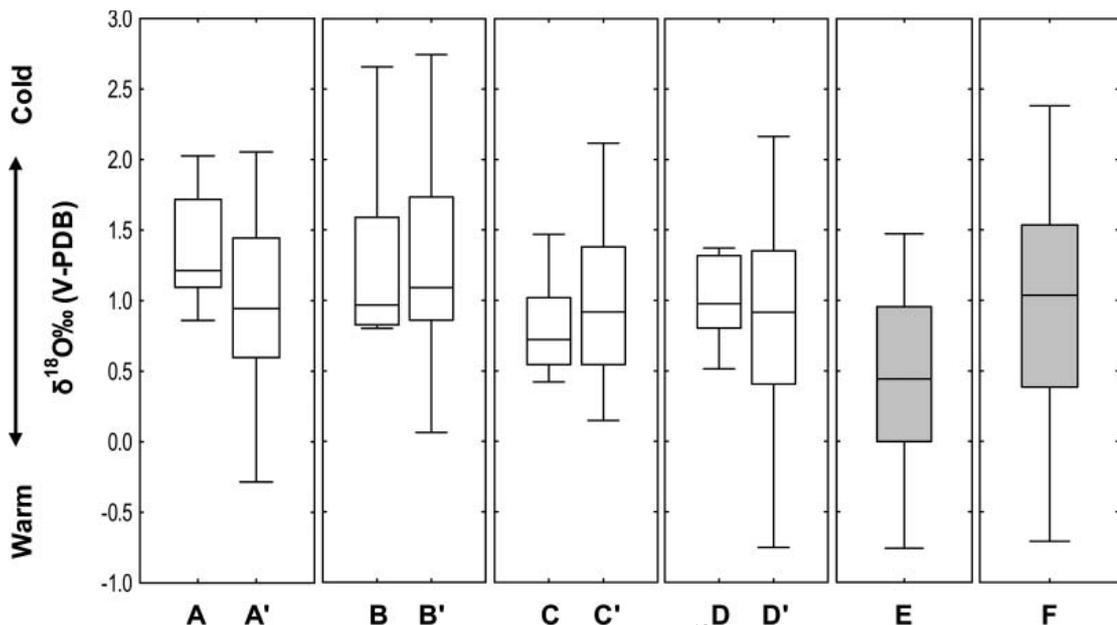


Figure 10 – Quartile distribution of archaeological shell-edge $\delta^{18}\text{O}$ from Túnel VII, occupation phase G (A), H (B), J (C), and Lanashuaia (D). Quartile distributions of ontogenic $\delta^{18}\text{O}$ values used as seasonal reference are reported for each occupation of Túnel VII, occupation G (A'), H (B'), J (C'), and Lanashuaia (D'). Quartile distributions of ontogenic $\delta^{18}\text{O}$ values of M8-19 (E) and of modern shells collected monthly (F) are used to compare main $\delta^{18}\text{O}$ differences.