Quaternary International xxx (2015) 1–8

Contents lists available at ScienceDirect

Quaternary International

journal homepage: www.elsevier.com/locate/quaint

Exploring body size of modern South American fur seal (*Arctocephalus australis*) for osteometric studies in zooarchaeological remains from northern Patagonia, Argentina

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ARTICLE INFO

Article history:
Available online xxx

Keywords:
South American fur seal
Osteometry
Skull size
Modern analogues
Northern and central Patagonia
Zooarchaeology

ABSTRACT

In order to assess the role of pinnipeds in prehistoric subsistence of hunter–gatherers from northern Patagonia, traditional osteometric studies based on modern collections of *Arctocephalus australis* (*Aa*) and *Otaria flavescens* (*Of*) with known age and sex are being employed with the aim of identifying species, sex and age-classes found in zooarchaeological assemblages. A preliminary research based on a very small sample of *Aa* from the Uruguayan coast suggested the absence of changes in the skull size of this species during the last five decades. *Of* skull size reduction through time was observed as a consequence of a density-dependence process in northern and central Patagonia. In this study we discuss the use of modern analogues for the study of zooarchaeological remains of *Aa*. With this objective in mind, osteometrical data from modern skulls of 30 adult male *Aa* collected along northern and central Patagonia were analysed to assess potential diachronic changes in body size of this species. The results showed that there is no evidence of change in the body size during the last three decades (1990–2013) in the *Aa* population from northern and central Patagonia. This result supports the relevance of investigations if there are differences in the body size of living individuals that will be employed as analogues, for evaluating the potential of these measurements before using them in the analysis of zooarchaeological remains. The use of modern animals of *Aa* in osteometric analysis of fur seal assemblages recovered in archaeological sites at northern Patagonia is reasonable.

1. Introduction

Due to the osteological similarities that seals have, the zooarchaeological study of these marine mammals has been subject to the ability of researchers for identifying species recovered in archaeological sites. In many coastal areas of the world, zooarchaeological researchers have been employing a combination of different analytical methods for this task: osteometrical analyses on modern samples to assess the archaeological bones; and identification of unique traits of each species of seals, to establish the epiphyseal fusion sequence (e.g., Hodgetts, 1999; Stora, 2000, 2002; Etnier, 2002; Stora and Lougas, 2005; among others). Osteometry has been one of the most frequent and important tools used to identify species of pinnipeds, and to evaluate the parameters of sex and age of exploited populations in the past (Borella, 2014).

The zooarchaeological researchers of southern South America frequently mention the exploitation of these marine mammals by hunter–gatherers. Two otariid species are the most common in the Patagonian archaeological record, the South American fur seal [*Arctocephalus australis* (hereafter *Aa*)] and the South American sea lion [*Otaria flavescens* (hereafter *Of*)]. Different investigations in otariid remains from Tierra del Fuego and Patagonia have been undertaken and developed since the 1980s (for an overview see Muñoz, 2011 and Borella, 2014), but none has applied osteometric analysis. However, there are very few studies on otariid remains that have examined the frequency of both species (*Aa* and *Of*) or the structure of age at death in the archaeological record (see Legoupil, 1989–90; Schiavini, 1990, 1993; Orquera and Piana, 1999; San Roman, 2011; between others), even though this information is

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http://dx.doi.org/10.1016/j.quaint.2015.07.038
1040-6182/

Please cite this article in press as: Borella, F., et al., Exploring body size of modern South American fur seal (*Arctocephalus australis*) for osteometric studies in zooarchaeological remains from northern Patagonia, Argentina, Quaternary International (2015), http://dx.doi.org/10.1016/j.quaint.2015.07.038

crucial to evaluate the role of these taxa in prehistoric subsistence of hunter–gatherers in Patagonia (Borella, 2014).

In recent years, *Aa* and *Of* have been identified in archaeological sites from the San Matías Gulf (Río Negro Province, Northern Patagonia-Argentina; Borella, 2006) by the presence of mandibles, although the most common is the finding of non-fused postcranial bones (Borella et al., 2011, Borella and Cruz, 2012). At present, both species share almost the same distribution range in South America (Fig. 1a), but its abundance in the Atlantic coast is not equivalent, as *Of* predominates significantly over *Aa* on the rookeries from northern Patagonia and Tierra del Fuego (Fig. 1b) (Dans et al., 2004; Crespo et al., 2015).

However, in the last two centuries the otariid populations had suffered dramatic changes because the marine ecosystems of Patagonia were subject to major human impacts (Saporiti et al., 2014). As a consequence of sealing, the *Aa* population was heavily reduced during the 18th and 20th centuries (Crespo et al., 2015), while *Of* population was decimated during the first half of the 20th century (Crespo and Pedraza, 1991; Grandi et al., 2015). In turn, the removal of these predators would have triggered the Magellanic penguin *Spheniscus magellanicus* population expansion during the past century, due to an increased availability of anchovies *Engraulis anchoita* by predation release (Boersma et al., 1990). Nevertheless, otariid populations have been increasing in number during recent decades (Crespo et al., 2015; Grandi et al., 2015), although in a new ecological scenario characterized by the removal of a large biomass of demersal fishes and squids by fisheries (Koen Alonso and Yodzis, 2005).

Both species of otariids are highly dimorphic, with males (*Of* about 300 kg and *Aa* about 140 kg, see Fig. 2) being much larger than females (*Of* about 140 kg and *Aa* about 50 kg; Bastida et al., 2007). Post-cranial skeletal morphology is remarkably similar between these pinnipeds, especially between adult female sea lions and adult male fur seals, increasing the difficulties in achieving specific determinations. Nevertheless, the greatest identification problems occur amongst non-fused individuals (young) (Legoupil, 1989–1990; Schiavini, 1990).

Fig. 2. Male South American fur seal (*Aa*) at Chubut province, Argentina.

The size of prehistoric species of mammals can be estimated from the analogous of living species assuming a similar scale (MacFadden and Hulbert, 1990). This implies the assumption that modern species have the same body size as in the past, although considering the importance of complexities of body size biology in each case of investigation (Weinstock, 2006). Using this basic principle, several osteometric researches were conducted in terrestrial vertebrates in order to determine the season of death based on the growth of long bones. In addition, osteometric analyses were applied to investigate the timing of hunting and the relative abundance of different species of seals in the archaeological

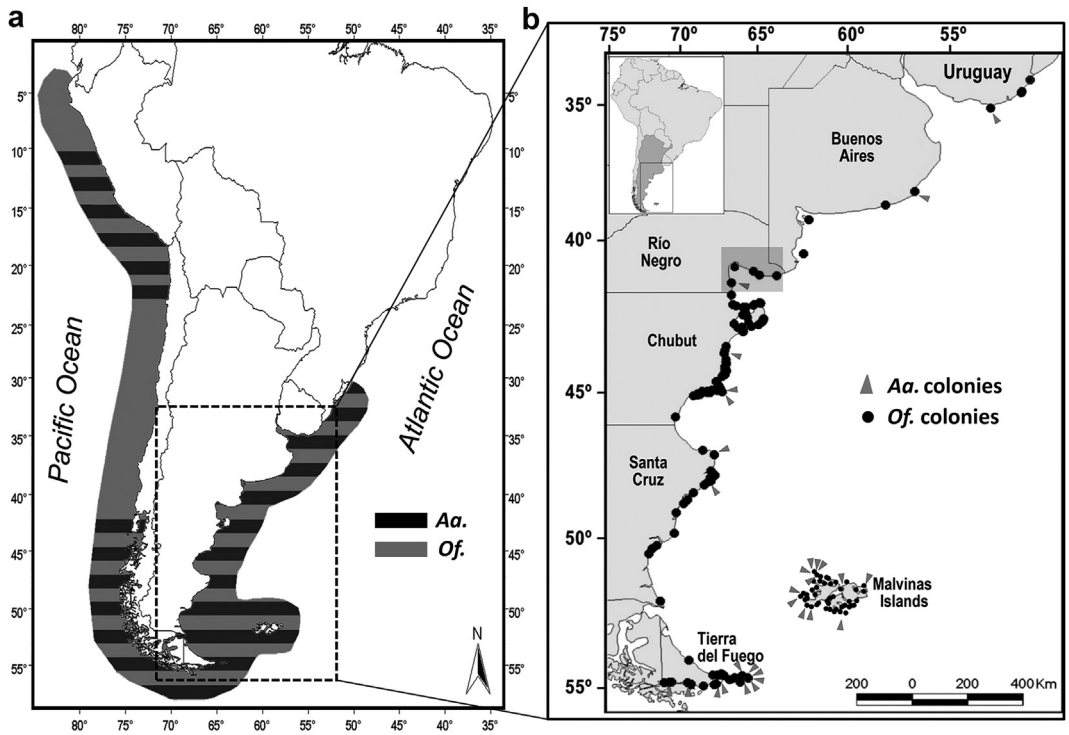

Fig. 1. (a) Distribution area for South American fur seal (*Aa*) and South American sea lion (*Of*); (b) Colonies of South American fur seal (*Aa*) and South American sea lion (*Of*) along the Atlantic coast of Patagonia. The shaded area marks the San Matias Gulf area where *Aa* remains dominate the archaeological record during the last 3000 years BP.

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record worldwide (Woodborne et al., 1995; Etnier, 2002; Stora, 2002; Hodgetts, 2005; Stora and Lougas, 2005).

However, in Patagonia it was not until recently that osteometric analyses, based on isomorphic studies, started to be employed in the studies of otariid remains in order to achieve a correct taxonomic identification and to discuss the hunters–gatherers' exploitation strategies (Borella et al., 2014; Borella and L'Heureux, 2014). Currently, these studies consist in the use of measurements obtained from modern specimens (with known age and sex) to explore the zooarchaeological assemblages in order to study the prehistoric exploitation of sea mammals (Hodgetts, 2005 and references therein).

Nevertheless, the assumption of isomorphic similarity is not always true, as there are complexities in the biology of body size that are sometimes overlooked. Many mammals show variations in body size related to physiological and ecological relevant variables such as diet, population density and home range size, body condition, thermoregulation, among others (Weinstock, 2006 and references therein). In the case of otariids, changes in the body size have been detected in response to changes in population density (e.g Etnier, 2002, 2004; Drago et al., 2010) or in response to different environmental pressures (Boyd and Roberts, 1993). Therefore, it becomes necessary to evaluate the applicability of this premise in each case study.

Marine mammal hunting and fishing have dramatically modified the structure of marine ecosystems of Patagonia during the last centuries (Koen Alonso and Yodzis, 2005; Saporiti et al., 2014). Recent research on *Of* from northern Patagonia (Chubut Province) showed a reduction in the skull size of adults during the period 1990–2000, attributed to a combination of factors related to the intensive fishing exploitation of the marine ecosystem and density dependent responses (Drago et al., 2010). Given that the size of the skull is highly correlated with body size in this species (Rosas et al., 1993), the reduction of skulls detected in recent decades would indicate a reduction in the body size of these animals. Contemporaneously, *Aa* increased their numbers at an annual rate of about 8% (Crespo et al., 2015), whereas the availability of some of the main prey of this predator was modified in the ecosystem by fishery activities (e.g. Argentine hake *Merluccius hubbsi* and Argentine shortfin squid *Illex argentinus*; Koen Alonso and Yodzis, 2005; Vales et al., 2015), although changes in body size were not investigated for this species.

Taking into account that inferences about the individuals found in the zooarchaeological assemblages are made from measurements obtained from skeletons of modern individuals, it is necessary to explore whether the recently detected variations in body size in *Of* may have occurred in *Aa*. This is important because fur seal skull dimensions are highly correlated with total body length (*e.g.* condylobasal length (CBL) *vs* standard body length (SL), Ximénez et al., 1984) and changes in skull size through time would be expected to correlate with variations in somatic growth, and thus may inhibit the use of modern bone collections of *Aa* to evaluate archaeological samples.

A preliminary study based on a sample of 18 adult males *Aa* from the Uruguayan coast (approximately 35° S) suggested the absence of changes in the skull size of this species during the last five decades (De Maria et al., 2012). However, given that the sample size used by these researchers is rather small, and it has been found that the body size of some otariid species may vary regionally (Etnier, 2002; Sepúlveda et al., 2013), it is necessary to reevaluate potential changes in the body size of fur seals through time using a larger sample size composed of modern specimens of *Aa* from northern Patagonia (approximately 41–46° S) before they can be applied as modern analogues.

2. Material and methods

Thirty skulls of dead fur seals stranded along the Atlantic coast of northern and central Patagonia (coasts of Río Negro and Chubut provinces) from 1990 to 2013 were measured from the scientific collection of the Marine Mammal Laboratory CENPAT (CONICET), Puerto Madryn (Argentina) (Table 1; Fig. 3). In order to avoid biases of size differences related to sexual dimorphism and growth, only skulls of adult males were analyzed. Individual ages were estimated from counts of growth layer groups (GLGs; Scheffer, 1950; Laws, 1952) in the dentine and/or in the cementum of teeth, and it was assumed that one GLG is deposited per year (Schiavini et al., 1992; Crespo et al., 1994; Molina-Schiller and Pinedo, 2004). The age of the selected individuals ranged from 8 to 19 years.

Table 1
Sampling data (locality and time period) and estimated age of adult male *Aa* from northern and central Patagonia. The collection sites are referenced in Fig. 3.

N	Code	Locality	Province	Time period	Age
1	Aa001	Playa del Barco Roca	Chubut	1990–1999	11
2	Aa012	Punta Norte	Chubut	1990–1999	11
3	Aa018	Isla Arce	Chubut	1990–1999	8.5
4	Aa019	Isla Arce	Chubut	1990–1999	12
5	Aa023	Cabo dos Bahías	Chubut	1990–1999	10
6	Aa033	Punta León Sur	Chubut	2000–2009	9
7	Aa036	Isla Tovita	Chubut	2000–2009	10
8	Aa038	Punta Delgada	Chubut	2000–2009	9
9	Aa042	Puerto Lobos N	Rio Negro	2000–2009	14
10	Aa043	Isla Arce	Chubut	2000–2009	13
11	Aa048	Barranca Final	Rio Negro	2000–2009	12
12	Aa050	La Pastosa	Rio Negro	2000–2009	9
13	Aa051	La Pastosa	Rio Negro	2000–2009	10
14	Aa052	La Pastosa	Rio Negro	2000–2009	9
15	Aa058	Isla Rasa	Chubut	2000–2009	13
16	Aa059	Islote Moreno	Chubut	2000–2009	9
17	Aa060	Islote Moreno	Chubut	2000–2009	10
18	Aa061	Isla Arce	Chubut	2000–2009	11
19	Aa078	La Rinconada	Rio Negro	2010–2013	9
20	Aa079	La Mar Grande	Rio Negro	2010–2013	14
21	Aa083	Islote Lobos	Rio Negro	2010–2013	13
22	Aa084	Islote Lobos	Rio Negro	2010–2013	>8
23	Aa085	Islote Lobos	Rio Negro	2010–2013	13
24	Aa086	Islote Lobos	Rio Negro	2010–2013	11
25	Aa088	Bajada Las Grutas	Rio Negro	2010–2013	19
26	Aa090	Isla Arce	Chubut	2010–2013	15
27	Aa091	Isla Rasa	Chubut	2010–2013	11
28	Aa094	Isla Rasa	Chubut	2010–2013	>8
29	Aa103	Punta Tafor	Chubut	2010–2013	>8
30	Aa107	Isla Escondida	Chubut	2010–2013	>8

Twelve craniometrical variables were analyzed (Brunner, 2002; Drago et al., 2010). Measures that best reflect the change in size of skull and mandibles recorded for another otariid species were selected (Drago et al., 2010) (Fig. 4). All the measurements were obtained by a single observer (F.B.) using a digital calliper with precision of 0.01 mm. Data were analysed through different univariate and multivariate statistical tests using SPSS 21 and SYSTAT 13.

The sample was studied initially as a single group and different statistical tests were applied to explore if natural groups emerged. Given that no particular pattern was identified, the sample was divided into three arbitrary periods of time for comparative purposes. Considering the changes in the marine ecosystem of northern and central Patagonia (Koen Alonso and Yodzis, 2005), the *Aa* population growth recorded for the region during the last decades (Crespo et al., 2015), and the reported changes in the somatic growth of *Of* (Drago et al., 2010), fur seal skulls were grouped by decades in 3 consecutive periods: A first period (1990–1999) characterized by a relative low abundance of *Aa* and the reduction of

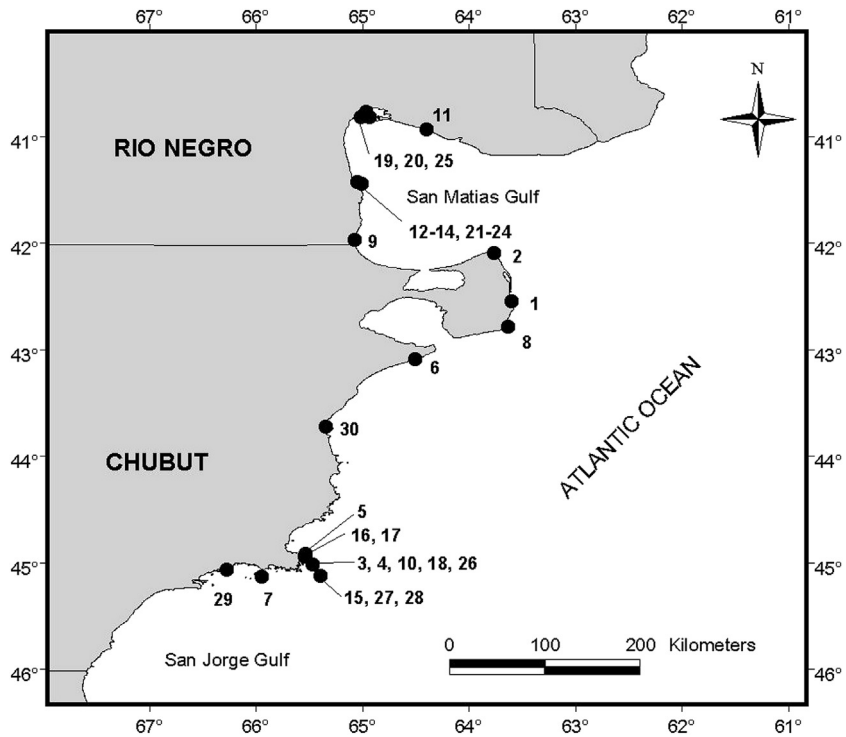

Fig. 3. Location sites of samples collection. See details of the samples in Table 1. Chubut: (1) Playa del Barco Roca; (2) Punta Norte; (3, 4, 10, 18, 26) Isla Arce; (5) Cabo dos Bahías; (6) Punta León Sur; (7) Isla Tovita; (8) Punta Delgada; (15, 27, 28) Isla Rasa; (16, 17) Islote Moreno; (29) Punta Tafor; (30) Isla Escondida. Río Negro: (9) Puerto Lobos N; (11) Barranca Final; (12–14) La Pastosa; (19) La Rinconada; (20) La Mar Grande; (21–24) Islote Lobos; (25) Bajada Las Grutas.

hake biomass by mid-late 1990's (n = 5); A second period (2000–2009) considered transitional between the first and the third, with a growing *Aa* population (n = 13); A third period (2010–2013) characterized by an increasing abundance of *Aa* at present (n = 12).

3. Results

Principal Component Analysis of craniometrical data showed that the first two components analysed explained more than 76.2% of the total morphological variation observed (Fig. 5a). Variables with the greatest loading in component 1 were CBL, GPPL for crania and ML for mandible (Table 2). The scatter plot of PCA displayed little size difference between skulls of *Aa* and showed almost complete overlap between the defined time periods (Fig. 5b).

Table 2
Component loading from principal component analysis for craniometrical variables of adult male *Aa*. For variable numbers and abbreviations see Figs. 4 and 5.

Skull variable		Component		
Number	Abbreviation	C1	C2	C3
1	CBL	0.948	−0.130	−0.133
2	GOCL	0.782	−0.409	0.125
3	GPPL	0.932	−0.156	−0.064
4	PL	0.782	−0.160	−0.347
5	BZRL	0.868	0.049	−0.198
6	ZL	0.871	0.028	−0.284
7	ZW	0.838	−0.077	0.297
8	MW	0.770	−0.309	0.466
9	CH	0.669	0.583	0.301
10	ML	0.942	0.038	0.036
11	MH	0.836	0.311	−0.108
12	ACL	0.859	0.306	0.031
Variance explained		8.580	0.870	0.678

Mean values for each variable measured of the three time periods of *Aa* analysed are shown in Table 3. The Discriminant Analysis (DA) did not significantly separate these sets (Wilks' lambda = 0.24; Approx. F = 1.2; p = 0.31). The classification matrix properly assigned 80% of the cases to the defined time periods. The jack-knifed classification matrix properly assigned only 37% of the cases, the last two time periods being better classified (Table 4).

Table 3
Mean for each variable measured of the three time periods of *Aa* analyzed. For variable numbers and abbreviations see Figs. 4 and 5.

Group means			
Variable	1990–1999	2000–2009	2010–2013
1 CBL	239.904	234.970	233.981
2 GOCL	205.044	204.638	205.313
3 GPPL	179.224	175.764	174.480
4 PL	107.016	102.965	102.374
5 BZRL	161.916	161.514	159.421
6 ZL	93.264	92.762	92.332
7 ZW	138.924	138.498	134.996
8 MW	129.078	127.435	126.752
9 CH	87.220	86.105	85.027
10 ML	166.996	162.773	162.201
11 MH	69.082	67.043	63.295
12 ACL	60.052	55.868	54.752

Table 4
DA. Classification matrix (a) and Jackknifed classification matrix (b). Frequencies of individuals classified by Discriminant Analysis into the correct period group.

a	1990–1999	2000–2009	2010–2013	%correct
1990–1999	4	0	1	80
2000–2009	0	11	2	85
2010–2013	1	2	9	75
Total	5	13	12	80

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Table 4 (*continued*)

a	1990–1999	2000–2009	2010–2013	%correct
b	1990–1999	2000–2009	2010–2013	%correct
1990–1999	0	3	2	0
2000–2009	4	6	3	46
2010–2013	3	4	5	42
Total	7	13	10	37

Although there were no statistically significant differences between time-groups, the scatter plot of DA showed a pattern where it is observed that groups were spatially separated. The individuals of the first period (1990–1999) were larger than individuals of the second period (2000–2009) and third period (2010–2013). The group of fur seals from the first period did not overlap with the 2000s (Fig. 6a).

The results of the analysis of variance (One-way ANOVA) for independent variables and their Geometric Mean (GM) were consistent with those observed previously. Although the ANOVA was not statistically significant (Table 5), the graphical representation of the ANOVA analysis showed a pattern with a greater MG and higher dispersion for the first period than other time groups (Fig. 6b). Summarizing, results suggest that no significant differences were recorded between the means of skull size of *Aa* of the periods 1 (1990–1999), 2 (2000–2009) and 3 (2010–2013).

Table 5
Analysis of Variance (ANOVA One-Way) for the Geometric Mean of the three time periods analyzed.

Source	Sum-of-squares	df	Mean-square	F-ratio	P
Period	60.884	2	30.442	1.185	0.321
Error	693.123	27	25.671		

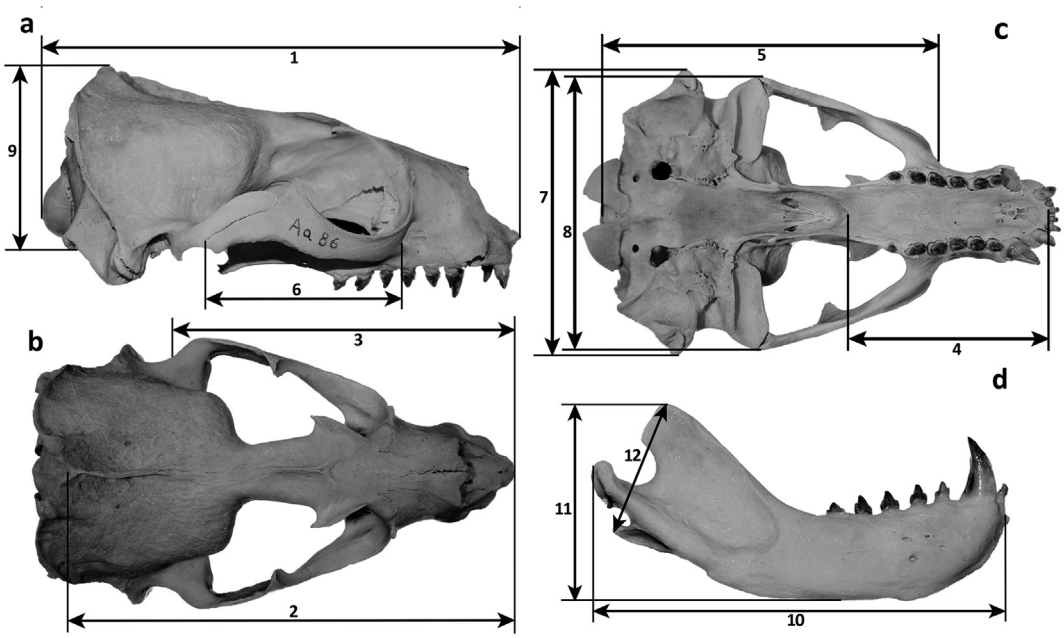

Fig. 4. Right lateral view (a), Dorsal view (b) and Ventral view (c) of the adult male *Arctocephalus australis* showing measurements taken in cranium (Drago et al., 2010): 1 condylobasal length (CBL); 2 gnathion-to-occipital crest middle length (GOCL); 3 gnathion-to-caudal postglenoid process border length (GPPL); 4 palatal length (PL); 5 basion-to-zygomatic root length (BZRL); 6 zygomatic length (ZL); 7 zygomatic width (ZW); 8 mastoid width (MW); 9 cranium height (CH) (Brunner, 2002; Drago et al., 2010). Right lateral view of the adult male *Arctocephalus australis* showing measurements taken in mandible (d): 10 mandible length (ML); 11 mandible height (MH); 12 angularis-coronoideus length (ACL) (Brunner, 2002; Drago et al., 2010).

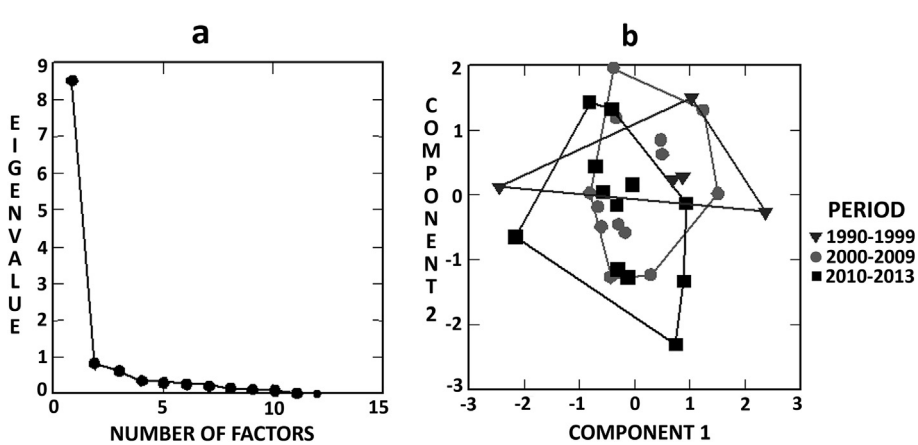

Fig. 5. PCA. (a) Screeplot of eigenvalues for each component; (b) Scatterplot using the two first components, that shows the pattern size generated by the three time periods of *Aa* (1990–1999; 2000–2009; 2010–2013).

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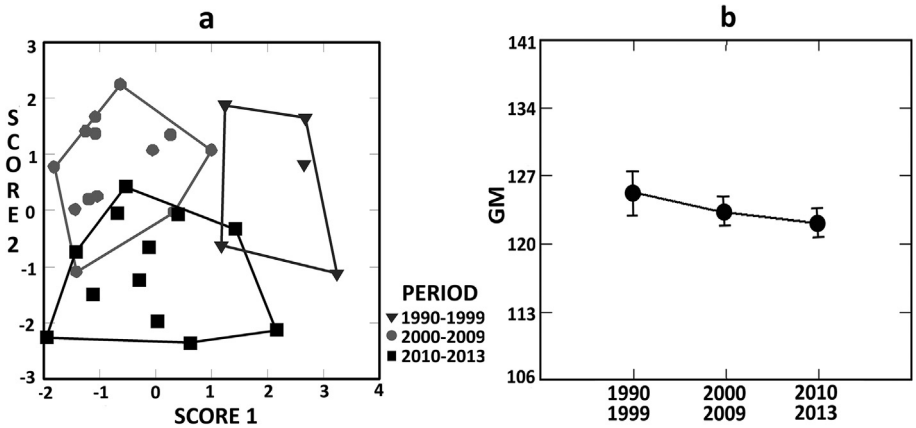

Fig. 6. (a) Scatterplot of Discriminant Analyses (DA) showing sizes differences between time periods of *Aa* (1990–1999; 2000–2009; 2010–2013); (b) Analysis of variance (ANOVA One-Way) for Geometric Mean of cranial measures of time groups of *Aa*.

4. Discussion and conclusions

The intensive exploitation of marine resources in historical times caused drastic changes in the marine ecosystem of the southwestern Atlantic Ocean (Balech and Ehrlich, 2008; Saporiti et al., 2014). Several high trophic level predators, including pinnipeds, have changed their population sizes, distribution and abundance (Crespo et al., 2012, 2015; Ferrari et al., 2013; Grandi et al., 2015). Likewise, shifts in the relative abundances of the demersal community over the Patagonian shelf were also observed (Koen Alonso and Yodzis, 2005). Recent studies on somatic growth in *Of* from northern Patagonia (Drago et al., 2010) and northern fur seals *Callorhinus ursinus* from Pribilof Islands, Alaska (Etnier, 2004 and references therein), highlighted that body growth was density-dependent in these species.

Body size variations observed in *Of* led us to think that potential biases could affect the use of modern analogues in the study of pinniped assemblages recovered in archaeological sites through osteometric analysis. At present, it is not well known how the fur seal population responded to changes in the marine ecosystem. Nevertheless, the few studies that exist suggest that in the southwestern Atlantic, fur seals have shown a different dynamic response than have sea lions.

Density dependence of somatic growth would be ultimately caused by a reduction in the per capita prey abundance (Trites and Bigg, 1992; Drago et al., 2010). However, despite the increasing population trend shown by the fur seals in recent years (Svendsen et al., 2013; Crespo et al., 2015) and the expected decreasing per capita food availability in northern Patagonia ecosystem, the diet of *Aa* remained unchanged during 1990–2013 (Vales, 2015). The diet of fur seals would not have changed for at least the last 2200 years (Vales, 2015). This is relevant because the lack of change in the skull size of *Aa* detected for the last 24 years may be characteristic of a longer period of time; although this hypothesis is hard to test, given that undamaged fur seal skulls are seldom found in the archaeofaunal record of Patagonia. Hence, considering the great abundance that would have had the population of *Aa* prior to the fur trade, and despite the recent population growth, which has a higher rate than sea lions (Crespo et al., 2012, 2015), it is possible that the current figures are still low for density-dependent mechanisms to be made manifest (Vales, 2015).

In conclusion, no changes were detected in the skull size of *Aa* from northern and central Patagonia during the last three decades. Our results are consistent with those obtained by De Maria et al. (2012) for the sample of *Aa* from Uruguay, which is in agreement with the fact that they belong to the same population (Crespo et al., 2015). Despite the latitudinal differences and the increase in the *Aa* sample size studied, the trend remains similar: no significant changes were observed in the *Aa* body size in the last decades. Furthermore, changes detected in the rostral level of *Aa* from Uruguay were considered possibly related to changes in their trophic habits (De Maria et al., 2012) and would not be necessarily related to somatic changes in the body size of this species.

This exploratory study is relevant because involves the stock of *Aa* used as modern analogues in the osteometric analysis of archaeological fur seal assemblages recovered in the area. Although the sample studied only covers a period of 24 years, this time range seems to be adequate to evaluate potential density-dependent changes in the body size of male fur seals, as significant changes have been observed for other otariid species in a shorter time interval (Trites and Bigg, 1992).

Despite density-dependent body growth of *Of* during 1974–2007 (Drago et al., 2010) and the absence of significant changes in body size of *Aa* during the period 1990–2013, modern analogues are still useful to differentiate between these species in the archaeological record. In this sense, an osteometrical study based on immature individuals (up to 5 years old) with known age and sex allowed the successful discrimination of both species and sexes in archaeological coastal sites from northern Patagonian (Borella and L'Heureux, 2014), although it still remains to test whether these differences remain in adult individuals. This has interesting archaeological implications because, although we cannot always track variations in the body size of otariid species in the past, morphological differences between *Aa* and *Of* seem to be large enough to allow differentiation of the species and sex of individuals from different age classes. Therefore, it is proposed that potential body size variations in *Aa* (and *Of*) through time do not preclude the use of modern analogues to discriminate morphologically between these two species in the zooarchaeological record.

For the aforementioned arguments, and assuming no major oceanographic changes occurred over the late Holocene (Schellmann and Radtke, 2010), we consider that modern specimens of *Aa* are valid to assess morphologically the archaeological assemblages of fur seals from northern Patagonia because they allow us to assume isomorphic similarities by analogies between modern samples and archaeological assemblages for this species. This is relevant because the zooarchaeological record from San Matías Gulf indicates predominance in the exploitation of *Aa* over *Of* during the last 3000 years (Borella and L'Heureux, 2014).

Please cite this article in press as: Borella, F., et al., Exploring body size of modern South American fur seal (*Arctocephalus australis*) for osteometric studies in zooarchaeological remains from northern Patagonia, Argentina, Quaternary International (2015), http://dx.doi.org/10.1016/j.quaint.2015.07.038

In brief, the assumption of isomorphic similarity between modern and archaeological individuals of a given species needs to be verified in every particular case. For northern Patagonia, osteometry is a valid tool to assess the frequencies of *Aa* and *Of* in the zooarchaeological record and its exploitation by hunters in the past.

Acknowledgements

The financing granted by CONICET (Projects PIP 6415; PIP 756; PIP 589) (Argentina) and ANCyT (Project PICT N° 38264) for conducting archaeological research in Río Negro coast awarded to Florencia Borella. To the Institutional support of INCUAPA-CONICET (UNICEN); IMHICIHU-CONICET and LAMAMA/CENPAT-CONICET.

Fur seal skulls were collected with financial support of the following projects awarded to E.A. Crespo: the Scientific Program of Cooperation between Spain and Latinoamerica (1996–1998), the United Nations Development Program (2005–2007), the Mohamed Bin Zayed Species Conservation Fund (Project N° 0925516) (2011–2013), the Amnéville Zoo (France) (2004–2013) and the IBOL Fund (2012). Samples collections were carried out under permits of the Provinces of Río Negro and Chubut. We would like to thank to Florencia Grandi and Néstor García for their help in the design of map figures. We would also like to express gratitude to the two anonymous reviewers and the editors (Luis del Papa and Fernando Fernandez for allowing to participate us to this special volume) who helped us to improve an early version of the manuscript.

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