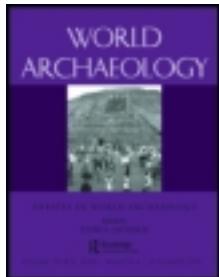


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Spatial patterns in Late Holocene lithic projectile point technology of Tierra del Fuego (southern South America): assessing size and shape changes

Judith Charlin, Marcelo Cardillo and Karen Borrazzo

Abstract

This paper focuses on the application of geometric morphometrics to the study of the lithic record in southern South America. We review the regional background, discuss methodological issues and summarize research advances. Here a geometric morphometric approach is applied to the case study of Late Holocene stemmed lithic projectile points from Grande Island of Tierra del Fuego (southernmost South America). Our aim is to assess size and shape changes in a broad spatial scale. Projectile point morphometric variations are used to discuss spatial scales of interaction and differentiation among past human populations across the island. Finally, several hypotheses are introduced to explain the patterns observed.

Keywords

Geometric morphometrics; lithic projectile points; Tierra del Fuego; Patagonia; hunter-gatherers; spatial variation.

Introduction

The earliest evidences for human presence in southernmost South America date to c. 10–12,000 BP (Bird 1938, 1946, 1988; Massone 1987, 2004; Nami 1985–6, 1987; Prieto 1991). Until 8000 BP the island of Tierra del Fuego was connected to the continent by a narrow land bridge (McCulloch et al. 1997, 2005). The first evidences of human presence in Tierra del Fuego were recorded at the Tres Arroyos 1 rockshelter, dated to 10,500 BP (Massone 2009; Massone et al. 1999). Early Fuego-Patagonian inhabitants were terrestrial hunter-gatherers with a diet centered on the consumption of the wild camelid guanaco (*Lama guanicoe*) (Borrero 2003; Massone 1987, 2004; Mengoni Goñalons 1987). They all shared a common background, both genetic

(González-José et al. 2004) and technological. The latter assertion is based on the presence of the so called ‘fishtail’ projectile points in Late Pleistocene-Early Holocene sites located on the mainland as well as on Grande Island of Tierra del Fuego (Bird 1946, 1969, 1988; Jackson 1987; Massone, Jackson, and Prieto 1993, among others).

By 8000 BP the land bridge connecting Tierra del Fuego with the mainland was definitively flooded, forming the Magellan Strait and Grande Island (McCulloch et al. 1997, 2005). Thereafter, terrestrial populations previously inhabiting the region were divided and isolated from each other by a marine channel whose width varies from 3.5 to 30km nowadays. After Tres Arroyos 1 Late Pleistocene archaeological record, two sites located on the southern coast of Grande Island (Beagle Channel) exhibit human occupations dated to the Early Holocene: Imiwaia I (7840 ± 50 BP) and Tunel I (6680 ± 210 BP) (Orquera and Piana 1999, 2009). These assemblages were assigned to terrestrial hunter-gatherers (Orquera and Piana 1999, 2009). Thereafter, Beagle Channel region records – along with the Western Channels – some of the earliest evidences for navigation technology recorded in the southern tip of America, dated c. 6400 BP (Legoupil 2003; Orquera and Piana 1999, 2006, 2009; Orquera, Legoupil, and Piana 2011), and this technology was in use within southern Grande Island and Western Channels populations until historic times (Bridges [1952] 2003; Gusinde 1982, among others). On the contrary, there is no archaeological and/or ethnographic record for the incorporation of navigation technology among northern island hunter-gatherers (e.g. Gusinde 1982; Morello et al. 2012).

Based on the geological changes undergone by southern South America geography, Borrero (1989–90) formulated the hypothesis of cultural divergence which states that, after the formation of the biogeographic barrier (Magellan Strait), a process of cultural divergence started both on the island and the southern mainland. Subsequent research supported his hypothesis. Bioarchaeological data show that Tierra del Fuego Late Holocene human populations exhibit a smaller size of postcranial skeleton and lack sexual dimorphism (Béguelin and Barrientos 2006). Moreover, differences in craniofacial morphology were recorded among mainland and island skulls during the Late Holocene (e.g. Cocilovo and Guichón 1985–6; González-José et al. 2004). L’Heureux (2008) also reports a reduction of guanaco body size in continental populations after the formation of Magellan Strait. Finally, while rock art is a common feature in the mainland archaeological record, it is completely absent from the Tierra del Fuego repertoire (Fiore 2006).

Regarding lithic technology, Junius Bird’s regional settlement sequence has been the main frame of reference for understanding continental Patagonia’s cultural evolution. Based on stratigraphic evidences from caves and other archaeological sites on the mainland, this researcher defined five prehistoric periods (I to V) from 11,000 BP to historic times (eighteenth century) (Bird 1938, 1946, 1988). He focused on size and shape changes in projectile points and the presence/absence of other cultural items to characterize each period. However, subsequent research provided new data that questioned this cultural and temporal sequence to some extent (see Charlin and González-José 2012 for a comprehensive review).

Bird’s periods IV and V correspond to the Late Holocene and were defined by the presence of certain projectile point types called *Patagónicas* or *Ona* points (Bird 1938, 1946, 1988). Bird named period V points ‘Ona’ because these continental artifacts were similar to those used by *Selk’nam* or *Ona* people, an ethnographic terrestrial hunter-gatherer group inhabiting northern Tierra del Fuego in historic times (Borrero 2001; Chapman [1982] 1986). He stated this analogy on the basis of the *Selk’nam*’s hafted projectile point collection exhibited in a local museum (Bird 1988, 34). Furthermore, he explained the small size of type V points as a result of the

introduction of the bow and arrow in southern Patagonia (Bird 1988). Although Bird's primary research had focused on the mainland, he made a brief characterization of southern Grande Island archaeology through the study of cultural materials recovered from his excavations in shell middens located on the Beagle Channel. There, he distinguished two periods (Early and Recent or Yaghan).¹ The Yaghan period includes a projectile point type which was thought to be exclusive to the Beagle Channel region (Bird 1943, 1946). However, subsequent research proved this point type was present all over the island (Borrero 1979).

In general, projectile point archaeological studies in Tierra del Fuego were primarily centered in functional and technomorphological approaches (Álvarez 2009a, 2009b, 2011; Huidobro 2012; Morello, San Román, and Prieto 2002; Ratto 1990, 1991, 1992, 2003).

In recent years, we have developed an archaeological research program ,directed by Dr. Luis A. Borrero, devoted to the study of Late Holocene lithic technology variability in the areas adjacent to Magellan Strait. First, exploration of stone-tool composition showed that Fuegian assemblages are more diverse than the southern mainland's (Cardillo, Charlin, and Borrazzo 2013). A similar pattern was observed when comparing lithic stemmed projectile point size and shape variations by means of geometric morphometrics (Charlin, Borrazzo, and Cardillo 2013). The differences recorded on both studies agree with the material expectations of the cultural divergence hypothesis (Borrero 1989–90). The study we present here continues this research program aim of assessing the scales of social boundaries and interaction among Fuego-Patagonian hunter-gatherer populations. This article explores spatial patterns of shape and size variations in stemmed lithic projectile points recovered from Late Holocene (3000 BP onwards) archaeological sites in Grande Island of Tierra del Fuego (52–54° S, 66–74° W, Fig. 1).

Geometric morphometric analysis: background

Geometric morphometric analyses have recently became a common technique in archaeological research, although they were first introduced by several authors years ago (Bookstein 1986, 1989; Rohlf 1990, among others). The delay in the generalized application of these techniques may be related primarily to the availability and/or acquisition of adequate hardware and software for image

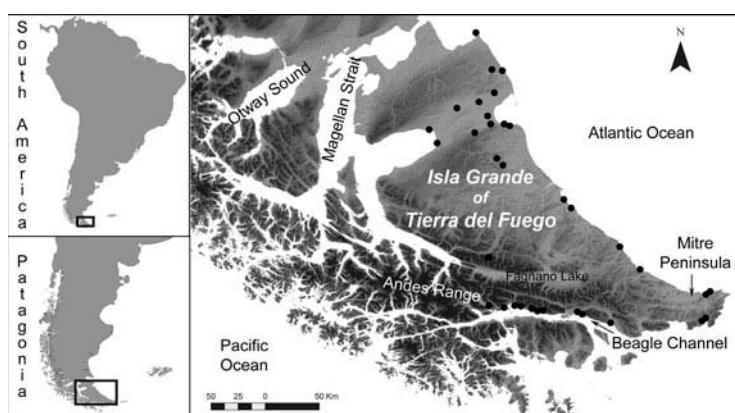


Figure 1 Map of the study region and sample provenience (black dots).

processing as well as the training required by their specific language (see Adams, Rohlf, and Slice 2004; also a recent update in Adams, Rohlf, and Slice 2013). Numerous variants of these techniques have been applied in archaeology, although two of them are the most popular: contour analysis based on Fourier decomposition (Brande and Saragusti 1996, 1999; Cardillo 2006; Cardillo and Charlin 2009; Gero and Mazzullo 1984; Iovita 2009; Iovita 2010; Iovita and McPherron 2011, among others) and landmark-based geometric morphometrics (De Azevedo, Charlin, and González-José 2014; Buchanan and Collard 2010; Buchanan et al. 2012; Cardillo 2009; Castañeira et al. 2011, 2012; Charlin and González-José 2012; Franco et al. 2009; González-José and Charlin 2012; Shott 2011; Shott and Trail 2010; Thulman 2012, among others). The former has proved its potential for closed contours and characterizes them on different scales of variation. The latter permits analysis of shape variation on discrete points, called landmarks, as well as groups of related points describing a surface (3D) or contour (2D), called semi-landmarks (Zelditch et al. 2004). In biology, landmark position responds to biological or phylogenetic issues, such as ontogenetic development and specific character inheritability (Bookstein 1991). In archaeology, these points cannot be defined according to homologous anatomical *loci*, but their homology is maintained following geometric principles (the same topological positions relative to other landmarks). Points located on identical morphological attributes (e.g. maximum curvature and/or distal and proximal ends of a piece) are considered type II landmarks (*sensu* Bookstein 1991). Moreover, semi-landmarks are used to describe certain aspects of shape without precise location or limits (such as irregular shapes or contours without marked inflexions), incorporating information about curvature in a geometric shape analysis (Zelditch et al. 2004).

In artifact analysis, it is possible to use landmarks as well as semi-landmarks. For the former, spots with a defined location can be selected (e.g. inflexions in projectile point design, such as those of the tip or the barb). Semi-landmarks, on the other hand, can be used to map the contour (e.g. the shape of the projectile point blade, Fig. 2), since no discrete morphological trait can be identified. The contour of any artifact part described with semi-landmarks has to be considered a homologous structures to other artifacts in the sample (Bookstein 1996–7) because each point is located not on a specific trait but in a position relative to another point.

There is no current agreement about which analysis, contour or landmark-based, is the best choice for archaeological research; their application depends on the specificity of each case study (see discussion in Gunza and Mitteroecker 2013; Rohlf 1990; Sheets et al. 2006). However, both procedures separate shape from size and represent them in a multidimensional space. For this reason, the application of multivariate techniques (such as principal component or factor analysis) is performed in order to reduce these dimensions and extract their morphological patterns at different scales (Bookstein 1989, 1991).

Graphic representation of these analyses permits exploration of morphological change as a continuum, which is an advantage over static or typological analyses centered more on morphological norm than on its variation (Cardillo 2010; Gero and Mazzullo 1984; Lycett, Von Cramon-Taubadel, and Foley 2006; Lycett, Von Cramon-Taubadel, and Gowlett 2010, among others). In the case of lithic artifacts, geometric morphometric analysis allows discussing spatial or temporal patterns of change, standardization, artifact life history and discontinuities among morphological ‘types’ (see Buchanan et al. 2010, 2012; Cardillo and Charlin 2009; Charlin and González-José 2012; Lycett, Von Cramon-Taubadel, and Gowlett 2010).

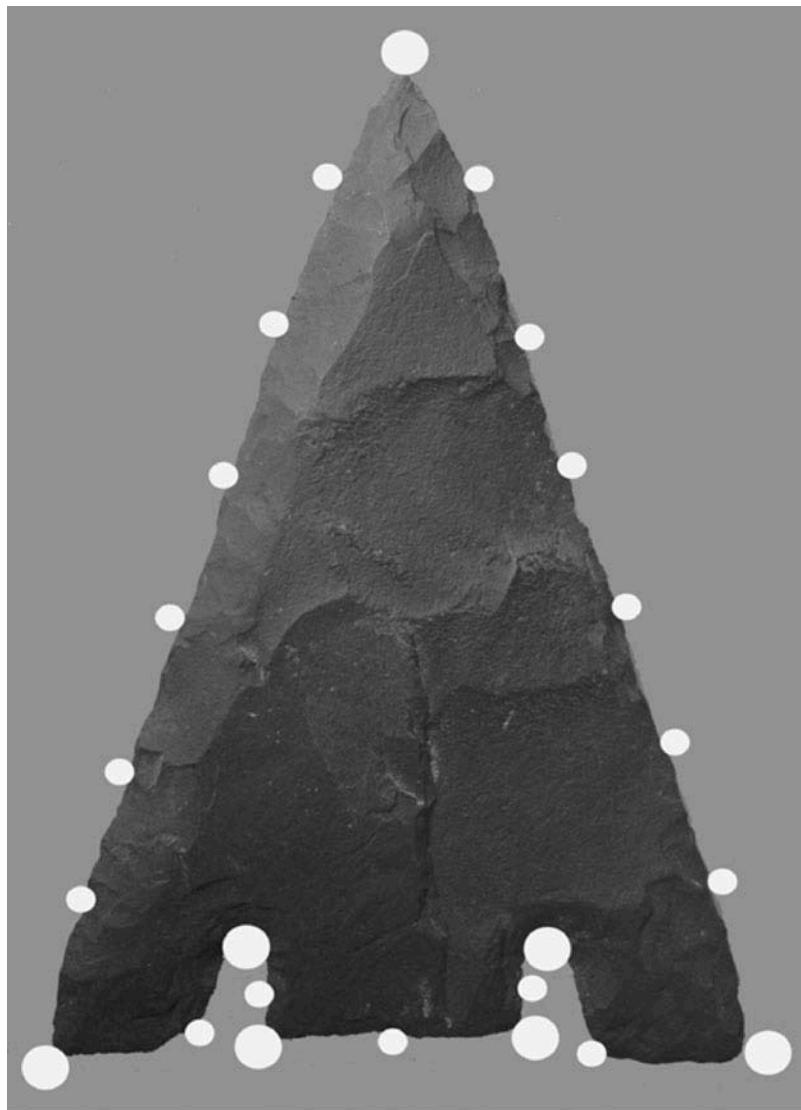


Figure 2 Landmark (large dots) and semi-landmark (small dots) locations on projectile points.

The new morphological variables obtained through a geometric morphometric analysis can then be employed in several univariate or multivariate exploratory analyses or hypothesis tests in order to examine possible causal factors of variation.

The application of geometric morphometrics to the study of lithic projectile point in Patagonia allowed the exploration of variation and change patterns in wide spatial and temporal scales (Cardillo and Charlin 2009, 2014; Charlin and González-José 2012; De Azevedo, Charlin, and González-José 2014; Franco et al. 2009; González-José and Charlin 2012; Scartascini and Cardillo 2009). In this way, Cardillo and Charlin point to the existence of a spatial pattern on the macro-scale, compatible with a model of isolation by distance, where morphological differentiation is not an abrupt phenomenon

related to a qualitative discontinuity but a gradual and relatively continuous one, explicable by the increase of spatial distance among samples.

The application of phylogenetic methods to mean morphologies (which represent approximately equidistant spots in the space) agrees with the hypothesis that space is a primary vector of change, and it probably worked as a selective factor that prompted a process of divergence in northern and southern Patagonia projectile points during the Middle and Late Holocene (Cardillo and Charlin 2014). From this perspective focused on the role of space and historical processes of differentiation, insular Patagonia – specifically Grande Island of Tierra del Fuego – is a case study of particular interest, since it is a unique laboratory in which to gain a deeper knowledge on processes of cultural divergence among human populations.

Material and methods

Lithic projectile points considered for this study were recovered from surface and stratigraphic archaeological sites located on Grande Island of Tierra del Fuego. Sample provenience is provided on the map (Fig. 1). Radiocarbon and relative chronologies for the tips are 3000 BP or later (Table 1). It is worth mentioning that the history and timing of geological and geomorphologic evolution offer a rough maximum chronological framework for the archaeological record of several regions in the north of Grande Island since numerous portions of the landscape became available and/or accessible for human occupations only after Middle Holocene (Bujalesky 2007; Vilas et al. 1986–7, 1999). This general pattern was regionally supported with archaeological radiocarbon dates (Borrazzo 2010, 2012; Favier Dubois and Borrero 2005; Morello et al. 2009, 2012; Salemme and Bujalesky 2000, among others). Moreover, lithic projectile points are absent from the scarce Middle Holocene lithic assemblages identified so far (Morello et al. 2012; Salemme, Bujalesky, and Santiago 2007; Santiago 2013; Zangrando, Vázquez, and Tessone 2011); the only known exception, Beagle Channel region, exhibits large stemmed leaf-like bifacial tips dated around 4000 BP (Álvarez 2009a, 2009b, 2011; Orquera and Piana 1999). Since 2000 BP, the archaeological signal all over the Grande Island records a significant intensification which has been explained as a result of demographic growth (Borrero 2005; Morello et al. 2012).

The sample analyzed here includes 154 digital images of complete or very slightly damaged stemmed projectile points. Slight damage to the point (≤ 3 mm) was tolerated if the shape could be reconstructed from the remaining planes of the piece. The sample was obtained from the authors' own research and published literature. In addition, several Chilean and Argentine colleagues collaborated with images of unpublished data and facilitated access to extant collections housed in several research institutes (see Table 1 for references).

For statistical comparative purposes, the sample was divided into two groups related to their geographical provenience: northern (N) and southern (S) areas. This differentiation has a biogeographic sense, because important environmental and geographical differences exist between the two areas. The northern area includes the portion of the island that extends between Magellan Strait and Fuegian Andes Range. The Fuegian Andes Range, which runs W–E up to $66^{\circ} 37'$ W and exhibits the maximum heights (1500 masl) recorded within the island, constitutes a natural barrier for N–S circulation (Fig. 1). To the east of the Fuegian Andes Range – and at the same latitude ($54^{\circ} 43'$ S) – eastern and southern island coasts get closer, forming the Mitre Peninsula, where the maximum distance between the coasts is c. 70 km (Fig. 1). Therefore, we

Table 1 Lithic projectile point samples from the Grande Island of Tierra del Fuego

Site/locality	n	Provenience	Chronology	Area	Source and/or references
Ajéj I	3	Stratigraphy	1300–1400 BP	S	Piana, Vázquez, and Álvarez (2008); Orquera's unpublished photographs
La Amalia (sites 4 and 5)	2	Surfâce	n.d.	N	Oriña (2009, 2012); Oriña, Saleanne, and Fernando (2010)
Bahía Valentín 11	2	Stratigraphy	1500 BP	S	Zangrandro, Tessone, and Vázquez (2009)
Bahía Valentín 42	2	Surfâce	1000 BP	S	Vázquez et al. (2007)
Bahía Valentín locality	3	Surfâce	1500 BP	S	Vázquez et al. (2011)
Bahía Inutil 14	1	Surfâce	≤2000 BP	N	Massone et al. (2003); Authors' photograph
Cabo San Pablo	1	Surface	≤1000 BP*	N	Borrero (1985); Authors' photograph
Caleta Falsa	8	Surface/ Stratigraphy	800 BP*	S	Chapman and Hester (1973); Guichón and Suby (2011)
Cabeza de León 1	5	Stratigraphy	≤2000 BP	N	Borrero (1979); Javier Dubois and Borrero (2005); Borrazzo (2009)
Heshkaia 35	1	Stratigraphy	≤800 BP	S	Zangrandro (2010)
Río Cullen	2	Surfâce	n.d.	N	Borrazzo (2010)
Lanashuaia	2	Stratigraphy	Nineteenth century	S	Piana, Estévez, and Vila (2000)
Lancha Packewaia	5	Stratigraphy	≤1500 BP	S	Orquera and Piana (1999); Orquera's unpublished photographs
Las Mandíbulas 1	2	Surfâce	≤2000 BP	N	Borrazzo (2010); Author's photograph
Las Mandíbulas 2	2	Surfâce	≤2000 BP	N	Borrazzo (2010); Author's photograph
Las Mandíbulas 4	2	Surfâce	≤2000 BP	N	Authors' photograph
Las Mandíbulas 9	1	Surfâce	≤2000 BP	N	Authors' photograph
Las Mandíbulas 10	1	Surfâce	≤2000 BP	N	Authors' photograph
Marazzi (sites I, H and J)	3	Surfâce	≤5500 BP	N	Morello et al. (1998); Morello, Contreras, and San Román (1999); Morello (2000); Massone and Morello (2007); authors' photograph
Maria Luisa	1	Stratigraphy	≤1000 BP*	S	Ratto (1991, 1992); Lanata (1995); authors' photograph
Mischihuen I	3	Stratigraphy	≤1000 BP	S	Piana, Vázquez, and Rua (2004)
Punta Catalina 3	1	Surfâce	≤2500 BP	N	Massone and Torres (2004); authors' photograph.
Punta María 2	8	Stratigraphy	≤1000 BP	N	Borrero (1985); Borella, Borrero, and Cozzuol (1996); Ratto (1990, 1992); authors' photograph
Puesto Pescador 1	1	Stratigraphy	300 BP	N	Santiago (2013)
Rancho Donata	12	Stratigraphy	1500 BP*	S	Lanata (1995); Ratto (1991, 1992); authors' photograph
San Julio 4	1	Surfâce	n.d.	N	Oriña (2009, 2012)

(continued)

Table 1 (Continued)

Site/locality	n	Provenience	Chronology	Area	Source and/or references
Los Chorrillos	5	Surface	\leq 1000 BP	N	Borrazzo (2010)
Shamakush I	3	Stratigraphy	\leq 1500 BP	S	Orquera and Piana (1999); Orquera's unpublished photographs
Shamakush VIII	2	Stratigraphy	\leq 1500 BP	S	Piana and Vázquez (2009); Salvatielli (2012)
Tres Arroyos I	4	Stratigraphy	\leq 1500 BP	N	Massone (1987); Morello et al. (2012); Huidobro (2012)
Tunel I	1	Stratigraphy	\leq 1000 BP	S	Orquera and Piana 1986–7
Tunel VII	37	Stratigraphy	Nineteenth century	S	Orquera and Piana (1999); Briz (2010); Orquera et al. (2012)
Cerro Bandurrias	1	Surface	\leq 5000 BP*	N	Borrazzo (2010)
Isla El Salmon	1	Stratigraphy	1800 BP	S	Figueroa Torres and Mengoni Goñalons (1986)
Marina I	1	Stratigraphy	\leq 2000 BP	N	Mansur, Martínoni, and Lasa (2000)
La 12	1	Surface	300 BP	N	Massone, Jackson, and Prieto (1993)
Laguna Vergara	1	Surface	2500 BP*	N	Morello et al. (2012); authors' photograph
Beagle Channel**	6	N/D	n.d.	S	Bird (1946)
Between Chico and Grande Rivers**	10	Surface	n.d.	N	Gusinde (1982)
Ea. Viamonte**	1	Surface	n.d.	N	Gusinde (1982)
Beagle Channel**	3	Stratigraphy	\leq 2000 BP	S	Álvarez (2009b)
Selk'nam ethnographic point**	2	Surface	n.d.	N	Massone (2010); Morello et al. (2012)

Notes * Based on radiocarbon dates available for the locality.

** No spatial coordinates available.

defined the southern area as the portion of the island located between the Fuegian Andes Range and the northern coast of the Beagle channel, and Mitre Peninsula, to the east.

The raw images were compiled and scaled in Tps programs (Rohlf 2004a, 2004b) and a total of seven landmarks and seventeen semi-landmarks were digitized on the outline of each projectile point (Fig. 2). Then, a Procrustes fit was obtained (Rohlf 2007), and shape and size matrices were exported to MorphoJ (Klingenberg 2011) to perform statistical analyses. Spatial coordinates of each specimen were subjected to the distance-based Moran eigenvector method (MEM) (Borcard et al. 2004; Griffith and Peres-Neto 2006) in order to obtain independent spatial variables. Then, the main shape and spatial variables were correlated, with the aim of exploring geographical patterns in shape distribution, using R software (R Core Team 2005) and spatial analysis in macroecology (SAM) (Rangel, Diniz-Filho, and Bini 2010).

Data analysis

This investigation explores the variations on three dimensions of data: shape and size of projectile points and the relationship between sample spatial distribution and morphological similarity. We next detail the statistical procedures selected in each case.

Shape analysis The main trends in morphological variation were explored with a principal component analysis (PCA) performed on the covariance matrix of shape coordinates. This method is useful for extracting simple patterns of shape variation from complex multidimensional data (Zelditch et al. 2004, 18). It allows the capture of most of the variation among specimens in a low dimensionality space, replacing the original variables with new ones (principal components) that are linear combinations of the original variables and independent (orthogonal) of each other (Zelditch et al. 2004, 156). So, most of the variation in the sample can be described with only a few PCs, which were afterwards used as response variables in other analyses.

On the other hand, differences between groups (according to their provenience area) were assessed by a discriminant analysis (DA). Whereas PCA is used to describe differences among individuals, DA is used to maximize the separation between groups (McCune and Grace 2002; Strauss 2010). The object of this analysis is to find, from a linear combination of variables, axes ('discriminant functions') that best discriminate among known groups (in our case defined by provenience area). It maximizes the between-group variation relative to the within-group variation and the shape coordinates are used as predictors (independent variables) of group membership (McCune and Grace 2002).

The discriminant function is the direction in which the group means are most different. Each group of individuals must be mutually exclusive and must differ by a categorical variable (called the 'grouping variable'). So each group shares a particular state of a discontinuous trait, and in this way the discriminant function is the most efficient discriminator, i.e. it finds the shape features that best distinguish among groups (Zelditch et al. 2004). The statistical significance of the differences between groups was tested using a permutation test (1,000 rounds) on the Procrustes distance. Procrustes distance is the square root of the sum of squared differences between the positions of the landmarks in two optimally (by least-squares) superimposed configurations at centroid size (Slice et al. 2013).

Size analysis Mean projectile point size between groups was compared by t-test using the centroid size estimate, which is the square root of the summed distances between each landmark coordinate and the centroid of the point (Dryden and Mardia 1998).

Spatial analysis Including space as a main variable in our analysis has valid analytical and statistical grounds. On the one hand, it allows the application of spatial models, such as the isolation-by-distance models (Cavalli-Sforza 2000), in which type and mode of information flow among individuals or groups is expected to be affected by space, a pattern that has been widely proved by several authors (Peres-Neto 2006; Perez and Monteiro 2009, among others). On the other hand, statistics assume that observation units are random since they can have any numerical value between certain ranges, that is to say, they are independent of each other. However, when these units are measured through a spatial axis (height, horizontal distance or depth; see Borcard et al. 2004; Borcard, Gillet, and Legendre 2011), it is possible that they are not completely independent since they share spaces with similar properties, mobility ranges, information flow and so on. This phenomenon, named spatial autocorrelation, can be modeled and included in the analyses to control space as a factor (e.g. employed as a covariate) as well as to explore its weight on the explanation of morphological change. We selected this latter function for the present investigation.

There are numerous spatial analysis techniques that employ not raw coordinates but mostly their spatial structures (Legendre and Legendre 1998). Although building and modeling these structures depends on the quantity, distribution and model selected to analyze the spatial units, the main goal is to explain the changing levels of association or differentiation among them. In our case, we found that models based on distance matrix multivariate decomposition are especially useful because they fit data matrices with regular as well as irregular (different distance among units) spatial structures, and allow spatial variation decomposition at different scales (Borcard et al. 2004).

As in other multivariate decomposition methods, MEM procedures extract new orthogonal spatial variables from a previously distant matrix. Each new variable explains an independent portion of total spatial variation. While the first vectors explain global-scale spatial phenomena, the subsequent ones do so at local (small) scales and also can show variation related to spatial random processes. As a measure of distance-dependent relation between spatial units, MEM's method employs Moran's I autocorrelation index. This index, like the well-known Pearson's correlation, varies between -1 and 1 . Positive values are related to 'contagious' processes (Borcard 2004) when a reduction of spatial distance is correlated with an increase similarity in the value of spatial units. On the contrary, negative values are related to 'repulsion' processes (Borcard 2004), where the opposite phenomenon is observed. Contagious phenomena are more common and can be explained in more parsimonious ways (at least in nature, see Legendre and Legendre 1998) than repulsion ones, although both may be important in shaping spatial structures.

For the present study, spatial coordinates (longitude and latitude measured in decimals) were used to generate a distance matrix and extract orthogonal spatial variables;² then each new variable was correlated with morphological vectors. When significant correlation was observed, the spatial variable was stored for further analysis. Finally, in order to explore spatial models of morphological variation, an ordinary least-squares regression procedure was used to extract linear combinations of morphological and spatial factors.

Results

Shape variation

The first principal component (PC1), which explains 56.36 per cent of total variance, depicts changes in the relative expansion and contraction of both blade and stem, shoulder angle and blade tip (from

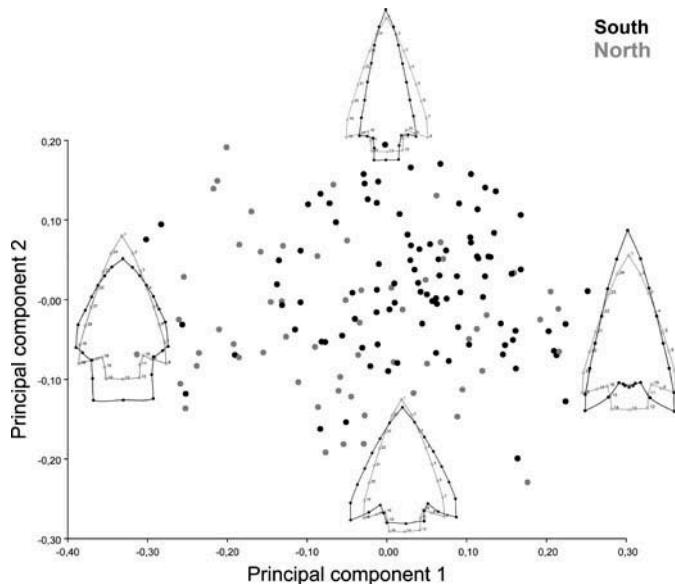


Figure 3 Principal component analysis of projectile point shape.

right to left, Fig. 3). PC1 positive scores show triangular long blades with acute tips, barbed shoulders and contracting stems. PC1 negative scores exhibit triangular short blades with rounded tips, sloping (obtuse) shoulders and long, wide, straight stems. The PC2, explaining 26.26 per cent of variance, records from wide expanded (negative scores) to narrow elongated (positive scores) shapes (from bottom to top, Fig. 3). PC1 and PC2 explain 82.65 per cent of total shape variation. In Fig. 3, gray tip outlines located at the end of the coordinate axes depict the average shape for the assemblage (the consensus shape) while black outlines show its variation.

A discriminant analysis was run to test the existence of morphological differences between provenience areas (Fig. 4). The permutation test on Procrustes distances finds significant differences (Procrustes: 0.099, $p < 0.001$). Table 2 shows the frequency of misclassifications, which is similar between the two areas (north = 19 per cent, south = 17 per cent).

Size variation

Since we detected spatial shape variations, we tested the existence of size variations through the island by means of centroid size. We performed a *t*-test which shows there are significant differences between groups ($t = 3$, $p = 0.003$). As was observed in projectile point shape variations, there are significant size differences between N and S samples, the first being the largest.

Spatial shape variation

The correlation between shape and spatial distribution was tested by Moran's I eigenvector method performed on longitude and latitude coordinates for each specimen. The first spatial vector was used to perform a regression analysis against PC1 of shape. Results show that the spatial distribution explains 9.83 per cent (R^2) of morphological variation ($F = 14.18$, $p < 0.001$). A surface plot of regression scores shows predicted morphological space (Fig. 5a), where darker

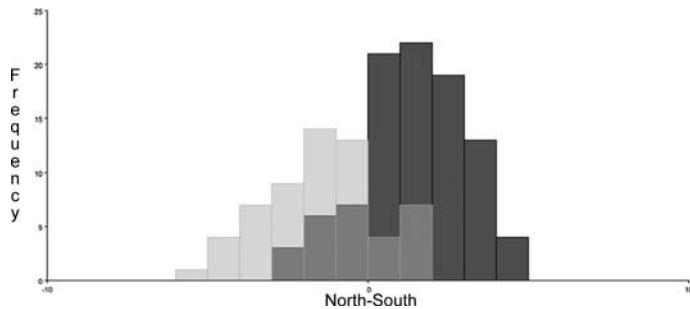


Figure 4 Histogram of discriminant scores for northern and southern groups of projectile points.

Table 2 Classification/misclassification table according to discriminant analysis

True group	Allocated to		Total
	North	South	
North	48	11	59
South	16	79	95

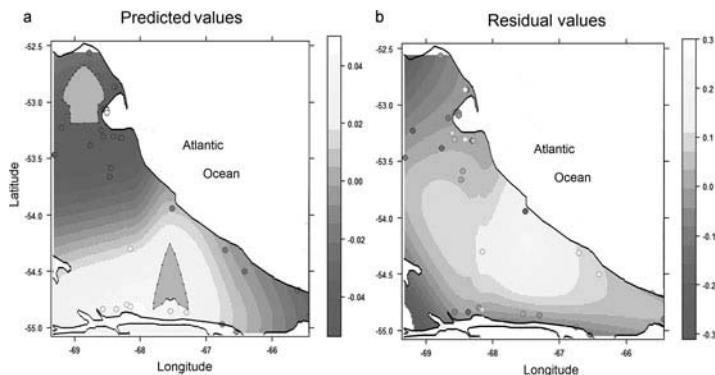


Figure 5 Surface representation of first axis of regression analysis between spatial dimensions and first principal component of shape.

areas indicate triangular short blades with rounded tips, sloping (obtuse) shoulders and long, wide, straight stems and lighter ones depict triangular long blades with acute tips, barbed shoulders and contracting stems, accordingly to PC1 (see Fig. 3). Also, a residuals map (Fig. 5b) suggests that the low percentage of explained shape distribution is related, at least in part, with scarcity of information in some areas, like the center of the island, since lighter areas indicate greater predictive error. In contrast, the pale gray areas are better predicted.

Discussion

Spatial and morphometrical trends highlighted by the present study have several implications for Late Holocene Fuegian archaeology. PCA was useful to characterize shape change as a continuous

phenomenon throughout the study area. However, DA suggests differences in shape between the north and south areas of the island, as also does size analysis. These differences are also observed by spatial and regression analyses. Shapes related to PC1 negative scores show wider distribution across the island and the Atlantic coast – including northern Mitre Peninsula – than shapes related to PC1 positive scores, which seems to be more restricted to Beagle Channel area (Fig. 5). This trend may be interpreted as a result of extensive replication of an efficient northern design combined with different mobility ranges.

In the Beagle Channel area, local archaeological studies record a diversification process in lithic technology by 2000 BP (Álvarez 2009a, 2009b, 2011; Orquera and Piana 1999). Several lithic projectile point designs appear around that date, which were interpreted as indicating major change, reorganization and diversification in prey acquisition strategies of littoral human groups (Álvarez 2009a, 2009b, 2011). However, this increase in tip design locally recorded is not self-evident at a greater spatial scale. Indeed, despite the Late Holocene occurrence of new stone tips, Beagle projectile points exhibit significant autocorrelation levels, indicating contagious shape effect among neighboring samples. Hence, this difference in the macro-scale may be pointing to a smaller degree of cultural interaction and/or permeability of Beagle Channel human groups. Several probable causes (hypotheses) of this large-scale trend can be proposed.

As we mentioned earlier, the Fuegian Andes range (1500 masl max) appears as a natural border of the southern area (Fig. 1). This does not imply that human groups could not go across these mountains – actually, several paths were known by native inhabitants during historic times, see Bridges [1952] 2003 – but the N–S vector to the south of Fagnano Lake may have carried higher costs for human circulation than moving about the rest of the study region.

One potential factor influencing the distributional shape patterns highlighted by this study is the temporal variation in human occupations represented within each area. Based on available Grande Island chronology, we selected a ‘coarse’ time span for our research (Late Holocene, last 3000 BP). However, as soon as more radiocarbon dates are available, smaller temporal scale analyses need to be performed in order to identify time-specific shape and size variations within the Late Holocene.

An alternative explanation for projectile point variability throughout the Grande Island is to consider the role of subsistence and technological factors. While northern groups had an economy centered on terrestrial resource exploitation (mainly guanaco), sea mammals and mollusks were the primary food source for Beagle Channel groups (Orquera and Piana 1999, 2009). Moreover, the latter were the only Fuegian hunter-gatherers with navigation technology. However, according to the morpho-functional model proposed by Ratto (1990, 1991, 1992, 2003), four technical systems using stemmed points were identified in the north (arrows, hand-throwing spears, thrusting spears and daggers), while only two systems were recognized among stemmed points (arrows and hand-throwing spears) in the Beagle Channel (Álvarez 2009a, 2009b, 2011). Further survey of Fuegian lithic collections is needed to assess these hypotheses.

Among the more specific results pointed out by our morphometric analyses is the fact that a complete green obsidian projectile point recovered at Amalia 5, located close to the Atlantic Ocean on the northern island (Oria, Salemme, and Fernando 2010), exhibits morphological similarities with neighboring samples, suggesting it was locally manufactured. The only known source for this rock is the Otway Sound-Riesco Island area (Morello et al. 2001; Morello, San Román, and Prieto 2004, 2012; Stern 2000; Stern and Prieto 1991, see Fig. 1) and its acquisition by Fuegian terrestrial hunter-gatherers was probably through exchange with canoe peoples inhabiting the Western Channels (Morello, San Román, and Prieto 2004, 2012). The similarities

detected by our research strongly point to the acquisition of blanks/nodules of this exotic rock and the local manufacture of the tip. As proposed by Morello et al. (2012), interaction with canoe peoples from the Western Channels starting 5000 BP may have mitigated terrestrial hunter-gatherer insularity.

Concluding remarks

The spatial patterns of shape variation in projectile points show different scales of interaction and differentiation in Fuegian lithic technology during Late Holocene. First, the data presented here show the existence of large-scale projectile point design circulation, which agrees with already available lithic raw material data (Borrazzo 2012; Morello et al. 2001; Morello, San Román, and Prieto 2004, 2012; Stern 2000; Stern and Prieto 1991). However, analyses suggest that the Beagle Channel sample is more homogeneous. Although some of its commonest designs are represented in northern and south-eastern samples, the Beagle Channel assemblage does not present the most frequent tip design recorded on the rest of the island. This trend may be alternatively or jointly explained by environmental and biogeographic (Andes range as a barrier) or socio-cultural and temporal factors that need further research. Finally, northern and Mitre Peninsula projectile points exhibit stronger shape similarities against Beagle Channel samples, suggesting a more intense interaction among their populations during the Late Holocene. The latter assertion provides new information for the current archaeological discussion regarding the time depth of the *Haush* ethnographic group configuration (Zangrando, Vázquez, and Tessone 2011).

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Notes

- 1 Yaghan or Yámana was the name of hunter-gatherer populations inhabiting the Beagle Channel by historic times, whose diet was centered on marine resources (sea mammals, mollusks, etc.) (Gusinde 1982).
- 2 Twenty-two cases were excluded from this analysis due to a lack of available information (see Table 1).

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