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Interaction without borders

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Archaeological fish hooks from the coast of Antofagasta (northern Chile) and from northern continental Europe: a geometric morphometric analysis

Germán Manríquez, Diego Salazar, Valentina Figueroa, Sönke Hartz and Thomas Terberger

In 2008 a collection of pre-Hispanic archaeological material from the Pacific coast of Atacama Desert (northern Chile) collected by Otto Aichel during the first decades of the 20th century was rediscovered by one of us (V.F.). It was housed at the State Archaeological Museum (ALM), Schleswig-Holstein, Germany, and initiated the first description and analysis of the metal artefacts from this collection forgotten for nearly 80 years. In this work we show the results obtained after applying standard geometric morphometric tools to compare Aichel's collection of fish hooks with archaeological hooks from Chile, Denmark and Germany. The main results obtained in this work show i) a pattern of fish hook size/shape variation expressed in long shank fish hooks with contracted rectangular bends and short shank hooks with expanded circular bends, corresponding to Aichel's collection of artefacts, ii) this pattern does not depend on the geographical origin, the chronological period, or the raw material the fish hooks were made of. In the light of these results, the contribution of quantitative shape analysis to understand the evolution of functional traits in archaeological fish hooks is evidenced.

Foraging for marine food supply has been one of the oldest economic activities of *Homo sapiens* (Klein et al. 2004; Marean et al. 2007; Richards/Trinkaus 2009), and perhaps of *H. neanderthalensis* too (Stringer et al. 2011). Due to very small population size and lack of appropriate technology, it is highly possible that the use of coastal resources in the Middle Palaeolithic was limited to sporadic visits to coastal sites. On the other hand many of these sites are submerged and difficult to explore due to a large rise in sea levels since the end of the last glaciation. Evidence of intensive exploitation of marine resources using new fishing technologies has been dated between 23 000 and 16 000 BP in Jerimalai shelter, East Timor (O'Connor et al. 2011), where shell fish hooks represent the oldest intentionally designed hooks to capture marine prey. In the Late Upper Palaeolithic, ungulate bone and mammoth ivory fish hooks were fabricated in northern central Europe (Pasda 2001; Gramsch et al. 2013), suggesting that human populations had already acquired new maritime skills before the beginning of the Holocene, a period of increasing availability of aquatic resources. In fact, isotope analysis of human bone collagen from the period *c.* 12 000 years ago shows that approximately one third of the protein consumption at that time could have been based on marine food (Richards et al. 2005; Terberger et al. 2012).

Available archaeological evidence represented by these kinds of artefacts strongly suggests that coastal migration contributed to the last stages of the migration of humans from Africa, populating in particular Polynesia (O'Connor et al. 2011; O'Connor 2012) and the Americas (Dillehay et al. 2008; Erlandson et al. 2011). Therefore it is highly probable that fishing was an economic and social activity of the greatest importance also for the communities sailing along the Pacific coast from the late Pleistocene, at least from before the Last Glacial Maximum. Later development of fishing worldwide during the Holocene is associated with high variability in the raw material used for fish hooks, including lithic materials, cactus thorns and metal artefacts, and the appearance of a diversified fishing technology that also included harpoons, barbs, wickerwork baskets and carriers, lines, nets, knives, scrapers and weights (Bleitz/Salls 1993). The appearance of this diversified technology has been considered a marker of specialized maritime economies and the emergence of complex coastal hunter-gatherers (Rick et al. 2005), while the recorded formal variability of fish hooks has been assumed to be a result of functional and/or stylistic causes (Tartaglia 1976; Salls 1989). From the start of the Middle Holocene

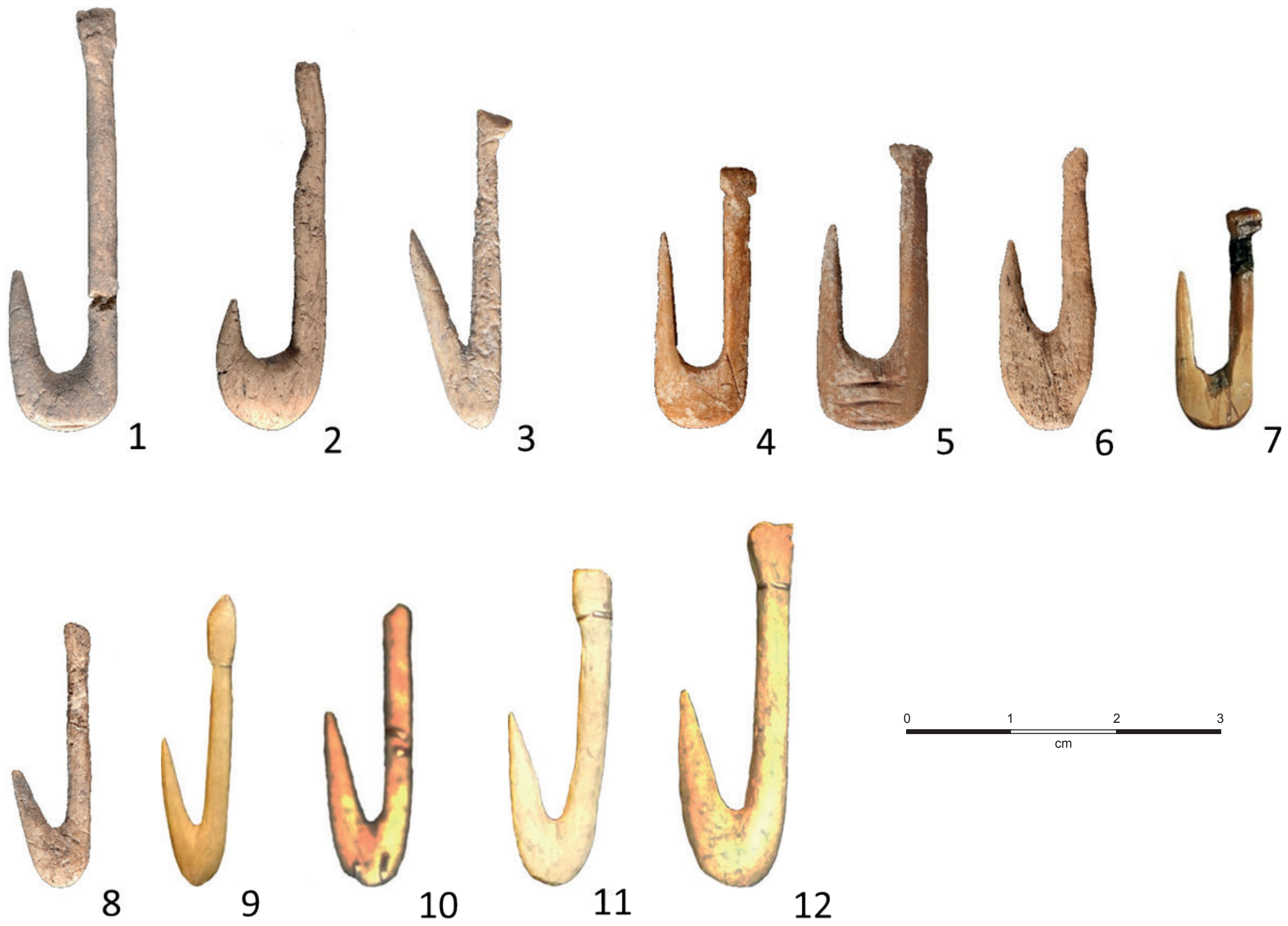

Fig. 1 Bone fish hooks from coastal Ertebølle sites in Denmark. **1–3** Havnø; **4–7** Tybrind Vig; **8–12** Ertebølle (*loc. class.*) (after Kruse 2014).

onwards, fishing tools made of mussel shells, animal bones and stone became an important part of the toolkit in prehistoric coastal economies along the Pacific coast. For the region of northern Chile, this was recently demonstrated by archaeological fishing tools from the area of Taltal (Morro Colorado and Zapatero sites), where among others shell fish hooks in all stages of production were discovered in a stratified multi-layered shell midden (Flores et al. 2015). In later periods the production of metal fish hooks, mainly from bronze (Europe and Asia) and unalloyed copper (Chile cf. Figueroa et al. 2015) appears.

A set of copper fish hooks from the coast of the Atacama Desert (Chile) is belonging to Aichel's collection housed in the State Archaeological Museum in Schleswig-Holstein (northern Germany). The large collection consisting of various bone harpoons, stone artefacts, ceramic vessels, textiles and wood and metal objects was reported for the first time by Salazar et al. (2013). It was created during the first decade of the 20th century by the Chilean physician and amateur archaeologist of German ancestry Otto Aichel (b. 1871 Concepción, d. 1935 Kiel), who excavated a series of pre-Hispanic mummified human remains of individuals in northern Chile. The amount and state of conservation of the material from the coast of Antofagasta included in the collection make it especially valuable because these artefacts belong to a geographical area of northern Chile where, for historical reasons, pre-Hispanic archaeological material is not well represented in local museums.

In Mesolithic settlements on the Baltic Sea coasts of southern Scandinavia, marine resources played a major role in the subsistence practice of the Kongemose culture starting in the middle of the 7th millennium BC (Vang Petersen 1984; Sørensen 1996). During the Atlantic period, local fishing societies developed a more diverse fishing technology like harpoons, nets, floaters and sinkers, leisters, composite fish hooks, traps and stationary fishing fences. In addition, vast quantities of fish bones have confirmed that fish constituted a major part of the resource at coastal sites, often located at good fishing spots. During the Ertebølle culture fishing and sea mammal hunting was practised all along the southern Baltic Sea coast both from semi-permanent residential sites and specialized fishing sites mostly using stationary fishing fences, nets, traps, and leisters (Andersen 1995; Fischer 1997; Johansen 2006). Even if fish hooks made from animal

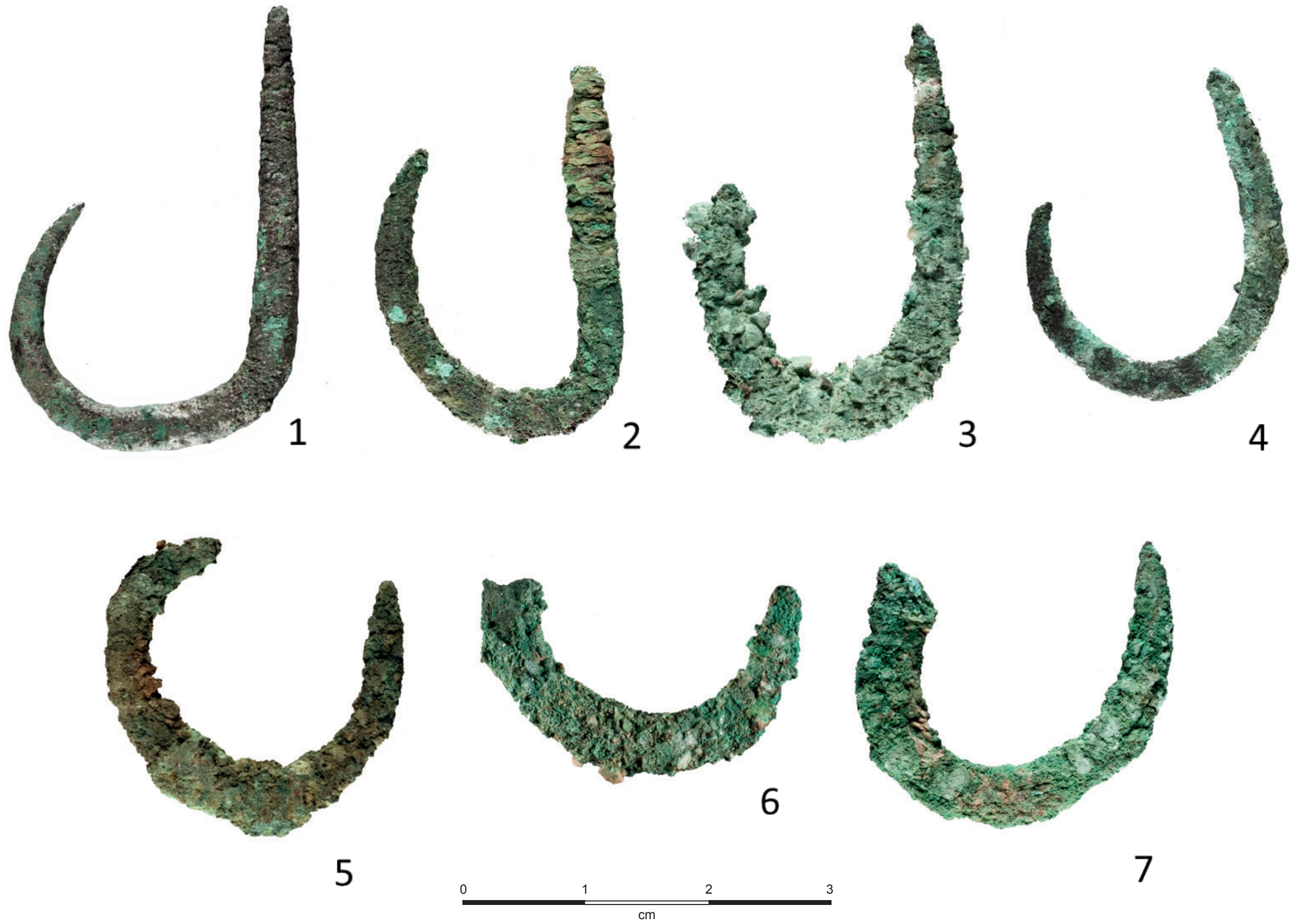

Fig. 2 Selection of copper fish hooks from Otto Aichel's collection housed at the State Archaeological Museum Schleswig-Holstein, northern Germany (Photos: ALM Schleswig).

bones were discovered on some sites as well, they appear only in small quantities (Ritchie 2010; Kruse 2014), with the more than 30 hooks from the site Asnæs Havnemark as a single exception. As they are rather small in size and made without a barbed point (**Fig. 1**), they were probably used for fishing flatfish, herring or eel.

In the present paper we seek to discuss fish hook shape variability from a double perspective: on the one hand by using a collection of well-preserved fish hooks that despite its small sample size represents different raw materials, regions of the world and chronological periods; on the other hand, by classifying this material using a geometrical morphometric approach. The aim of this study is to describe and analyse the pattern of shape variation of Aichel's metal fish hooks as markers of cultural evolution, representing direct evidence of adaptation of human populations to coastal environments through the exploitation of marine resources. Additionally, standard geometric morphometric algorithms were applied in order to compare Aichel's hooks with those from different archaeological coastal cultures like Chinchorro in Chile and Ertebølle culture in southern Scandinavia/northern Germany.

Our null hypothesis states that shape variation is independent of the geographical/cultural origin, the fish hook's raw material and/or chronology. We base this assumption on two arguments derived from the study of Hawaiian fishing technologies. First, to determine the pattern of fish hook evolution and to establish the level of its congruence with cultural evolution as a whole, it is necessary to analyse fish hooks' stylistic and functional traits separately (Pfeffer 2001). Second, from an evolutionary perspective, functional traits have an analogical origin explained by convergence processes (Allen 1996). As a result, artefacts having different geographical, chronological, structural and/or cultural origins should present similar forms (similar shape and/or size components) in response to similar environmental and mechanical constraints. In the case of a fish hook, its main functional attributes are bend shape and shank size (Allen 1996). By describing the fish hooks belonging to Aichel's collection and testing our hypothesis about the causes of their variation we hope to contribute to the understanding of the role played by fishing in prehistoric communities, promoting at the same time further application of quantitative tools for the classification and analysis of archaeological artefacts.

Fig. 3 Map of homologous landmarks used in the present study (1–10) for geometric morphometric analyses. Linear measurements (cm) are shown in solid lines (TL = total length, from landmark 1 to the orthogonal projection of landmark 3; FL = frontal length, from landmark 4 to the orthogonal projection of landmark 3; GL = gap length, from landmark 4 to the opposite side of landmark 2, following the standard nomenclature for fish hook anatomy; illustration: G. Manríquez).

Tab. 1 Sample of archaeological fish hooks used in this study (n = 38). Arica = Morro-1/Chinchorro culture, archaic period; Antofagasta = Aichel's collection/Late Intermediate Period; Taltal = Morros de Mique, Morro Colorado/archaic period; Denmark = Tybrind Vig, Havnø, Ertebølle (*loc. class.*)/Ertebølle culture; Germany = Wustermark/Late Upper Paleolithic sites. Centroid size is the square root of the sum of squared distances of a set of landmarks (1–10) from their centroid (Bookstein 1991).

Origin	n	Total length (TL) in cm	Front length (FL) in cm	Gap length (GL) in cm	Centroid size	Index (TL/FL)	Reference
Arica	3	3.37 ± 2.40	1.18 ± 0.49	1.13 ± 0.65	3.54 ± 2.1	0.44	Standen 2003
Antofagasta	10	2.76 ± 0.69	1.78 ± 0.41	1.29 ± 0.24	3.63 ± 0.76	0.64	this study
Taltal	7	1.81 ± 0.57	1.60 ± 0.44	1.11 ± 0.33	2.95 ± 0.73	0.82	this study
Ertebølle culture	12	2.88 ± 0.58	1.60 ± 0.27	0.54 ± 0.09	2.82 ± 0.53	0.57	Kruse 2014
Wustermark*	6	8.90 ± 2.11	3.99 ± 1.65	2.11 ± 1.00	8.71 ± 2.7	0.45	Gramsch et al. 2013

*includes fish hooks from France and Austria as described in Gramsch et al. 2013

Material and methods

In order to describe the pattern of fish hook shape variation in Aichel's collection (**Fig. 2**), standard geometric morphometric algorithms were applied (Bookstein 1991; Slice 2007). The geometric morphometric approach is based on 2D and 3D landmark coordinate matricial raw data obtained from a map of homologous landmarks (**Fig. 3**). This allows to partition shape and size components of form after removing the differences due to rotation, translation and scaling (Rohlf/Slice 1990) by a generalized least square analysis (Procrustes fit). For comparative purposes, landmark coordinate matrices of prehistoric fish hooks made from cactus thorns (*Cactaceae*) belonging to a northern Chile archaic site from the Chinchorro culture (Arica, Chile), archaic mussel shell fish hooks from the southernmost region of the Atacama Desert coast (Taltal, Chile), ungulate bone fish hooks from the Ertebølle culture (Denmark, Germany; **Fig. 1**), and Late Upper Palaeolithic ungulate bone and mammoth ivory fish hooks from meridional (France, Austria) and north eastern Germany were also included in the analyses (**Tab. 1**). Due to the homological nature of landmark coordinates, the analysis does not consider *a priori* stylistic traits (e.g. the presence of a barbed point in the Ertebølle culture artefacts) or the differences associated with the geographical origin or with the raw material used to make the artefacts. Therefore the data analysed in this study using the quantitative tools of geometric

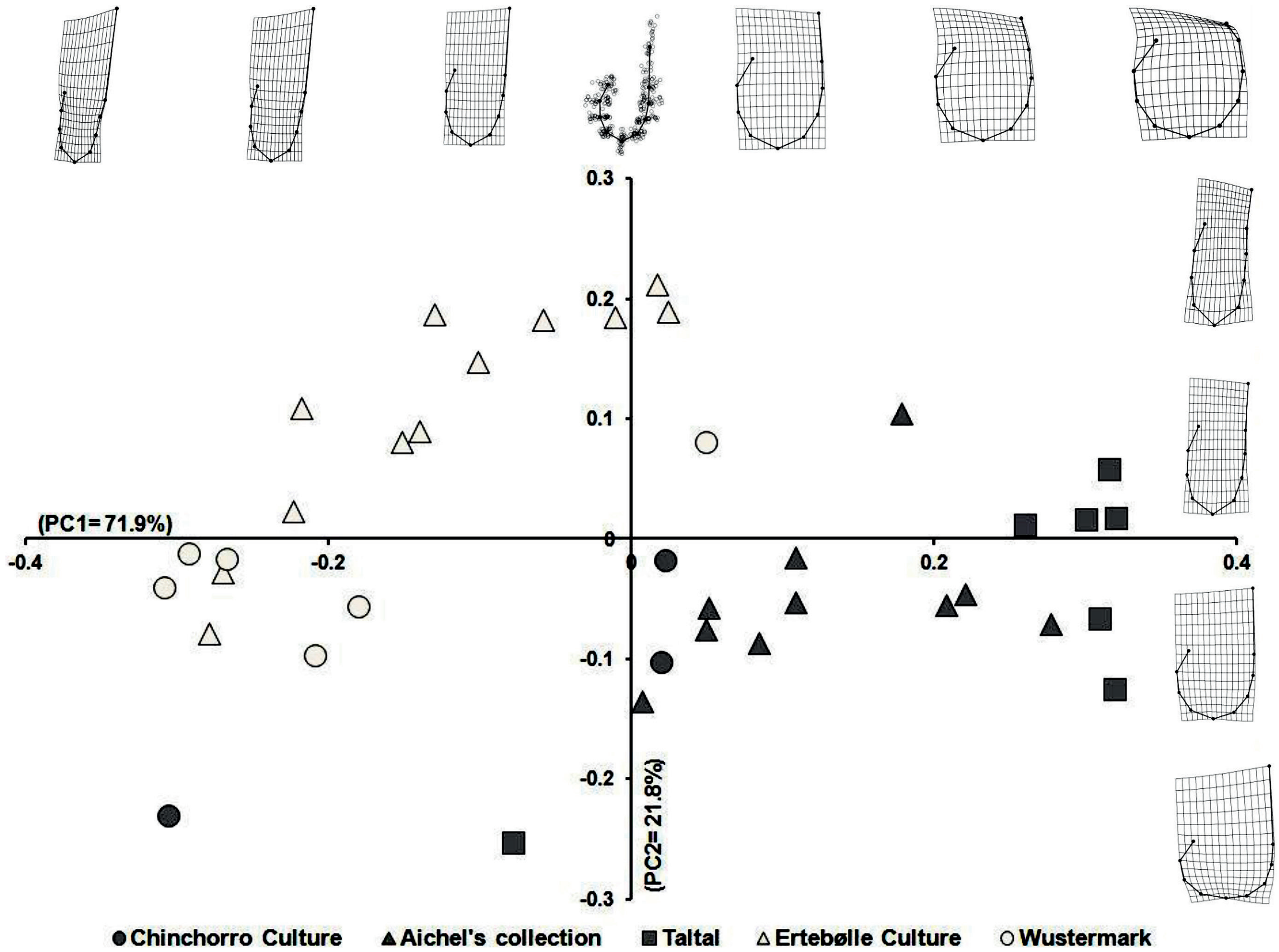

Fig. 4 Principal component analysis of the shape components obtained after applying a Procrustes (generalized least-square) analysis of the raw data (2D landmark coordinates matrices). The grids represent fish hook shape variation along the first (upper row) and second (left column) principal components after applying a thin plate spline function (Bookstein 1991).

morphometric approach are shank length (size) and bend curvature variation (shape). Landmark registering and linear measurements were carried out after applying standard tpsDig2 (Rohlf 2010a) algorithms on carefully scaled images. To analyse the results presented herein, tpsRelWarp (Rohlf 2010b), NTSYSpc (Applied Biostatistics Inc.) and MorphoJ (Klingenberg 2011) programs were used.

Results

Visual inspection of Aichel's fish hook collection shows that the majority of the artefacts have short shanks and circular shapes (**Fig. 2**). In spite of the fact that they are made of unalloyed copper instead of mollusc shells, this morphologic attribute is also shared by the archaic fish hooks from Taltal, located 250 km south of Antofagasta. So the source of the fishhooks' size variation in the total sample is related to differences in shank length (**Tab. 1**). In comparison with the longer shanks of the fish hooks from the Chinchorro, Wustermark, and Ertebølle sites, having a total/frontal length (T/L) index greater than 1.5, the hooks from Antofagasta and Taltal sites show a very short or absent shank (T/L index < 1.5). These differences in the size component of the hook form are statistically significant (short shank T/F index = 1.28 ± 0.15; long shank T/F index = 2.13 ± 0.11; one-way ANOVA F = 20.723, d.f. = 1.36, p = 0.000059). Regarding the main source of shape variation, the principal component analysis of the landmark data (**Fig. 4**) showed that shape differences are concentrated in the bend region. Specifically, the pattern of shape variation is explained by landmarks mapping the first half of the curvature in a shank-to-point direction (nos. 1–2 in **Fig. 1** vs. nos. 4–5 in **Fig. 2**), corresponding to 93.7 % of overall shape variance. The anatomical specificities emerging from this general pattern of hook shape variation are captured by the grids projected along the first two principal component axes after applying a thin plate spline function. As a result of the projection along the first principal component (71.9 % of the overall variance), two groups are clearly differentiated: i) long shank fish hooks with contracted bends, and ii) short shank hooks with expanded bends. Each of these groups occupies, in turn, two morphospaces defined

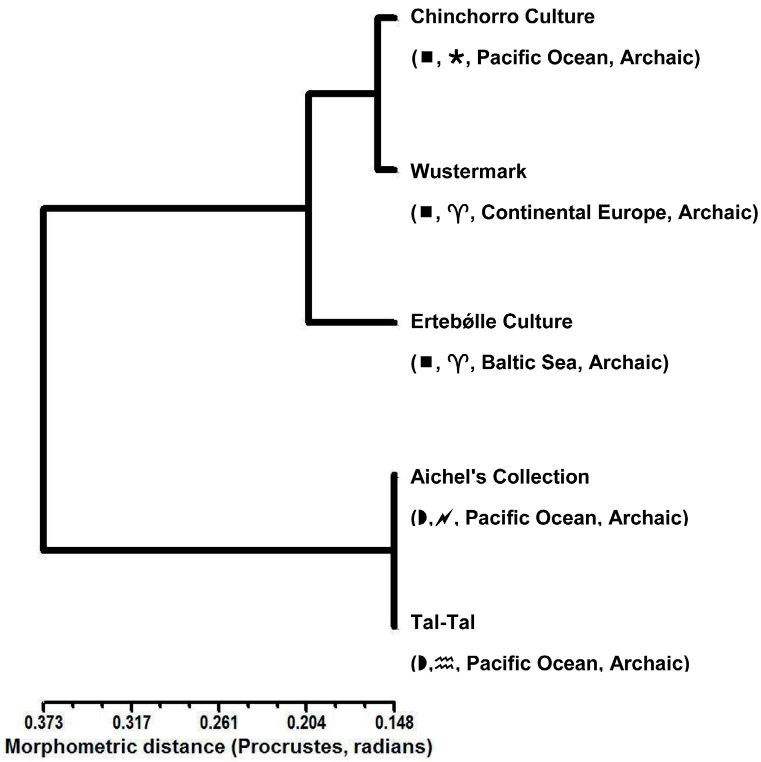

Fig. 5 Dendrogram of morphometric (Procrustes, radians) distances among consensus ('mean') fish hook configurations from the different archaeological sites using as grouping algorithm UPGMA (Aichel's collection = Antofagasta, Chile, Ertebølle culture; Chinchorro = Arica, Chile) (◗ = circular, ■ = rectangular, ★ = vegetal thorn, ⌿ = metal, ♈ = animal bone, ♒ = shell; illustration: G. Manríquez).

by the corresponding positive and negative values of the second principal component. In this case the main change occurs at the middle portion of the bend. The amount of overall variance explained by this axis (21.8 %) is mainly associated with a more curved point in the Ertebølle culture fish hooks set compared to the remaining rectangular hooks from the Wustermark and Chinchorro cultures (**Fig. 4**). It is noteworthy that this pattern of shape variation (i.e. from circular to rectangular hooks' shapes) does not depend on the geographical origin, the chronological period and the structural characteristics (raw material) of the fish hooks (**Fig. 5**; p-values from Hotelling's T2 for Aichel's collection/Taltal = 0.0801; Chinchorro culture/Wustermark = 0.2927; cactus/bone = 0.0545; shell/metal = 0.0791; archaic/late = 0.0458; archaic/Palaeolithic = 0.0462 after MorphoJ routine for canonical variate analysis with 10,000 permutation rounds in each test). In contrast, the Procrustes distance between circular and rectangular hooks (0.3344 radians) was statistically significant ($p << 0.001$), allocating the 94.1 % of circular and 85.7 % of rectangular hooks to their respective *a priori* defined groups (MorphoJ routine for cross-validated discriminant function analysis).

Discussion

The main results of our work show i) a pattern of fish hook size and shape variation reflected in two basic morphologies, that is long shank fish hooks with rectangular, contracted bends (cactus thorns from the Chinchorro culture and ungulate bone from the Ertebølle culture) and short shank hooks with circular, expanded bends (Aichel's collection of artefacts made of metal and Taltal hooks made of mussel shells), ii) that this pattern is independent of the geographical origin, chronological period and, to a lesser degree, fish hook structural characteristics (raw material). An additional result was an appreciation of the archaeological heritage of prehistoric populations inhabiting the coast of northern Chile.

The first of these results has taxonomic implications related to the *a priori* nature and the qualitative character of the classifications usually applied in archaeology to give diagnostics about artefacts' provenance and grouping (Rouse 1960). An almost inevitable consequence of this typological approach is the over-representation of categories and subcategories defining each group of objects. For example, the number of categories such as 'head shape', 'lashing device', 'point limb angle', and their corresponding subcategories 'flat' (vs. 'interior stepped', 'inward angle', 'concave', etc.), 'drilled hole' (vs. 'exterior notches', 'groove', 'interior protrusion or knob', etc.) and 'parallel' (vs. 'angled inward' and 'angled outward') proposed to classify Hawaiian fish hook attributes reaches 9 categories × 12 subcategories (Pfeffer 2001, tab. 3.1). According to other classifications that consider stylistic traits, this proportion gets to 3 categories × 14 subcategories just for fishhooks' head morphology without considering the other parts of a hook's structure (Allen 1996, tab. 1). The quantitative, *a posteriori* approach applied in the present work contributes not only to the simplification of the classification of archaeological artefacts, but it also allows the prediction of the occurrence of new shapes through the morphing of the thin plate spline function along the principal components shape axes (grids in **Fig. 4**).

More importantly, this approach makes it possible to test statistical and archaeological hypotheses, allowing us to search for the causal factors which eventually explain shape changes. With regard to the latter, we found that the observed pattern of fish hook shape variation can be explained by a factor or a set of factors different from the geographic origin, chronology or perhaps the raw material used to produce the artefact. In classic Polynesian archaeology, a direct relationship between hook curvature and prey retention has been proposed (Nordhoff 1930 cit. by Pfeffer 2001), suggesting that the orientation of the point limb relative to the shank limb could determine the 'jabbing' or 'rotating' hook function. The problem with this presumption is that it does not take into account the role that shape could play in prey retention or in prey attention, two additional and crucial moments in fish capturing practice. Therefore additional and alternative factors should be considered to explain the fishing success of a particular hook shape, such as raw material strength, hook size and hook design (Pfeffer 2001). In some cases raw material constrains the final hook shape, as certainly happens with fish hooks made from organic hard structures like shell or bone material. In this sense, the production of metal fish hooks represents a landmark in the cultural evolution of prehistoric populations exploiting marine resources. Regarding hook size, it is highly probable that a direct relationship between this variable and prey size exists. For example, the large type of bone fish hooks in the Maglemosian and adjacent Mesolithic cultures (Mathiassen 1948; Cziesla 2001) was probably used for big fish like pike or catfish. This hypothesis, however, is very difficult to test because it positively requires *in situ* availability of archaeo-isthyological remains, which do not always match with the presence of archaeological fish hooks.

A key limitation of our study is its small sample size. Because the main aim of this work was to describe and analyse the pattern of shape variation of the Aichel collection of fish hooks, as well as to introduce a new quantitative approach in archaeology to classify artefacts, the size of the sample was limited. Therefore further research should consider bigger hook samples. One subject that remains to be explored is the congruence between the pattern of fish hook shape variation and the prey's jaw size and shape variation. That means searching for archaeo-isthyological remains at the archaeological sites from Northern Chile Pacific coast.

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