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INTRODUCTION

Applications of Stable Isotope Analysis in Zooarchaeology: An Introduction

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ABSTRACT This special volume brings together works that present cases of studies that combine analysis of stable isotopes and zooarchaeology in different areas of Chile and Argentina, with special emphasis on the latter. These analyses were conducted in order to examine paleoecological conditions and interactions between humans and animal resources in different spatial and temporal contexts. In this introduction, we examine three ways in which stable isotopes have been applied in zooarcheology: (i) past animal-human relations, (ii) stable isotopes and zooarchaeology in conservation biology, and (iii) species biogeography, climate, and environment. The implications of the results of each of the papers in this volume stress that this type of study is a fruitful and promising line of research as it expands the thematic spectrum investigated, tests archaeological hypothesis, explores new lines of analysis, and enriches the interpretations about the past.

Key words: zooarchaeology; stable isotopes; human-animal relation; conservation biology; biogeography

Isotope analysis of the zooarchaeological record is fundamental for the accurate interpretation of stable isotope values obtained from human skeletal remains, provides data about the long-term ecosystem functioning, and can serve as a guide for establishing frames of ecological reference. Doing so demands analyses that successfully integrate data that differ in their units of analysis, degree of temporal resolution, and taphonomic history. While the need to integrate stable isotope studies in zooarchaeology has recently been recognized with the establishment of a new International Council of Archaeozoology (ICAZ) stable isotope working group (ICAZ Newsletter Fall 2012), comprehensive reviews, syntheses, or special volumes have been relatively rare (Birch, 2013).

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The aim of this special issue is to assemble case studies that articulate stable isotope studies and zooarchaeological analyses with the purpose of examining paleoecological conditions and interactions between humans and animal resources in different spatial and temporal contexts. This special issue was born from a symposium at the II National Congress of Argentine Zooarchaeology, which took place in Olavarria at the Facultad de Ciencias Sociales (UNCPBA) between 10 and 14 May 2011. It brings together original research articles that use stable isotopes to address paleoecological questions across a wide variety of environments throughout mainland and island Argentina and Chile (Figure 1). These touch on a range of different anthropological issues, from the colonization processes of marine hunter–gatherers to pastoralism in sedentary societies. As an introduction, we examine three ways in which stable isotopes have been applied in zooarcheology: (i) past human–animal relations; (ii) stable isotopes and zooarchaeology in conservation biology; and (iii) species biogeography, climate, and environment.

Figure 1. Locations of case studies presented in this Special Issue: 1. Samec *et al.*, 2. Dantas *et al.*, 3. Giardina *et al.*, 4. Tessone *et al.*, 5. Mendez *et al.*, 6. Tessone *et al.*, and 7. Zangrando *et al.* This figure is available in colour online at wileyonlinelibrary.com/journal/oa.

Past human–animal relation

As Butzer (1982: 191) pointed out, the higher aspiration of zooarchaeology is 'to study the relationship between people and animals as they interact spatially and as their mutual adaptive patterns change through time'. In this sense, stable isotope studies fit well with this primary aim and have been applied to the zooarchaeological record with three main goals: human dietary reconstruction, to explore herding and hunting strategies, and to analyse the influence of human hunting pressure on the foraging behaviour of animals.

The use of stable isotopes from zooarchaeological samples to reconstruct human paleodiets is perhaps the most widely applied. Such data are used to identify the foods consumed by humans in the past and to discuss dietary changes or variations in landscape use by human populations in different environments. Thus, the isotopic study of human paleodiet in several contexts led to reconstructing the natural distribution of stable isotopes – usually $\delta^{13}C$ and $\delta^{15}N$ – in different food chains and ecosystems (Tauber, 1981; Chisholm *et al.*, 1982; Sealy & van der Merwe, 1986; Ambrose *et al.*, 1997; Katzenberg & Weber, 1999, among others). While initial interpretations of human paleodiets were made mainly on the basis of isotopic values from modern animal tissues (i.e. Chisholm *et al.*, 1982; Sealy & van der Merwe, 1986; Walker & De Niro, 1986), in recent years, the isotopic analyses of zooarchaeological remains have become a common practice in order to generate a paleoecological framework where past human values can be examined. In this special issue, Mendez and co-authors's paper, 'Isotopic ecology and human diets in the Forest-Steppe Ecotone, Aisén Region, Central-Western Patagonia, Chile', builds an isotopic ecology from forest and steppe areas of Central Chile for the purpose of assessing long-term human diet. The authors demonstrate that these terrestrial ecozones can be differentiated isotopically through animal resource values, and they conclude that human dietary choices were focused on protein provided by mammals from steppe environments. Mendez *et al.* also suggest hypothetically that small carnivores, small omnivores, and birds may have been an important part of human subsistence in the Early Holocene.

Herding strategies have also been assessed by stable isotope studies. Balasse & Tresset (2002) explored the use of Neolithic domestic cattle in Bercy, France, by studying weaning patterns evidenced by biogeochemical changes in bovine teeth. The intra-tooth variation of $\delta^{15}N$ in collagen suggests that domestic bovines from the Neolithic site of Bercy were weaned earlier, which was interpreted by the authors as reflecting either a shorter length of lactation in domestic females, or weaning imposed by herders in order to reserve milk production for human consumption (Balasse & Tresset, 2002). The use of seaweed as fodder for Neolithic domestic animals was evaluated by stable isotope evidence ($\delta^{13}C$ and $\delta^{18}O$) in Scotland (Balasse *et al.*, 2006). Variation in enamel bioapatite carbon and oxygen isotope ratios in sheep teeth at the Holm of Papa Westray shows a significant contribution of seaweed to the winter diet of sheep (*ca.* 3000 BC), which was understood as a first step towards adaptation to reliance on seaweed (Balasse *et al.*, 2006). Camelid management practices were also evaluated by stable isotope evidence at Conchopata, Perú (Finucane *et al.*, 2006). Finucane *et al.* have identified a divergence in the $\delta^{13}C$ values of Conchopata camelids from both archaeological and modern contexts. The authors suggest that this divergence reflects two distinct forms of camelid husbandry in the ancient Andes: grazing on puna pasture, characterized by C_3 flora, and maize foddering (Finucane *et al.*, 2006). In the paper titled 'Llamas in the Cornfield: Prehispanic Agro-Pastoral System in the Southern Andes' of this special issue, Dantas and co-authors use stable isotope analyses and other archaeological evidence in order to investigate the organization of camelid production in the Ambato

Valley (northern Argentine Andes). The authors suggest the presence of an organizational mode for the production of plants and animals based on a new, integrated agro-pastoral practice which combines agrarian and livestock productive strategies. Since $\delta^{13}C$ values of domestic camelids reveal C_4 consumption, this new agro-pastoral practice combined pens and agriculture terraces in an annual productive cycle. During the dry season, llamas penned in agricultural terraces were foddered with maize residue and, at the same time, helped fertilize corn fields during fallow via their manure production.

Regarding hunting strategies, recent papers improve our understanding of prehistoric hunting practices using carbon, oxygen, and strontium isotope ratio variation, particularly to differentiate between individual hunts and mass kills (Hoppe, 2004; Widga, 2004; Fenner, 2008). The main assumption is that the variation in isotopic values of a zooarchaeological assemblage from different hunting events and probably different populations should be broader than that resulting from one hunting event and a single population (Fenner, 2008). The paper '$\delta^{13}C$ and $\delta^{15}N$ Variability in Modern Guanaco (*Lama guanicoe*) Assemblages in Southern Patagonia: Implications for Zooarchaeological Studies', presented by Tessone and co-authors, evaluates this assumption based on the degree of variability of $\delta^{13}C$ and $\delta^{15}N$ in different modern groups of guanacos and discusses the implications for archaeofaunal analyses in southern Patagonia. Tessone *et al.* reject the hypothesis that isotopic variability of a single herd is lower than that obtained from multiple populations and different hunting events of this resource in southern Patagonia; different reasons for this argument are discussed in the paper.

Finally, resource depression or decline in encounter rates of resources in marine ecosystems has become a topic of worldwide discussion in the last two decades. Human hunting and fishing activities in ancient coastal settings caused declines in overall foraging efficiency, triggered trophic cascades, or reduced the size of prey (Rick & Erlandson, 2009). However, human foraging behaviour has also varied in the past in response to the impact of climate change on the food web. Stable isotopes studies serve as a method of documenting long-term variation in marine community ecology (Newsome *et al.*, 2010a). Many stable isotope studies applied to the zooarchaeological record of coastal settings have emerged in the last decade, mostly concentrated in the Northwest Pacific Coast (Burton *et al.*, 2001, 2002; Gifford-Gonzalez *et al.*, 2005; Moss *et al.*, 2006; Newsome *et al.*, 2007; Corbett *et al.*, 2008; Misarti *et al.*, 2009; Szpak *et al.*, 2009; 2012; Krylovich, 2011). In the paper 'Zooarchaeological and stable isotopic assessments on pinniped-human relations in the Beagle Channel (Tierra del Fuego, southern South America)', Zangrando *et al.* explore changes in southern fur sea lions foraging habitats that would lead to variations in their availability at different times. This paper is based on the presumption that foraging dynamics of pinnipeds between different marine areas can be monitored through changes in carbon and nitrogen stable isotopes (Burton & Koch, 1999; Burton *et al.*, 2001; Gifford-Gonzalez *et al.*, 2005; Newsome *et al.*, 2010a). The authors observe that stable isotope analyses support changes in the foraging behaviour of female sea lions between early and late periods of the archaeological sequence, which could be interpreted as a female strategy of avoiding areas frequented by human predators. The decrease in body size of southern fur seals across the archaeological sequence of the Túnel locality also suggests that harvest intensity increased over time. On the basis of these factors, Zangrando and co-authors suggest that a resource depression of pinnipeds took place in the southern end South America.

Stable isotopes and zooarchaeology in conservation biology

It has long been recognized that zooarchaeology has much to offer conservation biology, and contributions to the field have become more frequent (Lyman, 1996; Rick & Lockwood, 2013; see contributions in Lyman & Cannon, 2004 and Wolverton & Lyman, 2012). Zooarchaeology, as well as paleoecology and paleozoology, allows for the study of changes and responses of species and ecosystems over suitable timescales. Lyman (1996) stressed four main areas in which zooarchaeological record becomes an essential tool in conservation biology: populations threatened with extirpation, re-establishment of extirpated population, identifying exotic animals and biological preserves, and planning for the future. Stable isotope analysis, by providing insights into dietary and/or residence patterns of an organism, is an extremely useful tool. For instance, Emslie & Patterson (2007) studied the dietary changes of Adélie penguin (*Pygoscelis adeliae*) from $\delta^{13}C$ and $\delta^{15}N$ analysis of various tissues recovered from Antarctica colonies, ranging in age from 100 to 38,000 years B.P. Other examples include evaluating dietary shifts of predatory birds from the Pleistocene to the historical period in North America, such as the California condor (*Gymnogyps californianus*, Chamberlain *et al.*, 2005) and bald eagle (*Haliaeetus leucocephalus*, Newsome *et al.*, 2010b). In a recent paper, Rosania (2012) provides tools for decision making and the reestablishment of the black

bear (*Ursus americanus*) in Missouri from the characterization of the diet of this species. In an analogous marine case, Newsome *et al*. (2007) discuss the re-establishment of colonies of northern fur seals (*Callorhinus ursinus*) in latitudes that were inhabited during much of the Holocene until it became extinct in recent times. Finally, $\delta^{13}C$ and $\delta^{15}N$ studies carried out on Rocky Mountain Bighorn Sheep (*Ovis canadensis*) provided a historical perspective on the habitat and range of this species in order to establish policies for their future management (Hughes, 2004). These studies highlight the importance of having a deep temporal record of stable isotope data for the recovery, restoration, and future preservation of the species analysed. The combination of these two disciplines provides a great opportunity for decision making and management of species and ecosystems.

In this volume, the paper '*$\delta_{13}C$ and $\delta_{15}N$ Characterization of Modern Huemul (Hippocamelus bisulcus) from the Patagonian Andean Forest. Scope and Limitations of Their Use as a Geographical Marker*', Tessone and coauthors provide $\delta^{13}C$ and $\delta^{15}N$ data on modern huemuls (*Hippocamelus bisulcus*) recovered from National Parks in Patagonia, Argentina. This cervid is considered an endangered species by the International Union for the Conservation of Nature (IUCN); since the colonization of the region by western populations, its distribution has contracted dramatically. Steppe habitats have been abandoned and modern ranges restricted to forest environments only (Díaz, 2000; Flueck & Smith-Flueck, 2012). The results of the current work show, in the first place, that there is no relationship between the isotopic values of modern huemuls and precipitation in the samples they recovered. Second, it is possible to differentiate the isotopic signals of huemul from guanacos, herbivores occupying arid Patagonian region. The authors highlight the utility of stable isotopes analysis to discuss the use of the habitat in the past of this species and test the paleobiogeographic hypotheses. There is a belief that stable isotope analyses of the specimens recovered in the zooarchaeological record are a powerful tool for future decision making and management of huemul.

Species biogeography, climate, and environment

The spatial distribution of stable isotopes varies with different climatic and environmental parameters. These spatial differences mean that under the right circumstances stable isotopes can be used to establish differential use of environments by an organism, such as the consumption of marine versus terrestrial resources (Chamberlain *et al*., 2005; Newsome *et al*., 2010b; Rick *et al*., 2011), the use of environments with different percentages of C_3 and C_4 plants (Cormie & Schwarcz, 1994; Cerling *et al*., 1999), or the use of marine resources from nearshore and offshore spaces (Burton & Koch, 1999; Burton *et al*., 2001; Newsome *et al*., 2010a). Furthermore, these variations in spatial scale permit studies of movement between habitats and the migratory patterns of various animal species (Hobson, 1999; Rubenstein & Hobson, 2004). These studies are also closely tied to the development *isoscapes*, defined as maps of variations in the natural distribution of stable isotopes (Bowen, 2010). Such studies have been done mostly on species of birds, fish, and marine mammals which migrate over broad spatial scales (Graham *et al*., 2010; Hobson *et al*., 2010).

Most of these studies were conducted with stable isotopes of oxygen ($\delta^{18}O$), deuterium (δD), and strontium (Sr^{87}/Sr^{86}), although stable isotopes of carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) are also applicable. In this regard, Drucker *et al*. (2008) looked at the use of $\delta^{13}C$ to establish if ^{13}C depletion in plants growing under forested closed canopies (the 'canopy effect') is recorded in the isotopic values of various species of large herbivores. The authors examine zooarchaeological remains from European sites and conclude that the canopy effect is the driving parameter for the decline in $\delta^{13}C$ of herbivores at the transition between Late-Glacial and Early Holocene in western Europe. Drucker *et al*. (2008) suggest that ^{13}C in zooarchaeological remains can be used to complement other paleoenvironmental tracers, as well as to analyse changes in the use of the environment by herbivore species.

In this volume, the paper '*Rheidae egg human explotation and stable isotopes: trends from west central Argentina*', Giardina and coauthors analyse $\delta^{13}C$ and $\delta^{18}O$ in rheidae eggshell – *Rhea pennata* and *Rhea ameriacana* – from Holocene archaeological sites of west-central Argentina. The authors identified isotopic differences relative to the ecological area in which the eggshell was recovered, coinciding with the geographical distribution of the two species today. They likewise recorded rheidae eggshell in ecological areas where these species are not currently found, so the stable isotopes are positioned as a tool to evaluate mobility and transport by human populations.

Stable isotope analyses of zooarchaeological or paleontological remains are also used as paleoclimatic and paleoenvironmental indicators over archaeological timescales. Stable isotopes of oxygen ($\delta^{18}O$) are most commonly used when performing such studies. This is due to the strong influence of climate and environmental parameters on the $\delta^{18}O$ signals of rainfall and the water cycle. $\delta^{18}O$ values from the hydroxyapatite of bones and teeth reflect those of ingested water and water

contained in food. Depending on aspects of physiology and environment and the contribution of drinking water to total body water, the $\delta^{18}O$ of hydroxyapatite reflects isotopic values of precipitation and local water sources (Sponheimer & Lee-Thorp, 1999; Hoppe, 2006; Fox *et al.*, 2007; Ugan *et al.*, 2012). All else equal, temporal differences in bone or enamel $\delta^{18}O$ are taken to indicate changes in the underlying climatic and environmental factors establishing the isotopic values of those sources.

Oxygen is not the only isotope used to establish climatic proxies. Another example is the analysis of $\delta^{13}C$ from the eggshells of flightless birds in Australia — *Dromaius novaehoilandiae* and *Genyornis newtoni*. An abrupt change in the contribution of C_3 versus C_4 plants in the diet of these species was inferred from shifts in the isotope values of their shells. This study allowed evaluating the evolution of C_3 and C_4 plants through time in Australia, its relationship to the extinction of one of these species (*Genyornis newton*), and the potential climatic and anthropogenic causes of the change (Johnson *et al.*, 1999; Miller *et al.*, 2005).

Similar studies are also performed with the analysis of collagen $\delta^{13}C$ and $\delta^{15}N$ of bones or teeth from zooarchaeological remains. In such cases, the isotopic signals indirectly reflect the evolution of climate and environment as they affect the $\delta^{13}C$ and $\delta^{15}N$ values of plants and soils. For example, changing collagen $\delta^{13}C$ and $\delta^{15}N$ values from horses, goats, and deer have been linked to oscillating climatic conditions in Europe over the last 40,000 years (Iacumin *et al.*, 1997, 2000; Richards & Hedges, 2003; Hedges *et al.*, 2004; Stevens & Hedges, 2004).

In the paper *'Exploring Human Subsistence Strategies and Environmental Change through Stable Isotopes in the Dry Puna of Argentina'* of this volume, Samec *et al*. analyse the collagen $\delta^{13}C$ and $\delta^{15}N$ values of vicuñas and guanacos from Hornillos 2, northwest Argentina, during the early and middle Holocene (9710–6130 BP). They demonstrate that the isotopic signatures of the two taxa do not differ, despite the fact that they have different dietary and habitat preferences. They also demonstrate changes in $\delta^{15}N$ values through time, with higher $\delta^{15}N$ during the middle Holocene. The authors see these changes as a reflection of increasing aridity during the mid-Holocene in the region – coincident with other proxies – and suggest the $\delta^{15}N$ of camelids may also serve as a paleoenvironmental proxy.

Final remarks

The papers presented here reflect the growing interest of researchers in incorporating new methodological tools in zooarchaeological analysis. The variety of topics that have been included in this volume clearly demonstrates the contribution of stable isotopes to address major issues in the interaction between humans and animals. In addition, this group of selected papers highlights the systematic and sustained development of zooarchaeology in the Southern Cone of America over the last 20 years. It expands the thematic spectrum investigated, tests archaeological hypothesis, explores new lines of analysis, and enriches the interpretations about the past.

The emergence and development of stable isotope studies in animals are possible thanks to the continuous growth and acceptance of the zooarchaeology worldwide. The maturity and consolidation of the discipline allow exploration of new lines of research and original contributions.

This volume shows how the integration of results obtained through the analysis of the archaeofaunal remains and their stable isotopes enriches the interpretations of the past and is positioned as a promising exploratory route.

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