SIZE AND SHAPE VARIATION IN LATE HOLOCENE PROJECTILE POINTS OF SOUTHERN PATAGONIA: A GEOMETRIC MORPHOMETRIC STUDY

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Since the beginning of systematic archaeological studies in southern Patagonia (Argentina and Chile), projectile points have played an important role as cultural markers. A sequence of projectile point types was established according to their changes in size and shape. These stone tools, along with others cultural evidences, served to differentiate a series of "cultural periods," which were, for decades, the frame of reference to understand the cultural evolution in southernmost Patagonia. Although later researches have questioned several of these assumptions, the classical typology of projectile points continued in use until the present day. The goal of this work is to evaluate size and shape variation in two late Holocene projectile point types, known as Fell, Bird, or Magallanes IV and V points or Patagónicas and Ona points, respectively. These two types are compared using geometric morphometrics and multivariate statistical analyses. The reliability in the discrimination between types is tested at the light of reduction. The analyses have shown a major incidence of reduction on shape rather than on size, and on blade rather than on stem. However, in average, types IV and V can be distinguished in terms of size, and stem shape despite reduction. Thus, even though successive cycles of use, damage and resharpening have a great influence over size and shape of projectile points, resharpening techniques are specific enough to maintain the differences of size and shape between types, a pattern that is probably related with functional requirements.

Desde los comienzos de los estudios arqueológicos sistemáticos en el sur de la Patagonia (Argentina y Chile), en la década de los 30's, las puntas de proyectil han jugado un rol importante como marcadores culturales. De acuerdo con sus cambios en tamaño y forma, se estableció una secuencia de tipos morfológicos de puntas de proyectil. Estos instrumentos líticos, junto con otras evidencias culturales, sirvieron para diferenciar una serie de "períodos culturales", los cuales fueron, por décadas, el marco de referencia para entender la evolución cultural en el extremo austral de Patagonia meridional. A pesar de que las investigaciones posteriores han criticado varios de los supuestos básicos con los cuales se construyó esta periodización, la tipología clásica continúa en uso hasta hoy. El objetivo del presente trabajo es evaluar la variaciones en tamaño y forma en dos tipos de puntas de proyectil del Holoceno Tardío conocidos como Fell, Bird o Magallanes IV y V, o puntas Patagónicas y Onas, respectivamente. Éstos se consideraron como tipos diagnósticos para distinguir los Períodos IV y V en la secuencia regional de ocupación propuesta por Junius Bird. Aquí se comparan ambos tipos mediante análisis de morfometría geométrica y estadística multivariada. Se prueba la confiabilidad en la discriminación entre tipos a la luz de la reducción. La consideración del tamaño y la forma de las puntas de proyectil como variables independientes, gracias a las técnicas de la morfometría geométrica, ha permitido evaluar la incidencia relativa de la reducción sobre ambas variables, y también en relación con las diferentes partes que componen la punta de proyectil. Los análisis han mostrado una mayor incidencia de la reducción sobre la forma que sobre el tamaño, y sobre el borde que sobre el pedúnculo. Sin embargo, a pesar de los cambios morfométricos producto de la reducción, los tipos IV y V pueden distinguirse, en promedio, en base al tamaño y a la forma del pedúnculo. En consecuencia, si bien los sucesivos ciclos de uso, desgaste y reutilización tienen una gran influencia sobre el tamaño y la forma de las puntas de proyectil, las técnicas de reutilización son lo suficientemente específicas para mantener las diferencias de tamaño y forma entre tipos, probablemente en relación con demandas funcionales.

In the last decades, the study of stone tools has neglected the old discussion between stylistic and functional explanations of the variations in size and shape of artifacts. Instead, more attention was given to allometric changes owing to reduction (Andrefsky 2008; Clarkson and Lamb 2005; Dibble 1984, 1987, 1997; Dibble and Pelcin 1995; Eren et al. 2005; Hiscock 2007; Hiscock and At-

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tenbrow 2002, 2003, 2005; Hiscock and Veth 1991; Holdaway et al. 1996; Kuhn 1990, 1991, 2004; Shott 2005; Shott and Ballenger 2007; Shott et al. 2007). Pursuing this goal, a broad spectrum of analytical techniques and procedures was developed and applied, starting with the experimentation in the manufacture, use, and rejuvenation of replicated stones tools in simulated use-life situations (Andrefsky 2006; Clarkson 2002; Clarkson and Hiscock 2008; Davis and Shea 1998; Flenniken and Raymond 1986; Hiscock and Clarkson 2005a, 2005b; Hunzicker 2008; Quinn et al. 2008; Towner and Warburton 1990; Wilson and Andrefsky 2008), and ethnographic and ethnoarchaeological observations (Shott and Sillitoe 2001, 2005; Shott and Weedman 2007), as well as the use of computational programs to the analysis of size and shape-related changes in digitized tools (Bradbury and Carr 2003; Buchanan 2006; Buchanan and Collard 2010; Cardillo 2009; Cardillo and Charlin 2009; Cardillo et al. 2010; Castiñeira et al. 2011; Charlin et al. 2010; Franco et al. 2009; Iovita 2009).

These studies have shown a continuum of morphometric variation along the use-life of several tool types identified in different archaeological contexts around the world. We can mention the debate about size and shape variation in Middle and Upper Paleolithic side scrapers and notches (Close 1991; Dibble 1984, 1987, 1991; Holdaway et al. 1996; Nejman and Clarkson 2008); Upper Paleolithic burins (Barton et al. 1996; Clay 1976); Australian tulas, horsehoofs, scrapers, points, and backed artifacts (Hiscock 1994, 2006, 2007; Hiscock and Attenbrow 2002, 2003, 2005; Hiscock and Veth 1991); and bifaces in North America (Andrefsky 2006; Bettinger and Eerkens 1999; Bettinger et al. 1991; Bradbury and Carr 2003; Buchanan 2006; Buchanan and Collard 2010; Flenniken and Raymond 1986; Flenniken and Wilke 1989; Hoffman 1985; Hunzicker 2008; Morrow and Morrow 2002; Shott and Ballenger 2007; Shott et al. 2007; Towner and Warburton 1990), among many others.

These studies have posed questions about the relationship between size and shape in stone tools, number of specimens and amount of work represented by them, kinds of use, rates of tool depletion and discard and, most importantly, they have developed some critical theoretical and methodological implications to the study of stone tools and for the inference of technological strategies as tool curation and its relationship with patterns of mobility and land use (Shott 1986; 1996; Shott and Sillitoe 2005; Shott et al. 2007). The open question is how to register the variability among stone tools and what it signifies. A derived conclusion of these works was a cautionary tale about the relevance of typological classifications usually employed in lithic studies.

Following a typological protocol, stone tool assemblages often are segmented and quantified according to size and shape in discrete "types." In this way, much continuous variation is arbitrarily subdivided on the basis of variables isolated by the typology to discriminate between types, which are considered as essences (Dunnell 1971, 1986; Hiscock 2007; Shott 2005). Thus, in many cases artifactual variability is under- or overrepresented. Furthermore, typological classification often presumes an analogy between tool shape and function, which have been questioned by many ethnoarchaeological and microwear studies (Álvarez 2004; Gould 1978; Gould et al. 1971; Hayden 1998 [1977], 1979; Odell 1988).

In sum, the allometric changes produced by reduction along an artifact use-life were identified and recognized through different lines of evidence and were understood under the "reduction thesis" (cf. Shott 2005).

However, a recent study makes claims that despite of variation because of reduction, recognizing shape differences between discrete types of artifacts is still possible (Buchanan and Collard 2010). In other words, the recognition of some traditional projectile point types using geometric morphometric methods was possible after controlling the effects of size, lithic raw material, and resharpening variation. Within this framework, the geometric morphometric analyses acquire a particular importance because they enable us to obtain a size estimator (centroid size) independent of shape variation and, thus, to assess their putative correlation. However, estimation of size after 2D data derived centroid size should be performed with caution because some projectile points can potentially vary in size owing to 3D form changes not necessarily recovered using 2D images (Shott 2010).

In the present study, we aim at evaluating the existence of size and shape differences between two projectile points types from the late Holocene of southern Patagonia (Santa Cruz Province, Argentina and Magallanes, Chile) before and after the effects of reduction are statistically removed. We refer to projectile points known as Bird, Fell, or Magallanes IV and V or Patagónicas and Ona points, respectively (Bird 1938, 1946, 1988). These points are relevant in the classical archaeology of southern Patagonia because they have been considered as diagnostic types to discriminate between periods and cultural groups (Bird 1938, 1946, 1988). Although the subsequent researches have pointed out the ambiguity of this classification and other morphological groupings were proposed (Gómez Otero 1986–1987, 1987; Massone 1979, 1981, 1989–1990; Nami 1984a, 1984b; Prieto 1989–1990; Ratto 1994; Sanguinetti de Bórmida 1984), the classical differentiation between IV and V types is kept in use.

Late Holocene Projectile Points of Southern Patagonia

Junius Bird's Periodization

Systematic archaeological research in southern Patagonia began in the 1930s with Junius Bird's investigations at Pali Aike and Fell caves, in Chilean Patagonia (Bird 1938, 1946, 1960, 1970, 1983, 1988). On the basis of stratigraphic evidences from these caves, as well as the information obtained from Cerro Sota and Cañadón Leona excavations, Bird proposed a regional settlement sequence from *ca.* 11,000 BP to historic times (eighteenth century; see Bird 1938, 1946, 1988). According with artifacts types and faunal remains, five prehistoric periods (known as Magallanes, Fell, or Bird I–V) have been differentiated previous to European contact (Historic period; see Bird 1938, 1946, 1988). Projectile points and scrapers shape and size were the key traits to discriminate among periods (Bird 1946).

Periods IV and V correspond to the end of the prehistoric, late Holocene sequence, and were defined by the presence of a given projectile point type (Bird IV–V; see Figure 1).

The Fourth period was characterized by the replacement of the period III stemless point by stemmed knife and projectile points. These artifacts are accompanied by small "thumbnail" scrapers, beads, ornaments, awls, and large bola stones. Burials are found in stone cairns, with the body in an extended position (Bird 1946).

Although Bird (1946) pointed out that the artifacts of the Fourth period may have been in use until the Historic period, he highlights the "evident" presence of another cultural group at that time. "Small arrow points of a type characteristic of the *Ona* associated with other typical *Ona* artifacts such as combs, beads, and rough bone tools show the relative late presence of this tribe on the mainland" (Bird 1946:20). The *Ona*, known also as *Selk'nam*, was an ethnic group who occupied the north of Tierra del Fuego in historic times (Borrero 2001, Chapman 1986 [1982]). On the basis of artifact similarities at the northern and southern coast of Magellan Strait, Bird held that this group habited southern Patagonia in previous times.

Even though Bird IV–V projectile points are the "index-fossils" to differentiate the later periods, they have not been described in detail by Bird. He only pointed out the shape and size differences in a general way. However, he has provided many useful photographs (Bird 1938, 1988:figures 15–16, 34–35, 76). The description of artifacts from Cañadón Leona, the first site excavated at the northern coast of Magellan Strait, is, in spite of its brevity, the most detailed report about Bird IV–V points. Here he notes: "From the floor of shelter 3 we have five of the small-stemmed, well-made Ona type arrow points. From there and from the main excavation [shelter 5] down to level 6, we have fifteen of the much broader-stemmed, more roughly made [Patagonian] points" (Bird 1988:43).

The emphasis in their description is on the fineness of manufacture (well-made vs. roughly made) and stem general size. To illustrate their shape and size, he provided some drawings of point types (Bird 1988:44–45). Bird (1988) explained the small size of type V or *Ona* points as a result of the introduction of the bow and arrow in southern Patagonia (see discussion below).

The classic Bird chronology of southern Patagonia was proposed before the invention of ^{14}C dating. In consequence, artifact types and faunal remains played an important role in assessing the relative antiquity of archaeological contexts.

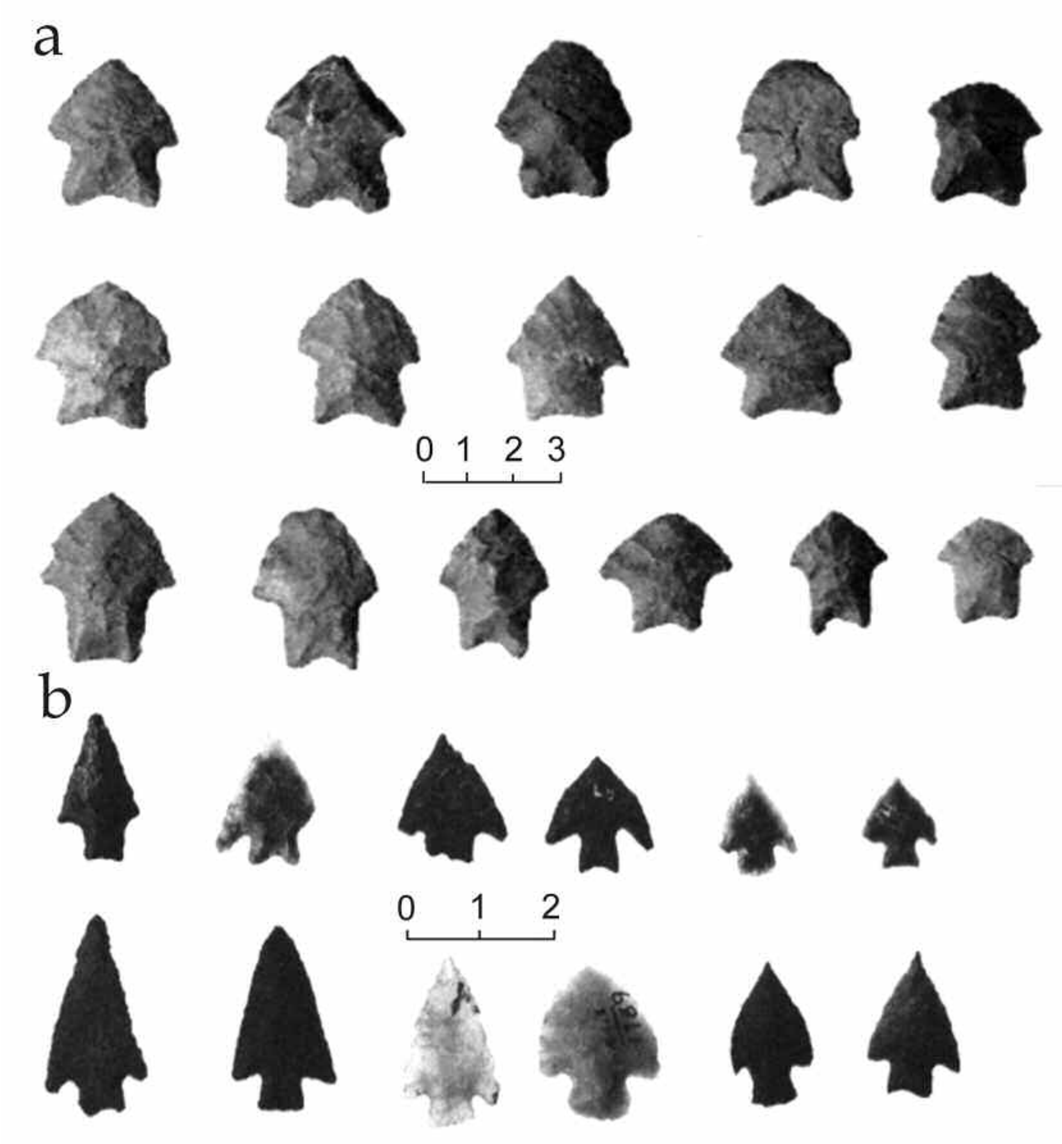

Figure 1. Bird IV (a) and V (b) projectile points identified by Junius Bird from Pali Aike cave (taken from Bird 1988:figures 34–35 with modifications).

After the arising of the ^{14}C technique, some samples from Pali Aike, Fell, and Mylodon caves were dated to provide absolute ages for periods I–V. The beginning of the latest period was established around 700 BP, arriving until the present (Bird 1983:annex IV, 1988:table 17), but there was no dating of period IV in these sites. Thus, it was assumed that it started at the end of period III (6500 BP) and continued until present day (Bird 1988).

The age of period IV was established afterward on the basis of Cañadón Cóndor radiocarbon dating (Bird 1983; Massone 1979). This site, localized in the northeast shore of Magellan Strait, provided dates of 3725 ±100 and 3475 ±100 BP for period IV, which were used to estimate the beginnings of this period in the inland (Massone 1979).

Later Researches: A Reevaluation of Bird's Periodization

Subsequent archaeological researches in southern Patagonia, especially in Argentina, provided new data that questioned to some extent the cultural and temporal sequence proposed by Bird. Here, we focus on the later periods, which are the subject of this article.

Although in some cases Bird had found type IV–V projectile points in association, as in Cañadón Leona (Bird 1938), he held that "instead of being a cultural introduction or development, they seem to belong to a distinct group" (1938:268). However, these findings started to be more frequent than expected and they were often out of temporal range. In Thomas Gould lagoon (Magallanes, Chile), the period IV goes back to 4560 ±130–4280 ±50 BP and Bird IV–V points were recovered in association between 470 ±130 and 250 ±120 BP (Massone 1989–1990). El Volcán cave 4 (Santa Cruz, Argentina) also gave an earlier date to Bird V points, ca. 3600 BP (Sanguinetti de Bórmida 1984). In this latter locality, Bird IV–V points were associated in both cave 2 and 4 (Nami 1984a, 1984b). In Punta Dungeness 2 site, on the northeast coast of the Magellan Strait (Magallania, Chile), the coexistence of the two point types has been observed within the same sedimentary stratum, with occupations dated to XVI century (360 ±90 BP) and later (Massone 1979). To the north, in Potrok Aike lagoon (Santa Cruz, Argentina), one type IV point was recovered from a stratum located above to another carrying a type V point, and no technological differences were observed between contexts (Gómez Otero 1986–1987).

Because of all these new observations, Massone (1981) proposed a more flexible periodization in terms of "cultural units." So, he reassembles the six Bird's periods into three broader cultural units, although he applies a similar frame of reference: Early (periods I–II), Middle (period III), and Late (periods IV, V, and Historic) Cultural Units. He considers type V projectile points as an addition to the repertory of period IV human groups, rather than the signal of a different culture. He also points out that bow and arrow probably had been introduced earlier than period V (see also Gómez Otero 1986–1987, 1987).

Beyond temporal discrepancies, other factors related to types IV and V shape-size variation have been noted by these new studies.

Nami (1984a, 1984b) has related Bird IV–V size variation with differences in their manufacture process. He discriminated two point categories (A and B) based on size, blank, and manufacture stages in the samples from El Volcán caves (Santa Cruz, Argentina). Despite the fact that A and B categories can be correlated with types IV and V, respectively, the fit is not perfect. Nami (1984a) points out an uncertainty horizon of medium-small sizes that shares characteristics of both point categories. A previous exploration of variability in Bird IV–V projectile points from Pali Aike volcanic field using geometric morphometrics tools (Charlin 2009), showed a strong correlation (r =.86 p = < .05) between shape variables and the point length to point thickness ratio (Iriarte 1995). Thus, it is likely that changes in size mentioned above are associated with increased reduction and shape changes. This relationship has also been noticed by Franco (1999), on her study of a stemmed projectile point's ethnographic collection from Punta Arenas (Magallanes, Chile).

An alternative way of grouping Bird IV–V projectile points was suggested by Gómez Otero (1986–1987, 1987, 1989–1990) on her research at Potrok Aike 1 (Santa Cruz, Argentina) and Juni Aike 1 (Magallanes, Chile). She discriminated three groups of projectile points based on blade, shoulder, and stem size and shape variations. The three groups of points in many cases were found together and do not show a differential distribution along site sequence.

Regarding the weaponry systems, Gómez Otero (1986–1987) discussed the previous assumption of type V projectile points as an indicator of bow and arrow hunting, holding that smaller and lighter Magallanes IV projectile points could have been hafted in arrows. Prieto (1989–1990) also discusses this assumption but on the basis of a different criterion. He holds that the size of Bird V points is too small to keep its effectiveness as an arrow because they could not cause the death of the prey by cutting and bleeding.

Ratto (1994) specifically studied this topic on Bird IV–V weapons through the analysis of many design variables, as aerodynamics, haft type, surface reinforcement, and tip angle and thickness (see similar analyses in Hughes 1998; Shott 1997; Thomas 1978). On the basis of these variables, she discriminated three technical systems within Bird IV–V point types: throwing spear, bow and arrow, and thrusting spear, in order of abundance. She notes their coexistence in space and time, at least between 3600 and 740 BP. Thus, she highlights that projectile point size differences are neither cultural nor temporal, but functional. Finally, recent studies were focused on stem size and shape, showing metric variability related with lithic raw materials, resharpening, and hafting type. However, these studies failed to show shape differences across a large area of southern Patagonia (Franco et al. 2005, 2009). Nevertheless, in these analyses the comparison has been made between spatial areas, not between point types. Differences in size and shape between Bird's point types taking into account the potential effects of reduction have not been tested yet. In consequence, the evaluation of the distinctiveness of these types is a necessary task aimed to provide insights into the prehistory of southern Patagonia.

Type Discreteness and Allometric Variation

One of the major problems with the typological classification of artifacts is that it is based on size and shape definitions of tool types, and both of them are considered as essential attributes. In ideal conditions, there is no continuum variation between types; their boundaries are strictly marked by gaps in size and shape (Dunnell 1971, 1986; Hiscock 2007; Shott 2005). However, many allometric and experimental studies have shown that size and shape in stone tools change with reduction, and thus these variables rarely kept constant along the life cycle of an artifact (Andrefsky 2006; Buchanan 2006; Clarkson 2002; Clarkson and Hiscock 2008; Clay 1976; Dibble 1984, 1987; Flenniken and Raymond 1986; Hiscock 1994, 2006, 2007; Hiscock and Attenbrow 2002, 2003, 2005; Hiscock and Veth 1991; Holdaway et al. 1996; Kuhn 1990, 1991, 2004; Shott 2005; Shott and Ballenger 2007; Shott et al. 2007). In consequence, in many cases the definition of morphological types is difficult and depends on the degree and pattern of artifact reduction at the moment of discard or loss.

A good example of this thesis applied to the classification of projectile points is provided by Bettinger and Eerkens (1999). They have pointed out how points can be classified as members of one type or another depending on the proximity of their discard to the raw material source in the Great Basin. This indicates that the typological classification is influenced by the stage of point reduction. Moreover, they denote that the regional variation in the frequency of projectile point types depends on the typology used in each area of the region (e.g., Monitor Valley or Berkeley typology), because the discrimination of point types (and therefore, weapon types) is based on different variables (basal width vs. weight, respectively).

Morrow and Morrow (2002) also provide a critical analysis of the fluted point type designations from the Midwestern United States. Their analysis remarks a typological convergence among Clovis, Gainey, and Folsom types through maintenance practices that must be seriously considered in fluted point typology. However, Buchanan and Collard's (2010) geometric morphometrics comparison of the shape blade of Clovis, Folsom, and Plainview points from the U.S. Southern Plains has shown that blade shape distinguishes Clovis points from both Folsom and Plainview points, but it is useless to discriminate between the latter types.

With a similar aim, Bradbury and Carr (2003) have examined traditional typological subdivisions of bifurcated-base bifaces from the southeastern United States. Their study reveals that the types are not as distinctive as had been suggested, because several types are grouped in a same assemblage by a K-means cluster analysis. In particular, temporally close specimens are clustered together suggesting some overlapping among the types. A similar conclusion is held by Flenniken and Wilke (1989) with respect to the Great Basin projectile points as "temporal markers."

Many experiments with projectile points have shown the same warnings. The replicative manufacture carried out by Flenniken and Raymond (1986) and Towner and Warburton (1990) in hafting, use, breakage, and rejuvenation of "Elko corner-notched" points shows changes in the type classification according to the different moments along its use life. The major changes in the point dimensions in these experiments were in length and width while thickness was kept quite constant (see a synthesis of these results in Flenniken and Wilke 1989 and discussion in Bettinger et al. 1991). A similar result was obtained by Buchanan's (2006) analysis of resharpening of Folsom points, in which he notes that the major mean variation in the point dimensions is in length characters while basal and width characters are the least variable.

Andrefsky (2006) points out, according to his hafted bifaces resharpening experimentation, that in those specimens where the blade length gets shorter relative to its width, resharpening was probably the result of the tip fracture owing to impact damage. In fact, this is the scenario shown by the experimentation with replicated Folsom points carried out by Hunzicker (2008) and in many studies on the morphometric variation in Folsom points (Bement 2002; Buchanan 2006; Morrow and Morrow 2002). Hunzicker's experimental results have provided quantitative measures of changes in point morphology resulting from successive damage and rejuvenation events. The evaluation of the fitness of some reduction indices on his sample has shown that the ratios length–thickness, mass–thickness, and area–thickness correlate significantly with stage of reduction (Shott et al. 2007). On the contrary, the major changes in blade width are usually related to the use of bifaces as cutting or multifunctional tools (Andrefsky 2006; Ballenger 2001).

Therefore, after these few but enough examples, it is suggested that the lithic reduction process compromises the integrity of tool types (Shott 2005). This fact is unavoidable because morphometric variation is an inherent factor to use-life of lithic artifacts (Andrefsky 2006; Hiscock 2007; Shott 2005).

Considering all the above antecedents, the main objective of this study is to assess the relative importance of reduction on the typological classification of Bird projectile points from southern Patagonia. To do so, we state the first null hypothesis that types IV and V remain significantly different in terms of shape after the effect of reduction is removed from data. The second null hypothesis states that size differences also disappear when the effects of reduction are removed from data. Then we will test both null hypotheses independently on the two main structures that integrate the projectile points, which are the stem and the blade.

Materials and Methods

Projectile Point's Sample

The analysis is based on 82 digital published images of projectile points recovered in 15 late Holocene archaeological sites from southern Patagonia (Santa Cruz Province, Argentina, and Magallanes, Chile; see Figure 2).

Projectile points were classified as Bird IV–V types by their own discoverers (see Source in Table 1), except 14 pieces corresponding to sites studied by one of us (JC, Cóndor cave 1, Norte 2, Laguna Azul, and Laguna Cóndor) and to previous collections that were reanalyzed pursuing another goals (Las Buitreras cave 1 and Laguna División). These points were identified following the traditional classification standards.

The total number of Bird IV–V included in this study are 68 and 14 pieces, respectively. It should be noted that the relative abundance of both types is not a sample bias introduced by the recovery method implemented here, but an empirical trend in the regional archaeology.

Most of the region considered here is covered by a volcanic field that represents the southernmost occurrence of the Cenozoic back-arc Patagonian Plateau Lavas, between 51° 26' and 52° 16' of south latitude, known as Pali Aike Volcanic Field (PAVF; see D'Orazio et al. 2000, 2004). South of PAVF, it is found the continental Patagonia southern limit, the Magellan Strait.

This region presents a diversity of archaeological contexts, which include low- and high-density sites. The areas south of Chico River have the highest frequency of sites and the longest occupation sequences (Barberena 2008; Borrero and Charlin 2010; Charlin 2009), with the first evidences *ca.* 11,000 BP in the Chilean portion of the PAVF (Bird 1938, 1946, 1988). However, most of the sites correspond to late Holocene, ca. 4000 BP, when the broader region was effectively occupied (in the sense of Borrero 1994–1995).

Further information about population dynamics, inferred gene-flow patterns and biological affinities on a regional and continental context can be find elsewhere (González-José et al. 2001, 2002, 2003, 2008; Lahr and Foley 1998; Sardi et al. 2005)

In Table 1, sites are presented according to their localization in the region, maximum and mini-

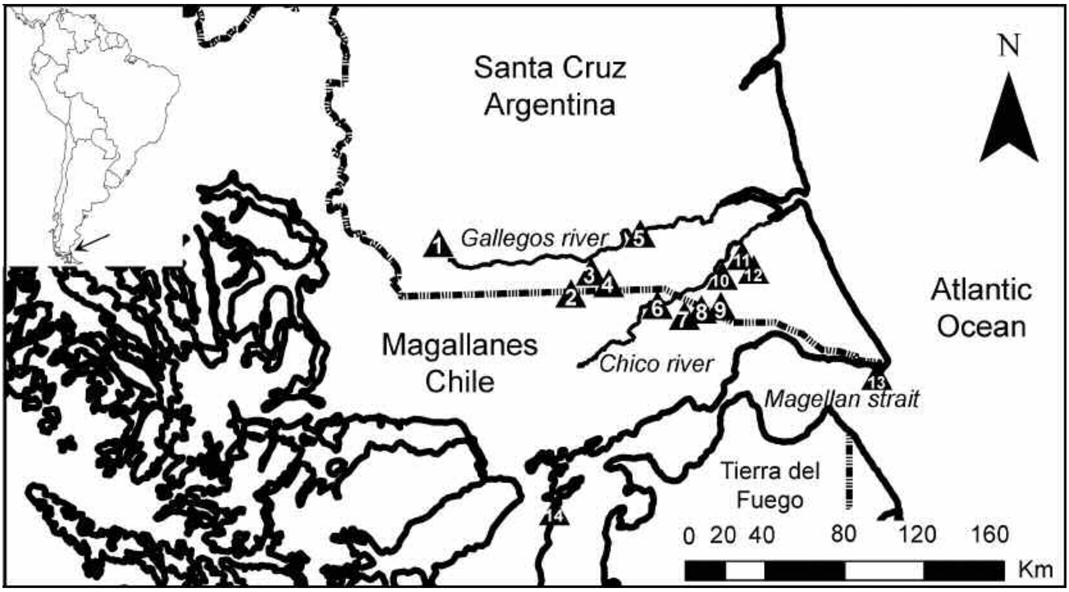

Figure 2. Site provenance of projectile point samples (southernmost Patagonia). References: 1. Laguna Cóndor, 2. Juni Aike 1, 3. Laguna División, 4. Potrok Aike 1, 5. Las Buitreras 1, 6. Fell cave, 7. Thomas Gould 8. Pali Aike cave and Pali Aike 2, 9. Laguna Azul, 10. El Volcán 4, 11. Norte 2, 12. Cóndor 1, 13. Punta Dungeness 2, 14. Bahía Laredo 1.

mum dates to late Holocene, total number of artifacts recovered, total number of projectile points, and number of entire points whose images were published and considered in the present study.

Concerning the lithic raw materials used in the manufacture of projectile points, it is important to note that there is no variability between Bird IV–V types. The predominant exploited rock is basalt, followed by chalcedony and, in very few cases, by opal and obsidian (Charlin 2009).

Data Acquisition

All published sources concerning regional archaeology were reviewed to obtain photographs or illustrations of projectile points. Two requirements were necessary to use them as data: the completeness of the point, and the presence of a scale in the image. Unfortunately, the ratio of complete pieces to the total of recovered projectile points by site is low (see Table 1). Small damages (≤ 3 mm) were tolerated and the shape was rebuilt from the adjacent planes of the piece. The majority of complete specimens of both types come from Pali Aike cave, one of the sites of reference that provided important evidences for the regional settlement sequence (Bird 1988). A known-size scale is necessary to obtain a size estimator for each projectile point. Illustrations and photographs were scanned in a digitizing tablet, keeping constant the digitizing scale (100 percent in cm) and resolution (100 ppp) and the point orientation (the tip toward the upper border). The raw images were compiled and scaled in the TpsUtil (ver. 1.26) and TpsDig2 (ver. 2.12) programs, respectively (Rohlf 2004, 2008).

Measurement of Reduction Indices over Images

To control the effects of reduction on size and shape configurations, three variables were measured using TpsDig2: tip angle (in plain view), blade length, and stem length. The latter two were used to compute the blade length to stem length ratio (Iriarte 1995).

These variables were chosen because many experimental and allometric studies have shown that, given that the major size and shape changes occur in the point blade, mainly in its length (Ahler and Geib 2000; Andrefsky 2006; Bement 2002; Buchanan 2006; Castiñeira et al. 2011; Flenniken and Raymond 1986; Hunzicker 2008; Iriarte 1995; Morrow and Morrow 2002; Shott et al. 2007; Towner and Warburton 1990), then they can be considered as reliable reduction estimators. Usually, the changes in blade length are associ-

Table 1. General Descriptive Information about the Sample of Bird IV and V Projectile Points Analyzed.

Site	Localization	Late Holocene Max.- Min. Dates (BP)	No Lithic Artifacts	No BIV-V Recovered	No BIV-V Included	Provenience	Source
Laguna Cóndor	Upper Gallegos River, Argentina	220±41, 187±41	282	1	1	surface	Charlin et al. 2012
Las Buitreras 1	Middle Gallegos River, Argentina	4310±110, 670±60	718	4	1	stratigraphy	Sanguinetti de Bórmida 1976
Laguna Division	Upper Gallegos River, Argentina		184	4	4	surface	Menghin 1952
Potrok Aike 1	Upper Gallegos River, Argentina	740±180	1354	16	5	stratigraphy	Gómez Otero 1986-1987, 1987
Juni Aike 1	Upper Gallegos Chico River, Chile	850±40	1283	17	6	stratigraphy	Gómez Otero 1989-1990, Prieto 1997
El Volcán 4	Middle Gallegos River, Argentina	3600±100	102[a]	20	1	stratigraphy	Sanguinetti de Bórmida 1984; Nami 1984[a,b]
Cóndor 1	Middle Gallegos River, Argentina	3440±70, 965±40	7783	16	6	stratigraphy	Barberena et al. 2007; Charlin 2009
Norte 2	Middle Gallegos River, Argentina	2070±80	446[b]	1	1	surface	Charlin 2009
Laguna Azul	Provincial reserve (Santa Cruz), Argentina		132	1	1	surface	Charlin 2009
Fell cave	Upper Chico River, Chile	685±90	~892[a]	57	1	stratigraphy	Bird 1938, 1946, 1988
Thomas Gould	Upper Chico River, Chile	4560±130, 250±120	unknown	unknown	4	stratigraphy	Massone 1989-1990
Pali Aike	Upper Chico River, Chile		~3800	50	42	stratigraphy	Bird 1938, 1946, 1988
Pali Aike 2	Upper Chico River, Chile	1990±90, 220±45	1929	14[c]	3	stratigraphy	Massone and Hidalgo 1981
Bahía Laredo 1	Northwestern shore of Magellan Strait, Chile	1540±45	33[a]	8	2	stratigraphy	Prieto 1988
Punta Dungeness 2	Northeastern shore of Magellan Strait, Chile	1590±110, 360±90	887	17[d]	4	stratigraphy	Massone 1979, 1984

[a]Only stone tools.
[b]Surface and stratigraphy included.
[c]Total of stemed and stemless points.
[d]Preforms are included.

ated with modifications in the tip angle and thus in blade convexity (Ahler and Geib 2000; Castiñeira et al. 2011). Experimental works have shown that the concentration of damages in the tip is independent of propulsion method (Odell and Cowan 1986) and haft type (Hunzicker 2008), both variables not controlled here.

Because of concentration of damage in the tip, successive cycles of use and rejuvenation cause a progressive decline in length and a change in point proportions. This change ratio is expected to be reflected on the blade length–stem length reduction measure to stemmed points proposed by Iriarte (1995), whose values are inversely proportional to reduction. Although in some experiments maximum thickness is the best constant (Andrefsky 2006; Flenniken and Raymond 1986; Hunzicker 2008; Shott et al. 2007; Towner and Warburton 1990), indexes derived from stem dimensions are the only option under this 2D study.

Tip angle (TA) and the index of blade length–stem length (IBS) were submitted to a Principal Component Analysis (PCA) to synthesize and reduce their variation to a single explanatory variable. The first PC explained 77 percent of total variance. IBS is positively correlated with the first PC whereas TA is correlated negatively. In consequence, negative scores for the first PC are occupied by more reduced points, whereas less reduced points occupy positive values of the first PC. For simplicity, this first PC will be referred in the following as RPC, meaning Reduction Principal Component. It seems excessive to perform PCA on just two original variables. However, we performed this analysis to obtain a single component or dimension that essentially measures degree of reduction: it becomes a control variable for later analysis. Note however, that because of the intrinsic characteristic of the stone tools manufacture, the computation of size, and reduction estimators, as well as size and reduction-free shape variables is still matter of debate (Shott 2010).

Obtention of Size and Shape Variables

A total of seven landmark and 17 semilandmark coordinates were digitized on the contour of the projectiles to achieve a good representation of its size and shape (see Figure 3).

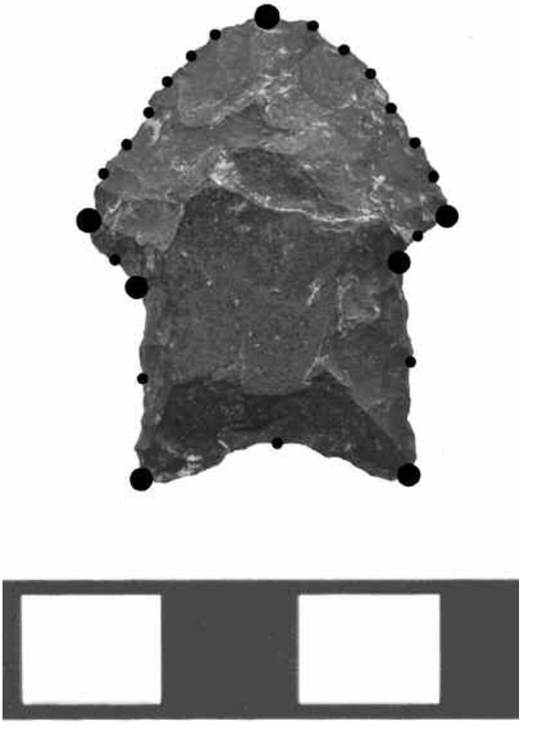

Figure 3. Landmark (large dots) and semilandmark (small dots) used in this study.

Landmark configurations were superimposed using a Generalized Procrustes Analysis (GPA; see Goodall 1991; Rohlf and Slice 1990) using TpsRelw (ver. 1.45) software. GPA removes the effects of translation, rotation, and scaling (Rohlf and Slice 1990). After superimposition, pure shape information is preserved in the specimens' aligned landmarks. Size is calculated as the centroid size, the square root of the summed distances between each landmark coordinate and the centroid (Dryden and Mardia 1998). The fitted coordinate configurations resulting from these procedures are then placed in the denominated Kendall's shape space (Rohlf 1999). As this shape space is non-Euclidean, further statistical analyses are performed by projecting the coordinates into a linear tangent space (Dryden and Mardia 1998).

All analyses were replicated using the whole landmark configuration, a blade subconfiguration, and a stem subconfiguration.

Statistical Analysis

Because use, damage, and rejuvenation of projectile points along their use-life affects their original size and shape design, it is necessary to control these effects to assess the variations between types. To evaluate Bird's typology effectiveness and reliability, the patterns of variation on size and shape of the projectiles were analyzed departing from the raw, superimposed coordinates, as well as from the reduction-free coordinates.

PCA was performed to visualize mean shape differences using the program MorphoJ (ver. 1.00e), and displayed as scatterplots of the first two principal components (Klingenberg 2008). Thin plate spline plus wireframe deformations of the first principal component were used to detect visually the magnitude and direction of mean shape change. Multivariate ANOVA on the Principal Component (PC) scores were used as a formal test to detect significant shape differences between types.

To remove correlations among shape variables and reduction effects, we computed the residuals of the multivariate regression of Procrustes coordinates (shape) on RPC using the MorphoJ regression command. Then, PCA was repeated using the free-of-reduction landmark coordinates.

Shape differences were tested using a Discriminant Analysis performed on the PC scores of the raw and corrected data. A parametric and a permutation T-square test for the difference between group means was obtained to check for the significance of among-type shape differences before and after removal of the reduction effects.

In a similar way, among-type size differences on size were statistically assessed using a t test of Student before and after the removal of noising effects (reduction).

Results

In Figure 4, we present the raw size variation on the entire projectile points, blade and stem of the two analyzed types. As depicted in this figure, size differences after a Student t-test are significant for the whole projectile ($t = 7.258$; $p < .00001$), for the blade ($t = 5.094374$; $p < .00001$) and for the stem size ($t = 9.87$, $p < .00001$). In other words, there are size differences between Bird IV and V complete projectiles as well as between their constitutive parts, being that Bird IV is the larger type.

The scatterplot corresponding to the first two principal components of the Procrustes superimposed data, without any correction of size or reduction effects, is presented in Figure 5. As observed in the projection of the points along these PCs, the majority of Bird IV projectile points occupy the positive values of the first PC, while the Bird V are mainly placed on the negative scores. However, the limit between them is not totally

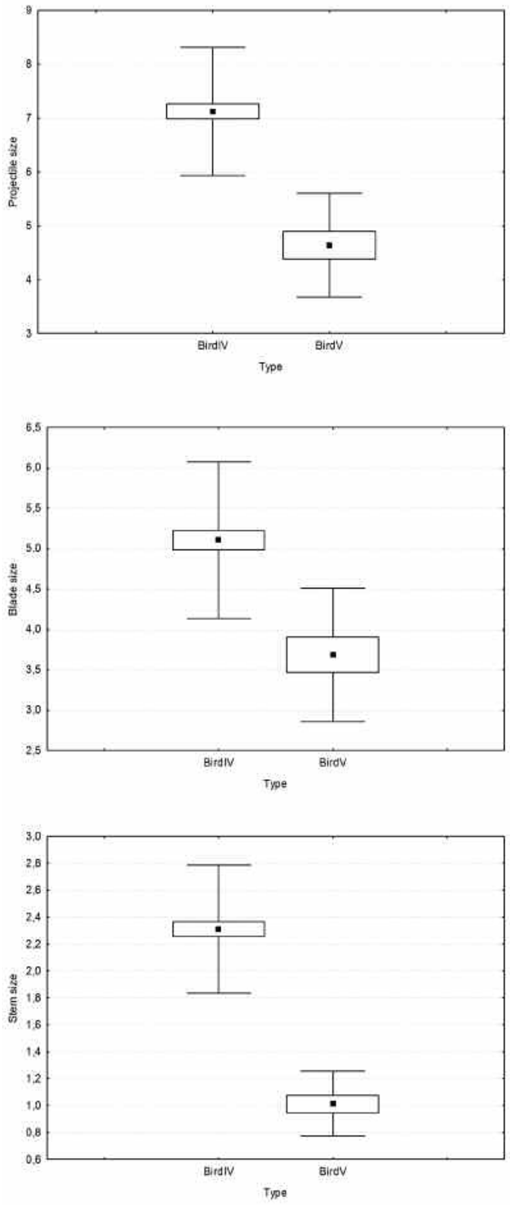

Figure 4. Raw size differences among types for the whole projectile (top), the blade (center), and the stem (bottom). Point: mean, box: standard error, whiskers: standard deviation.

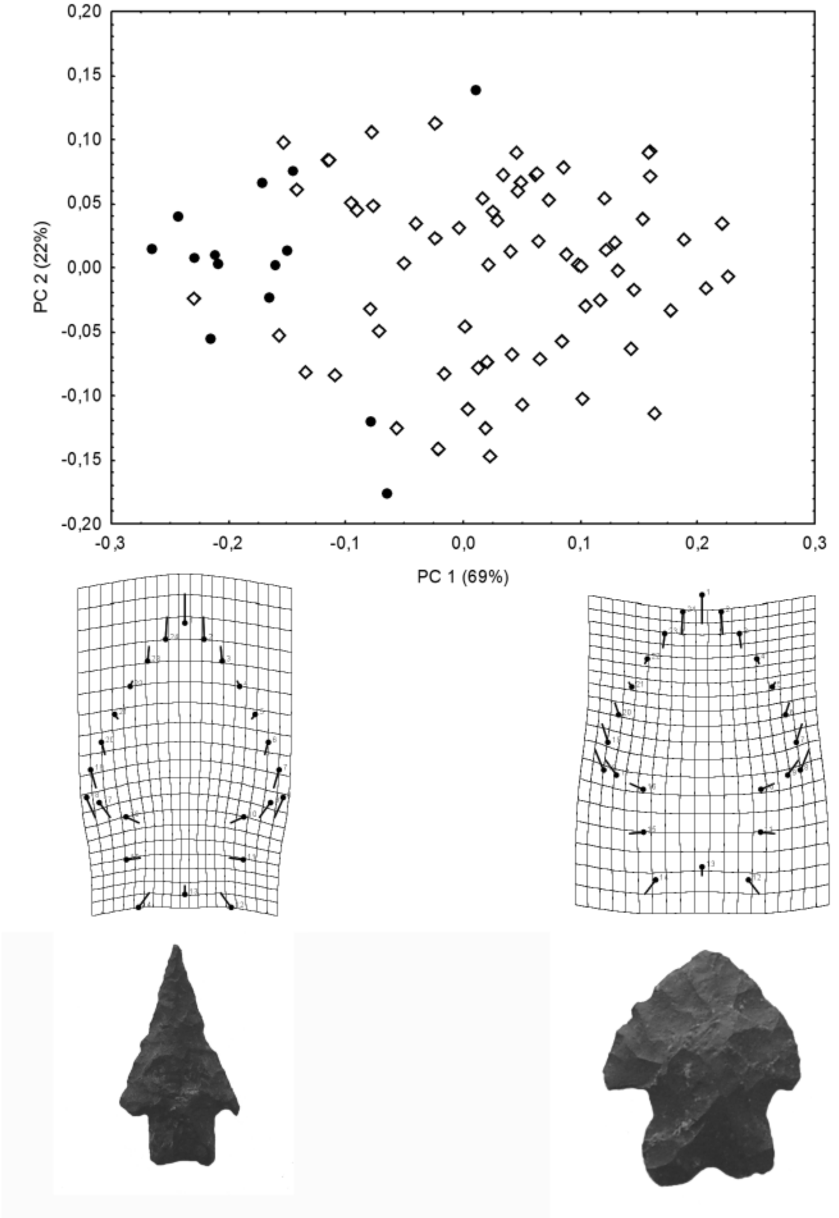

Figure 5. Two first PCs describing shape differences on the sample. Bird IV: open diamonds, Bird V: black dots. Percentage of variance explained for each PC is shown among parentheses. Grid transformations representing shape changes across the first PC are shown. Vectors on landmarks indicate the direction of shape change from the consensus towards positive or negative values of the first PC. Real Bird IV and Bird V points are displayed on the bottom.

clear and some Bird IV and Bird V appear mixed. Indeed, if the types had not been marked in Figure 5, no obvious groupings are discernible.

Bird IV projectile points tend to present more compressed blades in the longitudinal axis and more laterally expanded stems in relation to the blade, while Bird V points present the opposite trend of shape variation. Note that a multivariate ANOVA performed on the PC scores indicates that shape differences are significant for the whole projectile, the blade, and also the stem (see Table 2).

Finally, the Discriminant Analyses performed on the raw shape data resulted on significant dif-

Table 2. One-Way MANOVA for Shape Differences between Types Considering the Whole Projectile Point, the Blade, and the Stem.

	Wilks' Lambda	*F*	*p*
Whole Projectile Point	.461258	3.132	.000252
Blade	.543006	3.703	.000110
Stem	.622486	9.218	.000001

Table 3. Discriminant Function Results for the Shape of the Whole Projectile Point, the Blade and the Stem. P-Values for the T-Square Statistic Were Obtained after 10,000 Permutations.

	T-square	*p*	Percentage of Bird IV Correct Classification	Percentage of Bird V Correct Classification
Whole Projectile Point	93.439	.0002	85.29	57.14
Blade	67.327	.001	83.82	71.43
Stem	48.517	< .0001	85.29	85.71

ferences for the whole projectile, the blade and the stem (see Table 3). In addition, Bird IV points are more likely to be correctly classified on their own type when compared to Bird V points.

The influence of reduction on size and shape was explored by reanalysis of raw data after removal of the reduction effects using the residuals of regression tests of size and shape on RPC.

The simple linear regression of size on RPC is shown on Figure 6. The regression was significant at $p = .0028$ ($F = 52.68$), and around 11 percent of variation on size is explained by reduction.

In Figure 7, we present the multivariate regression of shape on RPC. The permutation test against the null hypothesis of independence among whole shape and RPC is significant after 10,000 randomization rounds ($p < .0001$) and around 54 percent of shape variation is explained by reduction. Figure 7 indicates that the reduction affects mainly the shape of the tip of the point: positive values of the regression indicate nonreduced points carrying sharp and longer blades, whereas more reduced points present blunt and shorter blades. An expansion of the stem on the reduced points (negative values) maybe indicates a reduction of the whole blade in relation to the stem, rather than a direct, focalized reduction of the base of the projectile. Two relevant results arise from the regression of size and shape on reduction: Bird V points present lower levels of reduction, and reduction seems to affect more the shape of the projectile than its size (11 percent vs. 54 percent of variation on size and shape explained by reduction, respectively).

To detect if type differences observed on size (see Figure 4) or shape (see Figure 5, Table 2) remain important after removal of reduction effects, we have repeated some of the previous analyses on the residuals of the regression of size or shape on our reduction index (RPC). The size differences (see Figure 8) after removal of the reduction effects remain significant for the whole point ($t = 4.355$; $p = .00004$), the blade ($t = 4,126$; $p = .00009$), and the stem ($t = 3.650$; $p = .00046$).

Conversely, shape differences tend to disappear when reduction is controlled. For instance, a PCA analysis made on the residuals of the regression of shape on reduction indicates no clear differences among the shape of Bird IV and Bird V points. This lack of typological structure on the corrected data is evident for the whole shape, but also for the blade subconfiguration (results not shown).

A multivariate ANOVA performed on the residual PC scores, representing the shape free-of-reduction effects, indicates that shape differences turn nonsignificant for the whole projectile and the blade, but still remain significant for the stem (see Table 4). In other words, if reduction effects are removed, there are subtle, not observable on the scatterplot of the first two PCs, but significant, differences on the stem shape among types. The Discriminant Analyses performed on the corrected, free-of-reduction effects data (see Table 3) confirm both the PCA and ANOVA results. In particular, comparisons using the whole projectile and blade configuration result on nonsignificant differences, whereas the among type comparison of the stem provide a significant shape difference.

In consequence, removal of the variation because of reduction seems to affect mainly the shape of the blade, whereas shape differences on the stem, as well as size differences remain significant.

Discussion

As many studies have pointed out, the degree of reduction of artifacts has great influence on size

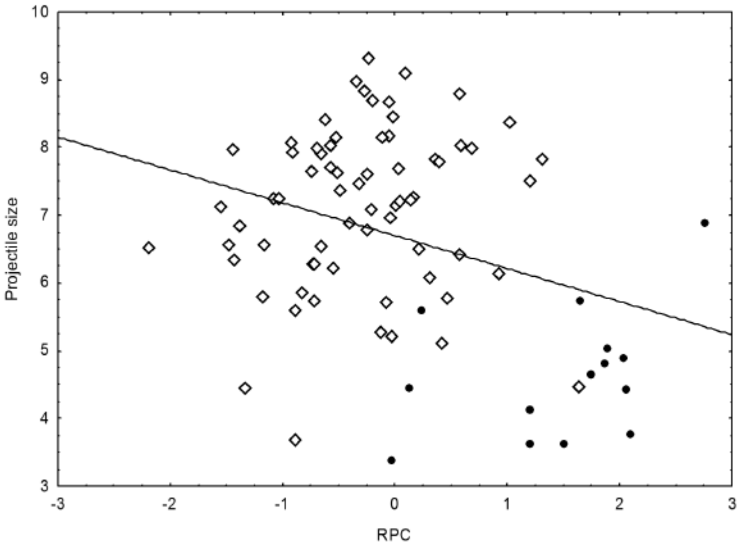

Figure 6. Simple linear regression of projectile size on RPC. Bird IV: open diamonds, Bird V: black dots.

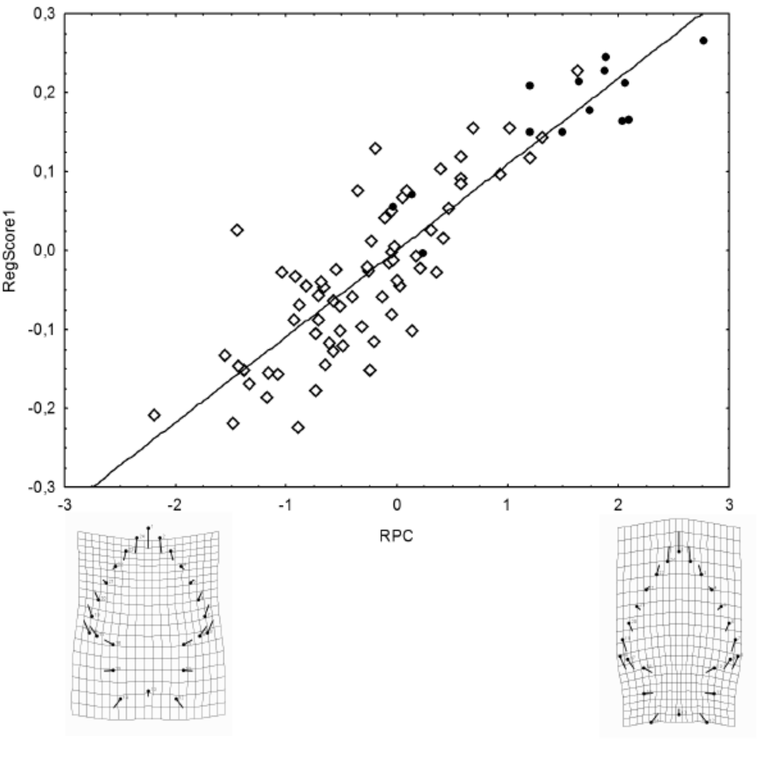

Figure 7. Multivariate regression of shape on RPC. Bird IV: open diamonds, Bird V: black dots. Grid transformations representing shape changes across the reduction axis (RPC) are shown. More reduced points occupy the negative values of RPC.

Table 4. One-Way MANOVA for Free-of-Reduction Effects Shape Differences between Types Considering the Whole Projectile Point, the Blade, and the Stem.

	Wilks' Lambda	*F*	*p*
Whole Projectile Point	.793308	.699	.822562
Blade	.868042	.668	.804966
Stem	.811809	3.523	.006428

Table 5. Discriminant Function Results for the Residual, Free-of-Reduction Shape of the Whole Projectile Point, the Blade and the Stem. P-Values for the T-Square Statistic Were Obtained after 10,000 Permutations.

	T-square	*p*	Percentage of Bird IV Correct Classification	Percentage of Bird V Correct Classification
Whole Projectile Point	20.843	.8247	64.70	21.42
Blade	12.16	.7929	58.82	42.85
Stem	18.54	.0072	75.00	64.29

and shape variation (Andrefsky 2008; Hiscock 2007; Shott 2005). However, in some cases its incidence is not enough strong and/or uniform to delete particular traits of design, which are maintained after the using of resharpening techniques. As observed in our analyses, the case of Bird IV–V projectile points from southern Patagonia represent an interesting example to detect the relative influence of reduction on the size and shape of the constitutive parts of a projectile point.

The analyses carried out show that size differences on whole projectile points as well as on the blade and the stem remain significant despite removal of reduction effects. Conversely, when the variations in tip angle and blade relative length used as a proxy to measure reduction are controlled, shape differences between Bird IV–V disappear, excepting for the shape of the stem (see Tables 4–5).

Overall, these results demonstrate that reduction is an important factor that affects projectile points shape more than their size. Also, the influence of reduction seems to be more focused on the blade, rather than the stem, as expected (see below). As a general observation, it seems that resharpening strategies are strongly linked to the particular shape of the artifacts, at least in the case of southern Patagonian stemmed points.

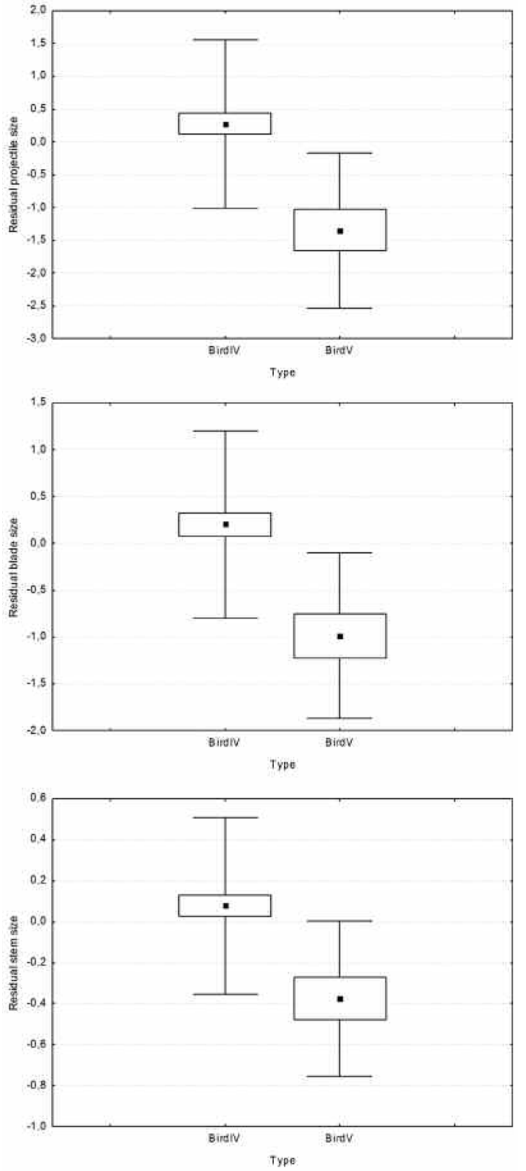

Figure 8. Free-of-reduction (residual) size differences among types for the whole projectile (top), the blade (center), and the stem (bottom). Point: mean, box: standard error, whiskers: standard deviation.

Even though the main shape modifications are focused on the blade of the point, an expected result considering that it is the structure more affected during the lifetime of the projectile, shape design is not totally eroded by reduction (see Tables 2–3), probably as a consequence of functional requirements. This suggests that there are differences regarding how the types are being

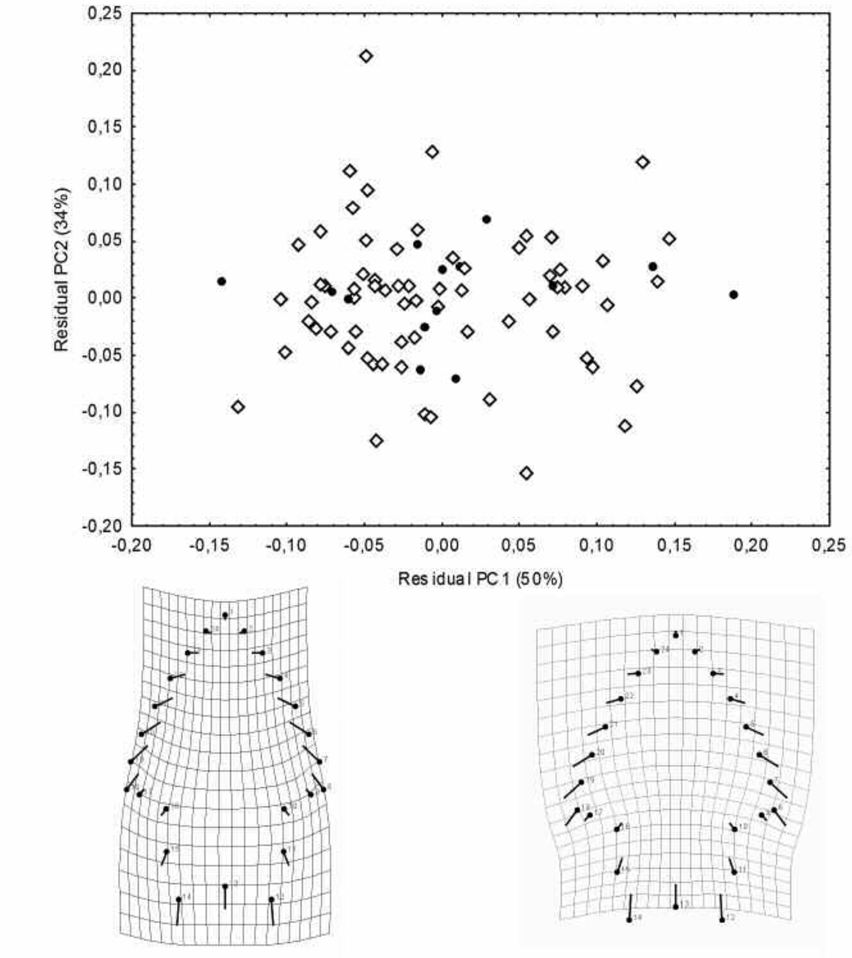

Figure 9. Two first PCs describing free-of-reduction (residual) shape differences on the sample. Bird IV: open diamonds, Bird V: black dots. Percentage of variance explained for each PC is shown among parentheses. Grid transformations representing shape changes across the first PC are shown. Vectors on landmarks indicate the direction of shape change from the consensus towards positive or negative values of the first PC.

resharpened and, by implication, in how they are being used.

These results led us to some functional considerations. For instance, the main differences in the blade shape between types, from convex shapes in the Bird IV points to more elongated in the Bird V ones, and the lower degree of reduction in the latter (see Figure 6) can be indicative of some functional differences. Bird (1988) has pointed out the possible use of many Bird IV tools as hafted knives. The same has been held by Ortiz Troncoso (1972) concerning the stemmed projectile points from Posesión Bay, at the north shore of the Magellan Strait, who observed differences on the asymmetry, the lack of a penetrating tip and the presence of one side of the blade more retouched than the other. Evidences on these points show that they have been reused as knives and also as notches (Ortiz Troncoso 1972). Something similar was proposed for Fell, Bird, or Magallanes I points, more currently known as Fishtail points, regarding the convexity of their blade (Baeza and Femenías 2005, Castiñeira et al. 2011) and the results of microscopic analyses (Bahamonde and Jackson 2006).

Considering all the above, the blade convexity of Bird IV points could be explained in two ways. On the one hand, this morphological trait can be considered as a direct indicator of function and thus Bird IV could be interpreted as hafted knives. On the other hand, the Bird IV type could have been designed and used primarily as a projectile point and secondary as knives, when its efficiency for the first purpose is over, at the end of their use-life. The continuum spectrum of shape changes presented in Figure 5 seems to support this latter hypothesis, but microwear studies will be of great utility to shed more light on this issue. Alternatively, more insights on this topic are to be explored by stating competitive morphofunctional models, and testing if expectations about the asymmetry and covariation (modularity) patterns expected under such models fit real data. On the contrary, more acute angles and relative longer blades in the Bird V points can be likely understood as constitutive traits of an efficient and reliable weapon to perform tasks when are needed (Bleed 1986). Indeed, a sharp tip is necessary and mandatory to penetrate the prey's fur, and hence there could be some relationship to the hunting strategies implemented. This efficient and reliable technology can be related with economic risk conditions (Bousman 1993, 2005) caused by paleoenvironmental changes which were frequent in southern Patagonia late Holocene, especially during the last 2000 years (Favier Dubois 2003; Haberzettl et al. 2005; Mancini 2002, 2007; Mayr et al. 2005; Zolitschka et al. 2006). This period was punctuated by short-term but strong environmental fluctuations as the Medieval Warm Anomaly (Habertzettl et al. 2005; Lamb 1965) and the Little Ice Age (Mayr et al. 2005) that affected in different ways the subsistence and settlement patterns of human populations in diverse areas of southern Patagonia (Belardi et al. 2003; Borrero and Franco 2000; Franco et al. 2004–2003).

Beyond these morphofunctional considerations, size can be viewed as the main trait defining Bird IV and Bird V types. However, note that there is no clear-cut size value capable of strictly defining these types, because the distribution of the size versus reduction curve is quite continuous (see Figure 6). Finally, our results suggest that even when subtle, there are some shape traits on the stem that are independent of the reduction and may help to define Bird IV and Bird V types.

Conclusions

The comparisons of size and shape of projectile points before and after controlling for some aspects of reduction have allowed us to measure and calibrate in a relative way, the morphometric changes related with use, damage and resharpening of late stemmed projectile points of southern Patagonia. Geometric morphometric methods are valuable tools to study artifact size and shape as independent variables. This is of crucial importance, because shape traits are traditionally derived from size variables (dimensions) in archaeological studies. Moreover, geometric morphometric analyses enable a formal quantitative approach to size and shape variation encompassed with a visual representation of changes. The treatment of size and shape as independent variables showed that reduction affects both parameters in quite different ways. In fact, the biggest projectile points were also the most reduced and the resharpening of point blades was an important source of shape variation. As many experimental and allometric studies have pointed out, the stem is the portion of the point less affected by reduction and therefore is the best discriminator among types.

The present work has showed that, when global size differences and stem shape are considered, it is possible to distinguish between Bird IV and Bird V projectile points despite reduction. This distinction is also possible to be applied on the usually most common projectile point fragment recovered in the archaeological sites, the stem, because the difference in its size and shape remain observable in this smaller portion. However, most of these results are based on size and shape averages and even though the types can be distinguished through statistical analyses to a great extent, the continuum spectrum of morphometric variations is still an important observation that should not be disregarded. To define strictly discrete classes of artifacts is a difficult task because their limits are likely to disappear because of reduction, as suggested here and as evidenced by previously discussions on the classification systems proposed to Bird IV–V projectile points. Nevertheless, in the case of Bird IV–V projectile points, when geometric morphometric tools are applied to the constitutive parts of the projectiles, resharpening techniques are not strong enough to completely erode differences in artifact designs, probably because of functional demands. Understanding of the evolution and usage patterns of projectile points will be benefited from future works focused on studying expected levels of asymmetries and modularity patterns under different morphofunctional models.

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