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Combining morphological and metric variations in the study of design and functionality in stone weights. A comparative approach from continental and insular Patagonia, Argentina

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ABSTRACT

This paper aims to apply statistical and comparative methods to characterize and establish the potential functionality of artifacts with little or, virtually, no modification, such as lithic weights which are used as a part of fishing lines or nets. To this end, two samples from contrasting archeological and environmental contexts of the Patagonian and Tierra del Fuego coasts are used. Contour analysis (Fourier outlines) and Multiple Factorial Analysis were used to compare different data sets and to assess variation ranges. The results suggest that it is possible to determine differential shape and size ranges. With this information it is then possible to assign these artifacts to different environmental contexts and/or types of fishing gears.

1. Introduction

The setting of design parameters regarding artifacts whose manufacture requires low-energy investment posits important analytical difficulties. This is because these simple shapes tend to present wide parameter variation, such as in the case of informal or expedient artifacts (*i.e.* Torrence, 1983; Andrefsky, 1994, 2005, among others), even though we would expect variation to be limited by the needs of basic performance. These requirements can also manifest themselves as morphological regularities, in metric attributes or in qualitative aspects (*i.e.* production technology, raw material).

In this article, we analyze the case of lithic weights commonly used as ballast for fishing lines and nets, a key functional element of this technology. These artifacts are well represented on coastal sites of varying antiquity throughout the world (Bernal-Casasola, 2008; Galili et al., 2002; Owen and Merrick, 1994; Greenspan, 1998; Massone and Torres, 2004; Torres, 2007a, 2007b, among others). It is important to note that these artifacts form part of more complex technological systems; as defined by Oswalt (1976), they are known as techno-units. As such, they do not possess functionality by themselves, but rather as part of a composite artifact. In the case of net weights, these artifacts are represented by many similar units (various weights) and the mesh of the net; meanwhile with fish-lines there is usually a single weight which is part of a system that can include, for example, a hook, or a knot for bait and a holding line (fishing-fly) (Von Brandt, 1984; Owen and Merrick, 1994) (Fig. 1). The problem with these fishing systems is that they are mostly composed of perishable components, and therefore their archeological visibility is low. Indeed, our most complete typological and functional knowledge regarding this technology comes to us from historical and ethnographic data (Leach, 2006; Gusinde, 1982). Given that each unit has to interact with other parts of a technical system, is it likely that aside from the performance requirements of each artifact there are other design criteria linked to efficiency within the system, to both line-, or net-fishing.

Therefore, we believe that it is possible to narrow down the minimum efficiency criteria of the different fishing systems in association to at least two basic inter-related themes: the efficiency of the fishing system in its totality (such as a hafted knife or spear) and the artifacts efficiency in its interaction with other components within the system (such as the shaft of an arrowhead). This is a fundamental distinction given that, for example, in the case of a net, each weight is important to maintain the system submerged in a stable manner, such that we would expect that their morphology or size would tend to be similar in the same area within the system (Von Brandt, 1984).

Likewise, with a fishing line, the weight is the only item that maintains the system underwater, this implies a surface link or holding mechanism, as well as a weight and morphology commensurate to the type of fishing undertaken (*e.g.* ground-angling or mid-water angling). The ethnographic information available for the Beagle Channel

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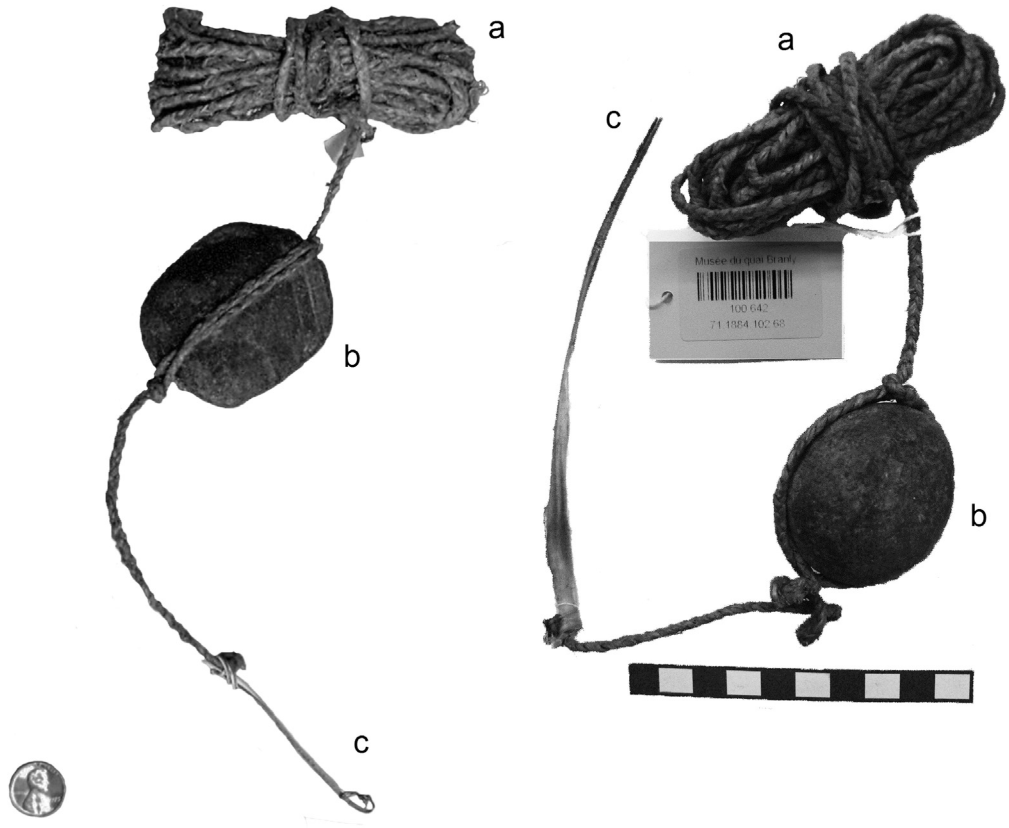

Fig. 1. Yámana fish-lines (19th Century), showing the guanaco tendon line (a) line, (b) the weight, and (c) knot for the bait. Left, Yaghan fish-line obtained by Charles Furlong (1909), American Museum of Natural History, US; Photograph by Junius Bird presented to Luis Orquera. The knot for the bait was manufactured using a segment of seagull feather. Right, a Yaghan fish-line manufactured from cetacean beard, French mission to Cape Horn (1882–1883). Quai Branly Museum, France (Photo: courtesy of Judith Charlin).

area illustrates this very well. Gusinde (1982) states that with line fishing the modification and size of the weight varied if the line was made from braided guanaco tendons, or from the stem of a macro-algae (*Macrocystis pyrifera*). Both of these types implied a different investment of energy, with the former being better cared for than the latter.

Lithic weights generally have little or no modification so that they tend to share broad morphological similarities and their shape depends to a large degree on the nodule form being used. It is possible that in most cases, the shape and size of the nodule was as, or more, important (in terms of selection and investment of effort) than later modification. We believe that there are certain design aspects, especially those related to the functional dimension (Dunnell, 1978) (which depends on energy and the type of marine substrate), that vary according to the type of technical system of which the artifact forms part (fish-line or net), the fishing method, *etc*. For example, biconvex or rounded shapes could be understood as a basic morphological convergence related to hydrodynamic requirements. A fact that is repeated in weights recovered from archeological assemblages and modern samples (Von Brandt, 1984).

Based on these assumptions, the aim of this article is to explore the relationship between the environment, design and potential functionality of lithic weights. These variables are assessed through a consideration of the fact that these artifacts are simple in shape but require varying labor investment in their manufacture. Therefore, we compare technological studies of lithic weights from two southern South American coastal areas: the North Patagonian coast and the southern coast of Tierra del Fuego (Fig. 2). These regions are geographically distinct insofar as their physiographic, ecological and environmental makeup is concerned. However, in both areas, fishing was a staple strategy of human subsistence during the Middle and Late Holocene. This has been documented from different methodological perspectives (*i.e.* archeofaunal, stable isotopes, taphonomy and technology) (Favier Dubois et al., 2009; Favier Dubois and Scartascini, 2012; Scartascini, 2010; Orquera and Piana 1999; Zangrando, 2009).

While we have evidence for the use of boats in marine foraging activities around the southern archipelago of the Tierra del Fuego, along the North Patagonian coast the harnessing of fish and other marine resources was primarily land-based. We believe that this difference in scenarios and in the strategic organizational aspects of fishing allows us the opportunity to explore variations in the design and functionality of lithic weights in varying contexts of use, given that it is likely that these changing circumstances would have had an influence on the fishing strategies employed.

Likewise, the geographical distance between the analyzed samples minimizes the probability that potential morphological similarities are related to horizontal transmission of information between groups (*sensu* Cavalli-Sforza and Feldman, 1981). In this case, similarities in design probably emerged as an adaptive response by the artifacts to basic functional requirements, such as the previously mentioned hydrodynamics. Equally, we should highlight that these two far south, South American coastal areas hold great significance for this type of study given that lithic weights are present as a conspicuous technology within the archeological record of both locations. In contrast, in other nearby areas these weights are found in very low quantities, or very occasionally. In this article, the sample studied constitutes practically the totality of the materials recovered from both areas (see methodology).

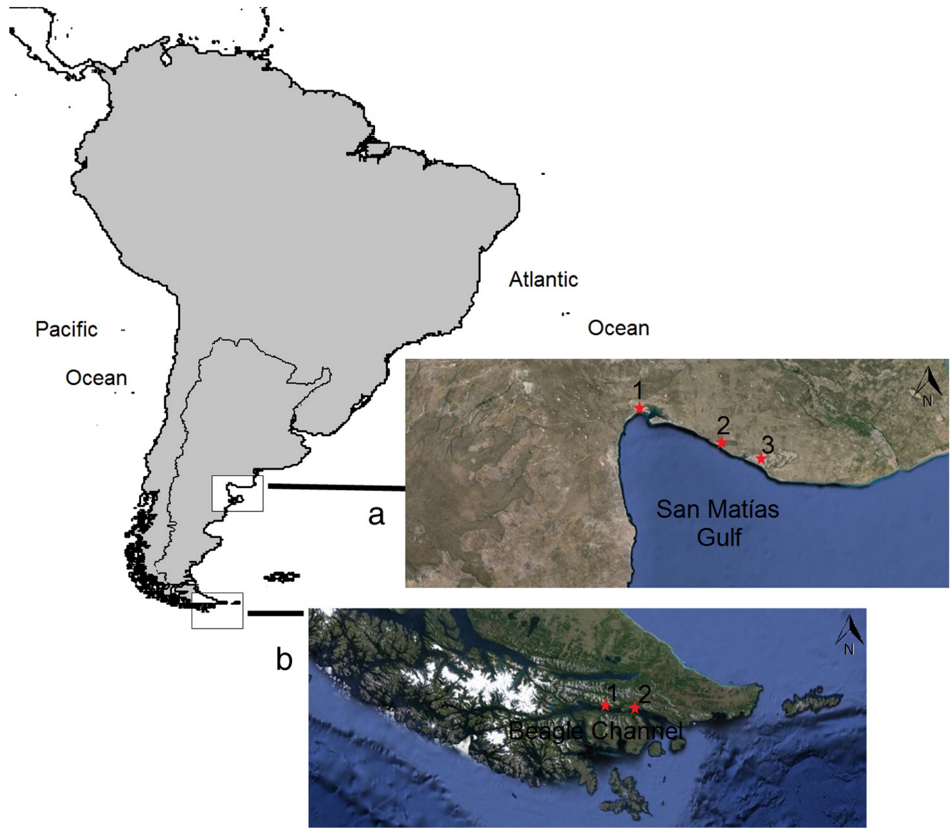

Fig. 2. Provenance of analyzed samples (a) North Patagonian area; principal sample locations: 1. San Antonio Oeste, 2. Bajo de la Quinta, 3. Bahía Creek, (b) Beagle Channel 1; principal sample locations: 1. Túnel I, 2 Imiwaia I.

2. Case-studies: natural and cultural contexts

2.1. North Patagonian coast

The coast of the Rio Negro Province extends more than 360 km from the mouth of the Negro River, on the border of the Buenos Aires Province (41° 02′ 46″.41 S 62° 47′ 19″.64 W) up to Lobos Port, on the border with the Chubut Province (42° 00′ 00″S 65° 04′ 06″.31 W), thereby covering a large part of the San Matías Gulf (Fig. 2). The Rio Negro coast includes coastal cliffs and topographic lows. In all cases it correspond to a low slope coast with extensive rocky coastal plains and development of salt marsh with sandy and loam funds (Favier Dubois and Borella, 2011).

Across the whole of its extension, the environment of the Rio Negro littoral corresponds principally to the Argentine Monte eco-region, with a predominance of bush steppe (Cabrera and Willink, 1980). The region is characterized by having a semi-arid temperate climate, with annual mean temperatures of *ca.* 12 °C and mean annual precipitation levels of between 100 and 350 mm (Olivares and Sisul, 2005).

The San Matías Gulf is a semi-closed basin that connects to the Argentine Sea through a 51 km opening. The semi-diurnal tide varies between 3.20 m (mouth of the Rio Negro) and 7.10 m (San Antonio Bay) (González et al., 2010). The physical and environmental characteristics of the Gulf itself create unique ecological conditions within the Argentine marine system, seen in the great marine and littoral biodiversity (Di Giácomo et al., 2005; González et al., 2010). In addition, the Gulf waters function as the transition between two marine biogeographic provinces (Bonaerense and Magellanic), which confers an additional specific richness. Some of these species developed the sum total of their life-cycle within this semi-closed basin, thus constituting independent sub-populations to those present in the continental shelf, such as Argentine hake (*Merluccius hubbsi*), Argentinian sandperch (*Pseudopercis semifasciata*), and invertebrates such as the Tehuelche scallop (*Aequipecten tehuelchus*), blue mussels (*Mytilus* sp.), the purple clam (*Amiantis purpurata*) and the small Patagonian octopus (*Octopus tehuelchus*) (González et al., 2010).

The ethnographic data for northeast Patagonia is scarce and fragmentary and there are no historical references concerning fishing methods or the consumption of fish in this sector (Nacuzzi, 1998; Moreno, 2008). In contrast, the archeological evidence recovered from the North Patagonian coast shows a clear and systematic signal in respect to the use of marine resources from *ca.* 6000 years BP, coinciding with the oldest registered human occupation of the area (Favier Dubois et al., 2009; Borella et al., 2011). Fish were among the most consumed animal resources, these were exploited systematically from between *ca.* 6000 up to 800 years BP. Throughout this archeological sequence, a dominant massive exploitation of Whitemouth croaker (*Micropogonias furnieri*) (Scartascini et al., 2009; Favier Dubois and Scartascini, 2012) and the consumption of more than 18 different fish taxa were recorded (Scartascini, 2010, 2012, 2014). In general terms, these 18 taxa are benthic near-shore species and inhabited coastal waters the whole year round (Scartascini 2014).

Surface assemblages of lithic weights appear in direct association with ichthyoarcheological remains. Since these artifacts were found on the surface it was not possible to give them a reliable absolute chronological date. Nevertheless, relative chronologies where obtained based on dating associated material (*e.g.* fish remains) and the geoforms on which these assemblages where located (*e.g.* marine terraces, beach ridges, *etc.*); this method has allowed us to generate time-spans with relative minimum and maximum dates for these archeological assemblages (Favier Dubois and Scartascini, 2012, see below).

2.2. Beagle Channel

The Beagle Channel is located at the extreme southern end of the American continent (54° 50′ S, between 66° 30′ and 70° W). It stretches approximately 180 km and has a width that varies between four and seven kilometers (Fig. 2). It is a glacial valley that runs from east to west, which has been filled with marine water since the Early Holocene (Rabassa et al., 1986), thereby connecting the Pacific and Atlantic Oceans. Parallel to the Beagle Channel runs a mountain chain, the Fuegian Andes, with heights of 2470 m at Monte Sarmiento and 1470 m at Monte Olivia. The proximity of this cordillera in turn breaks up the coastal zone, making the area affected by tides, relatively narrow, consequently the sea rapidly gains significant depth.

The majority of the fish species present in the coastal waters of the Beagle Channel belong to the Nototheniidae Family, in which there is a prevalence of small-sized fish, for instance Magellanic rock-cod (Nototheniidae: *Paranotothenia magellanica*) and cod icefishes (Nototheniidae: *Patagonotothen* spp.), which live in the intertidal areas and in the giant kelp (*M. pyrifera*) ecosystem (Moreno and Jara, 1984; Vanella et al., 2007).

Ethnographic data demonstrates that the Yaganes o Yámana (hunter–gatherer and fisher groups that lived in the archipelago sector to the south of Tierra del Fuego in the Nineteenth Century) mainly fished in the *M. pyrifera* ecosystem. This activity was mainly undertaken through the use of fishing lines (Fig. 1) from canoes along coastal habitats. The ethnographic record makes this point often (a synthesis of this information can be found in Orquera and Piana, 1999: 156; or in Fiore and Zangrando, 2006: 386). Furthermore, the ethnographic record points out that the Yaganes did not traditionally use nets, and the few mentions of nets occur very late on and as a process of eventual adoption of European fishing nets.

The archeological evidence from the north coast of the Beagle Channel shows that this sector was inhabited by hunter–gatherer–fisher societies whose subsistence was strongly linked to the exploitation of marine resources from approximately 6400 years BP to the nineteenth century (Orquera and Piana, 1999, 2009). The fish zooarcheological assemblages demonstrate that these societies consumed a large variety of fish species both in coastal and pelagic habitats throughout the whole of the occupational sequence (Zangrando, 2003, 2009; Tivoli and Zangrando, 2011). In respect to coastal fishing, the zooarcheological data shows that this activity focused on exploiting *P. magellanica* and *Patagonotothen* sp.; these taxa comprise nearly 90% of the littoral fish represented in archeological bone assemblages. Similarly to the North Patagonian coast case, the artifacts that form the material studied in this article were found in association with these fishbone assemblages.

3. Material and methods

3.1. Sample selection

The sample is composed of a total of 131 artifacts that represent practically the total number of lithic weights recovered from these two Patagonian sectors. Among them, 62 are from the surface assemblages collected along the north coast of Patagonia and dated through association with *M. furnieri* otoliths to between 6000–3000 BP. The geomorphological and contextual analysis (Favier Dubois and Kokot, 2011; Favier Dubois and Scartascini, 2012) suggest that, the use of this type of artifact would have been during this period, although at this stage it is not possible to determine the oldest context of use. These materials generally appear, in a relatively concentrated manner in certain sector together with other types of artifacts, such as denticulate tools and small choppers (Favier Dubois et al., 2008; Cardillo, 2013).

The Beagle Channel samples (Fig. 2) yielded 69 artifacts from stratigraphic contexts dating to the Middle and Late Holocene. Regarding Mid-Holocene contexts, 53 of these were recovered at the Second Component of Túnel I (5960 $\pm$ 70–5020 $\pm$ 100; 6912–5588 cal. BP), and 14 from the lower shell-middens of Imiwaia I (layers K, L and M) with a radiocarbon date of 5943 $\pm$ 48 (6804–6558 cal. BP). For Late Holocene contexts, one artifact was obtained from Layer B of Imiwaia I (1577 $\pm$ 41; 1327–1522 cal. BP), and one was found at Shamakush I (940 $\pm$ 110; 1101–650 cal. BP). All these artifacts were recovered from shell-midden layers at these sites. With the exception of 11 weights found in a group within Layer D of Túnel I, these artifacts appear as isolated finds within their given deposits.

An initial step, prior to selection and recording of variables of interest, consisted in the detailed survey of the availability of rocks in both areas, thus taking into consideration available raw material as well as the shape and size of the shingle and pebbles. Along the North Patagonian coast, we observed a large availability of rock morphologies in secondary deposits of present-day as well as palaeo-beaches (Fig. 3A). The predominant material is acidic vulcanites of a porous texture and regular/bad knapping quality given the presence of crystalline inclusions (Cardillo and Scartascini, 2011, Alberti, 2012). The better quality, though scarcer, rocks where used mainly in the manufacture of retouched tools (Cardillo and Scartascini, 2011; Alberti, 2012; Cardillo and Alberti, 2013).

By way of contrast, along the Beagle Channel coast there is the presence of both primary (outcrops) and secondary sources of raw material. Hornblendite is the material most used for the manufacture of weights, it is found in low quantities in secondary deposits (*i.e.* beaches, till outcrops, *etc.*) and in primary outcrops of restricted extension (Fig. 3B). Along the coast of the Beagle Channel, near the city of Ushuaia, there are plutonic rock outcrops that are found within the Yahgán Formation (Kranck, 1932). These formations contain rocks made up mainly of hornblendite (hornblendite with lesser quantities of clinopyroxene, biotite and epidote) (Suárez et al., 1985; Acevedo et al., 2002, González-Guillot et al., 2009).

As was mentioned in the Introduction, the samples analyzed here represent practically the sum total of the material recovered from both areas and the only artifacts which were not studied were those fragmented or which did not permit a proper morphological analysis (see section below).

3.2. Methods

For the present study, we used four quantitative variables (three blocks of morphological data obtained through a Fourier analysis and weight) and two categorical ones (modification axis and knapping), see Fig. 4, table (1). The first variables were used to record shape and size, and allowed us to discuss the guidelines and the criteria used in the selection of nodules. In contrast, the categorical variables describe the modification patterns of the nodules and they relate to the tying method of the technical system. The two types of variables that describe the acquiring and the processing of the nodules will be presented in greater detail below.

3.2.1. Image acquisition

For this study only artifacts that where complete or had minor fractures where analyzed given that these best allowed for their measurement and weight estimates. Each sample was photographed on grayscale with a digital camera mounted on a tripod at a focal distance of 30 mm, at a resolution of 5 megapixels, and maintaining the lens in a perpendicular position to the object, thereby avoiding deformation of the image. Each object was photographed maintaining the axis of modification perpendicular to the frame of the image. This orientation was used across all three perspectives — front, lateral and top (Fig. 4).

Subsequently each of the three perspectives where processed separately through the TpsDig2 program (Rohlf, 2006), with each contour traced using 30 points generated through use of the automatic digitizing function which permits the regular spacing between these points (location of each point is defined by two x-y coordinates). The points were registered as landmarks and were later used for the elliptic Fourier analysis (see Frontal.tps, Lateral.tps and Top.tps archives in Supplementary material).

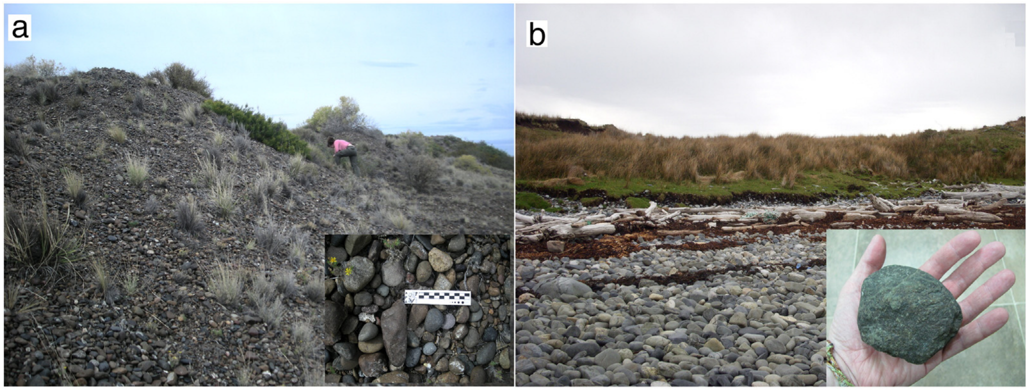

Fig. 3. Availability of lithic raw material on both coasts. See variability on nodule forms and lithology. A. Beagle Channel (detail: hornblendite pebble). B. North Patagonian Coast (detail: Vulcanites).

3.2.2. Shape and size analysis

The Fourier analysis is particularly useful in the study of closed contours of varying complexity in cases where it is not possible to establish beyond doubt a discrete point in the morphology (or landmark). Fourier analysis has been used previously to the study of lithic artifacts (Cardillo, 2006; Cardillo and Charlin, 2009; Scartascini and Cardillo, 2009; Iovita, 2010; Iovita and McPherron, 2011). The Elliptic Fourier analysis (Kuhl and Giardina, 1982; Rohlf, 1990, 1998) sets out from a number of bi-dimensional coordinates (x and y) around which are adjusted a series of related harmonic ellipses (harmonics). The harmonics are defined by a mathematical function composed of four terms (An, Bn, Cn, and Dn) that successively increment the adjustment around the original contour. The more harmonics used, the better is the adjustment of the function to the contour that is being described, so that the sum of these descriptors represents an approximation of the form in its totality, as has been shown by Kuhl and Giardina (1982; Rohlf, 1998).

The first harmonic describes the contour in its global shape (low order harmonics), while the later ones (high order harmonics) describe more local aspects of the contour. The optimal number of harmonics to be employed depends on the complexity of the contour and there are various methods to establish the minimal number of necessary parameters. The criteria for the selection of the optimal number of harmonics are a consideration of the amount of variance described by each harmonic in relation to the total variance (Kuhl and Giardina, 1982; Rohlf, 1990, 1998). This function, known as harmonic power, serves to determine the percentage of variance described by the contour, in this case, 12 harmonics where retained which together described 99% of the variance. This allows us to discard the last harmonics, which usually possess little relevant information and/or are related to random variations. Likewise, given that the object of this analysis is to capture the shape of the artifacts, each contour was standardized by size, traslation and rotation based on the first ellipse (Kuhl and Giardina, 1982), so that the remaining information is one essentially of shape. This procedure also serves to minimize digitization error linked to position or differences in the orientation of pieces during the image capture phase. Moreover, this method is standard and is comparable to the Procrustes superposition commonly employed in landmark-based geometric morphometrics.

After the process of standardization, the first coefficient of the first harmonic transforms into a constant and is left aside. These harmonics where later used in multivariate analysis (Principal Component Analysis and Multiple Factorial Analysis), which reduces their dimensionality and permits the extraction of general tendencies in morphological variation (see Script outlines.txt in Supplementary material). Similarly to other morphometric methods, the relative variation in terms of shape can be reconstructed within the PCA using Fourier's reverse function application (Ferson et al., 1985; Claude, 2008).

Using the elliptic Fourier analysis we generated three data matrixes, one for each perspective used to take the weight photographs. We undertook an analysis of the principal components for each of these perspectives (Figs. 5, 6 and 7). In each case, the first two components resume the general tendencies in morphological variation between the sectors and describe at least 80% of the original shape variation (Figs. 5, 6 and 7).

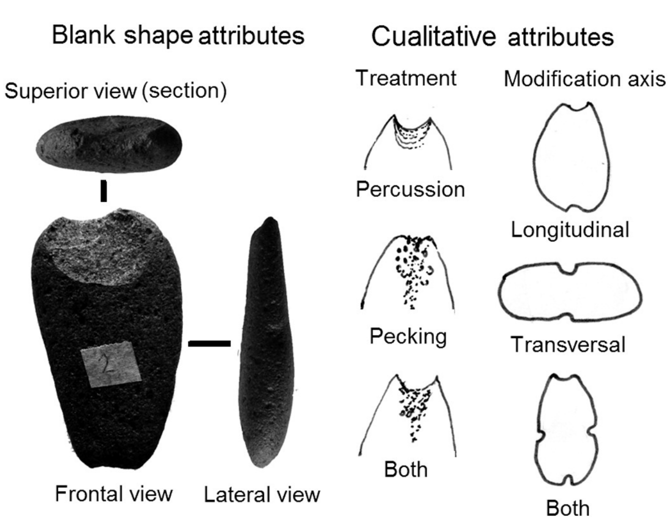

Fig. 4. Attributes of the morphological and qualitative variables considered in this analysis.

3.2.3. Categorical variables

A particularly relevant aspect of lithic weights from the North Patagonia coast and Beagle Channel is that they have short production sequences and the different stages do not tend to obliterate the preceding ones. For this reason, the different features can be compared with a low incidence of potential biases. In this case two basic steps were quantified (see Fig. 4, Table 1) in the modification paths of the nodule, this has also been observed by Torres (2007a, 2007b) and Scartascini (2010). The axis of modification can be longitudinal or transversal in relation to the maximum dimension of the nodule, and three possible methods of manufacture have been recognized: flaking by direct percussion, pecking, and flaking followed by pecking (Fig. 4, Table 1). Finally, the general abrasion of the artifacts is related to the intentional rounding of the internal edge of the tying notch. Since this last element is not easily identifiable, especially in the surface lithic assemblages, it was not quantified in the present analysis.

With the purpose of extracting global variation tendencies in the data, and taking into consideration the different dimensions of the variations studied, each group of harmonics was used in a Multiple Factorial Analysis (MFA) together with the metric and categorical variables.

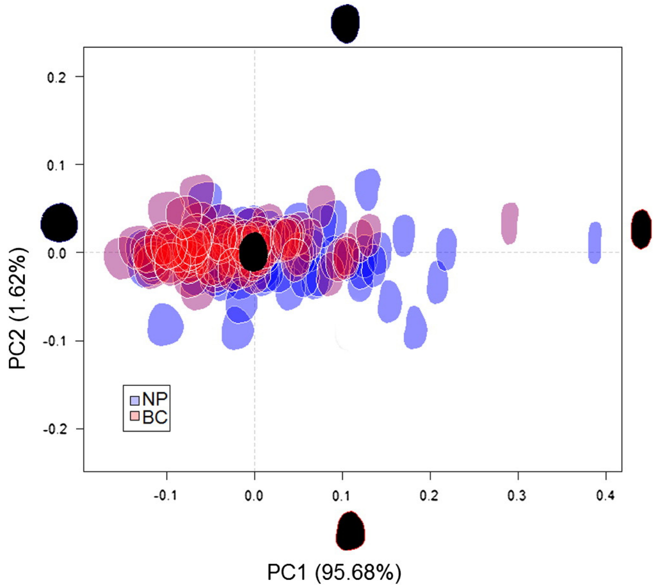

Fig. 5. First two axes of PCA based on Fourier harmonics. Frontal perspective: North Patagonian coast in blue and Beagle Channel in red. Center (mean shape) in black. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

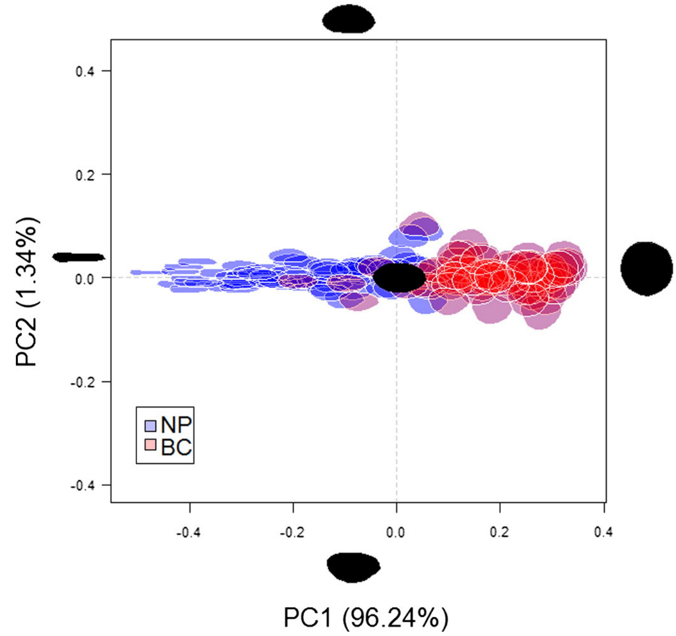

Fig. 7. First two axes of PCA based on Fourier harmonics. Top perspective: North Patagonian coast in blue and Beagle Channel in red. Center (mean shape) in black. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

This method is an extension of the Principal Component Analysis (PCA), which has the advantage of analyzing in parallel more than one group of discrete and continuous variables simultaneously; in this case, harmonics and metric variables including weight and two categorical variables. An analysis of the principal components in each group or a correspondence analysis in the case of categorical variable groups are developed in this way. In turn, this procedure permits us to undertake a global factorial analysis of components that significantly contributes to the observed variability (Scoffier and Pagés, 1998; Pagés, 2002).

In the case of shape variables, each perspective was treated independently and considered as a shape module. The use of MFA entails two basic steps. First, values were assigned to each group of variables according to the first eigenvalue for the PCA of each group. Thus, the maximum axial inertia of each group of variables is equal to 1 (Scoffier and Pagés, 1998; Pagés, 2002). This standardization is important because if all sets of variables are introduced as active elements, without balancing their influence, a set with more shape variance can over-contribute to the make-up of the first axis because of the inertia distribution in multivariate space. Second, a global analysis with normalized matrices was performed thus the structure of each group was respected (Scoffier and Pagés, 1998; Pagés, 2002). As in other ordination methods, this analysis is correlative because it excluded the possibility of causal influence on a dataset by other variables (Borcard et al., 2011), yet one or more explicative variable vectors can be fitted *a posteriori*. The resulting coordinates of the components are known as factor scores and these can be used to plot maps of the scores in which each case is represented as points, such that the distances in the map best reflect the original similarities between each one (Abdi et al., 2013). Likewise, the contribution of each group of variables as well as each individual variable to the total variation (loadings) reflects its importance in the construction of new axis.

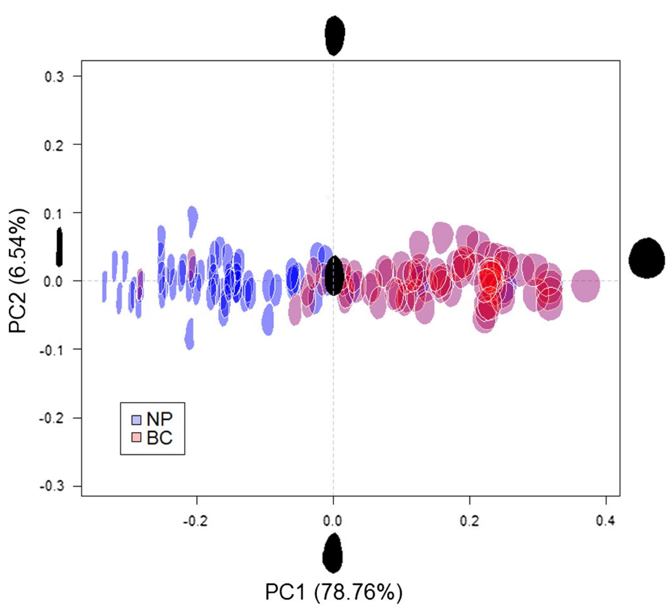

Fig. 6. First two axes of PCA based on Fourier harmonics. Lateral perspective: North Patagonian coast in blue and Beagle Channel in red. Center (mean shape) in black. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Table 1
Statistic description and frequency of qualitative variables used in the statistical analysis.

	NP	Beagle
Total *f*	62	69[a]
Minimum weight (g)	21.9	23
Maximum weight (g)	308	699
Mean weight (g)	101.95	149.54
Stand. dev weight (g)	64.16	143.97
Coeff. var weight (g)	62.93	96.28
Modification axis	f	f
Both	1	0
Longitudinal	31	64
Transversal	30	5
Treatment	f	f*
Flaking by percussion	29	0
Flaking percussion and pecking	26	34
Pecking	7	33

[a] In the Beagle Channel sample, one case could not be clearly differentiated and these was left aside (resulting in the Factorial analysis of 68 cases for this sector).

The MFA also supports the use of active and passive variables; active variables are used to define the distance between individuals, while passive variables intervene independently one of the other. Equally, both variables can co-relate with each other (shape, treatment, weight, axis of modification) thereby facilitating the interpretation of results in accordance to a specific hypothesis. For this reason, the passive variable used in this article is geographical location (coded as a categorical variable, see Location.txt in Supplementary material).

Finally, we undertook a discriminant analysis on the basis of the first two MFA axes, with the aim of contrasting the hypothesis concerning morphological and technological differences linked to the two different coastal Patagonian environments (see WeightStone.txt dataset and ScriptMFA.txt in Supplementary material for step by step analyses).

The statistical analysis were undertaken using a Tpsdig2 program (Rohlf, 2006) and Geomorph (version 2.1.1), Momocs (version 0.2.6), FactoMiner (version 1.27) coded into the R 3.03 package (R Development Core Team, 2009).

4. Results

4.1. Shape analysis

The PCA applied to the three groups of harmonics point towards general tendencies in morphological change for the assemblages of the North Patagonian coast and the Beagle Channel. We observed that the first component described a large part of the total variation for each of the perspectives, while the second contained basic information on the symmetry of the artifacts. The frontal perspective (Fig. 5) shows that the general variation tendency extends from rounded shapes to oval and relatively plain shapes. This general tendency is represented by the first component, which explains 95% of the total variation. Insofar as distribution of correspondent cases from each sector, we noted a considerable amount of overlap.

A similar tendency on morphological variation can be inferred in the lateral and superior (top) perspectives (Figs. 6 and 7), although the distribution of cases in the morphospace suggests a clear separation between North Patagonia and Beagle Channel assemblages. Concerning the lateral perspective, the cases from the North Patagonian Coast tend towards a lenticular and flattened shape (PC1 78.76%), while along the Beagle Channel coast the shapes are oval and rounded.

In respect to the top perspective, the first component (PC1, 96.24%) shows that the shapes along the North Patagonian coast tend to be more compressed, while those from the Beagle Channel are rounded or oval, with little overlap between either of the distributions across the length of this axis (Fig. 7).

In sum, the results of the three perspectives suggest that the top and lateral plane was the most discriminating in both sectors, while the frontal perspective are not.

4.2. Multifactorial Analysis

The Multiple Factorial Analysis (MFA) is presented in Fig. 8. Table 2 shows that the three components together explain 72% of the variation, while the next components explain very little of this variation (eigenvalues less than 1, see ScriptMFA.txt in Supplementary material). More than half of the variation of the first axis (72%) is described by shape (see also Table 2). In contrast, the second axis, is mainly described by the method of modification (74.45%) and in lesser measure by other variables. Weight contributed very little to these two first axes and it is mainly linked to the third component (not shown) (Table 2). This result suggests that size does not correlate with the main morphological variations and the technical elements analyzed. Nevertheless, as can be observed in Table 1, there is a difference between the mean weights of both areas (North Patagonian coast 101.95 g; Beagle Channel 149.54 g), although this difference becomes less when one considers the median (North median 99.3 g, Beagle median 96.64 g), which in turn suggests that weight is basically a factor of variation. The non-parametric Mann–Whitney Test on both median weights shows that the difference is not significant (U = 1712, p = 0.09)..

Similarly, the distribution across the length of the first axis is significantly correlated to the passive variable of spatial location ($R^2 = 0.67$, $p < 0.001$), which suggests that the separation noted throughout the first axis has geographical significance (Fig. 8). Therefore, the first two axes represent the general tendencies of the total variability. High and

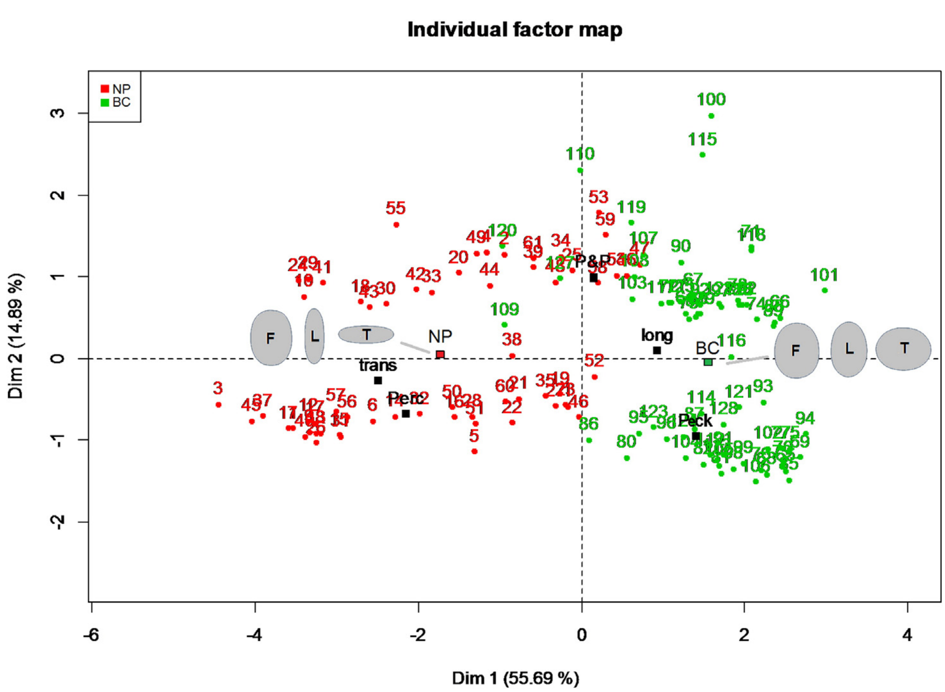

Fig. 8. First two dimensions of the Multiple Factorial analysis (MFA). NP: North Patagonian assemblages; BC: Beagle Channel; Perc: treatment by percussion; P&P: Percussion and pecking; Peck: pecking only, Tran: transversal axis of modification; Long: longitudinal axis of modification. Full contours represent the estimated average shape achieved through the use of Fourier inverse function for each sector in their Frontal (F), Longitudinal (L) and Top (T) perspectives.

Table 2
Percentage contribution of each group to MFA principal axis.

Variable contribution to the first MFA	MFA1 (%)	MFA2 (%)
Front	24.16	0.74
Lat	24.16	0.74
Sup	24.16	0.74
weight	2.10	21.00
Treatment	10.75	74.45
Mod_Axis	14.69	2.32
Total (%)	100.00	100.00

positive values on the first axis are linked to rounded or oval section morphologies, while negative values signal a more plane lateral perspective. This is congruent with what has been observed in the morphological analysis, where we can observe general variation tendencies in the contours and in their relation to geographical location (Figs. 6 and 7).

Likewise, treatment method is also a discriminating variable between the sectors given that the flaking alone technique is more frequent along the North Patagonian coast (47%), while along the Beagle Channel flaking by direct percussion was only used in conjunction with pecking (51%). Pecking alone was employed in 49% of the artifacts from the Beagle Channel, and only in 7% of the artifacts from the North Patagonian coast. Similarly, transversal axis of modification was more common along the northern coast (48%) while longitudinal ones are more common to the Beagle Channel (93%) (Fig. 8, Table 1).

Finally, the discriminant analysis of the sectors on the basis of the first two MFA axes support this hypothesis ($F = 134.41$, $p < 0.001$). Misclassification error is low for each sample, but is higher for north Patagonian sample (13%) than Beagle Channel (5.88%), which could be linked to greater standardization of the latter ones. Overall results shows that 90.7% of the individuals could be correctly assigned to one, or the other, region based on these two first axes. This demonstrates that metric and morphological variability is significantly linked to geographical location of these samples.

5. Discussion

The morphometric analysis suggests that the main differences between lithic weights from the North Patagonian coast and the Beagle Channel are linked to the top and lateral section (Figs. 5 and 6), and to a lesser degree the frontal section (Fig. 4). This correlates with what has been observed for the first MFA axis (Fig. 7). Similarly, the technical elements analyzed also reveal differences between the sectors, mainly in the second MFA axis.

The samples from the North Patagonian coast are frequently flaking by percussion manufactured, while those from the Beagle Channel are pecked (or *via* a combination of both techniques). These two extremes coincide with the average shape of each of these artifacts in their respective geographical regions, so that the lithic weights from Northern Patagonia tend to be flat and lenticular when they are sectioned, while those from the Beagle Channel are more oval and circular (Fig. 7). The discriminant analysis of the first two MFA variation axes supports a geographical differentiation hypothesis, both in shape and in method of manufacture.

We believe that, in part, this morphological variation could be related to the selection of nodules based on distinct functional criteria, and in the case of the Beagle Channel, to a larger degree of use of techniques of percussion and pecking that molds the primary morphology to the design requirements. Nevertheless, these differences are not associated to the unequal incidence of raw material given that, as was mentioned previously regarding both sectors, there is enough availability of shapes. Consequently, we consider that the observed variation could be linked to other aspects such as technical choices or functionality.

One of the main functions of weights is to avoid line-drags by currents, entanglements or knots, factors that can affect the efficiency of fishing or can occasion the loss of the whole tool-kit. In the case of fishing lines, the manner in which the ballast is used varies according to the type of fishing practice, especially if it involves ground-angling or mid-water angling, and the weight varies in relation to the hydrodynamics present (Von-Brant 1984). These inferences about functionality are well illustrated through the two cases assessed here. In the Beagle Channel, coastal fishing took place mainly within the macro-algae ecosystem (*M. pyrifera*), this is documented both in the ethnographical and archeological record. Magellanic rock-cods and cod icefishes were the resources with the highest biomass in such ecosystem, where mature specimens had sizes normally between 11 and 24 cm in total length (Moreno and Jara, 1984). These taxa have a bentopelagic behavior, moving vertically along coastal waters to feed (Lloris and Rucabado, 1991). The bone remains of both species predominated in the archeological record and appeared in clear association with sub-spherical lithic weights (Zangrando, 2007, 2009). Accordingly, this contextual information supports the idea that sub-spherical shapes were better adjusted against sea-current drag than the flatter ones. In contrast, along the North Patagonian coast, lenticular and flat-shaped weights were linked to another technical system. In fact, Scartascini (2010) sustains that it is possible to characterize the lithic weights recovered from the San Matías Gulf coast as artifacts from net fishing. His argument is supported by, in the first place, the reduced variability registered in morphology, sizes and weights of the artifacts (see also Scartascini and Cardillo, 2009). Secondly, as it was mentioned previously, these artifacts were normally found in spatially segregated concentrations, which are normally observed in archeological net fishing assemblages (Greenspan, 1998; Torres, 2007a, 2007b). Also, taxonomic representations and estimations of total sizes for ichthyoarcheological specimens in the North Patagonian coast were also consistent with net fishing strategy (Scartascini et al., 2009). In current times this coastal species are fishing by small boats using long lines and gill nets, however this would not be an option because the terrestrial hunters did not use boats to fish and this limits possible fishing techniques.

Considering the morphological variables of lithic weights, their discreet concentrations in archeological contexts and the available ethnographic data, Torres (2009:127) has also recognized flat lithic weights at the north coast of Tierra del Fuego and suggested that these artifacts would be associated to net-fishing by land-based hunter–gatherer groups.

6. Conclusion

Given the extreme variation observed, as well as the concordance between morphology, weight, environmental data and ethnography, we believe that it is possible to suggest that the differences noted between both regions could be related to a major reliance on one or another of the technical systems. The use of a large number of contextual variables, the incorporation of ethnographic artifacts and/or belonging to different habitats, could help to establish, with greater certainty, a link between the variation pattern of the artifacts and their potential functionality.

The combination of statistical and morphometric methods achieved the aim of generating the tools to evaluate the probability behind the hypothesis concerning the differences in fishing technologies at both studied areas. This analysis combines both metric and qualitative variables and has particular relevance for the study of artifacts with scant modification (lithic weights, flake instruments, chopping tools, percussion hammers, *etc.*) In cases such as these, the inherent variation presents itself more as a continuum rather than as discrete categories. Therefore, the combination of different analytical criteria within a comparative scheme allows us to restrict the patterns of variation. In turn, these studies can be interpreted through the appreciation of resource exploitation models and technological strategies. In this sense, the comparative analysis of two artifact assemblages separated spatially and culturally, but generated by hunter–gatherers with an important economic emphasis on fish exploitation within different environments of Patagonia, was of great use in studying the relation between design and functionality. We believe that this statistical approach is applicable beyond these particular case-studies, and it can be generalized and applied to other assemblages and to similar artifacts.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.jasrep.2015.10.030.

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