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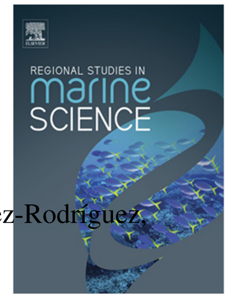

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Hindcasting to forecast. An archaeobiological approach to the European hake (*Merluccius merluccius*, Linnaeus 1758) fishery: Iberia and beyond

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"[Spain's] *fields and…..seas are synonymous. So bear witness the uncountable crops of…..hake that never disappear from our beaches…..*" (Sáñez Reguart, 1791-1795)

Abstract: This article attempts to set out a research agenda on the origin and evolution of hake exploitation in the Northeast Atlantic through a combination of zooarchaeological data with history and fisheries biology. An overview of archaeological hake remains from the Iberian Peninsula is presented and discussed in terms of a series of long-established paradigms. These are later expanded through an overview of issues currently facing the hake fishery, in particular its southern stock. The work concludes by specifying some research problems these issues imply an how historical and biomolecular analyses of archaeological specimens may improve our understanding of hake fisheries in former times in an attempt to implement a hidcasting to forecast strategy that could synergize with current fisheries research on the species.

Keywords: European hake, *Merluccius merluccius*, Iberia, Archaeological record, fishing,

1-Introduction

1.1- Habitat use and range

The European hake (*Merluccius merluccius*, L. 1758) is one of the most important commercial fish species of the world with annual catches currently exceeding 100,000 tones (FAO, 2016; MAPAMA, 2015). Hake is a demersal and benthopelagic species, found mainly within water depths between 70 and 370 m. However, it is not restricted to this range and is commonly found in inshore waters, 30 m, and down to depths of 1000 m (Murúa, 2007, 2010). Whether or not such a bathymetric range was held in the past is a matter of debate and a crucial issue to explain the scarcity of hake remains in the European archaeological record (Morales et al. in press, in prep.). Indeed, according to Kennedy (1954), ca. 70% of hake catches in the NE Atlantic took place at depths of more than 100 m and only a minimal fraction (i.e. ca. 6%) at depths of less than 36.5 m but nowadays juvenile hakes (i.e. fishes below 30 cm), mostly found in shallow waters, constitute a substantial fraction of the catch. Given that, technically speaking, a deep-water fish species is defined as one where most of its members live at depths below 400 m, hake does not qualify as deep-water. But for archaeologists and traditional fishermen alike, the term *deep-water* would not conform to that definition (e.g.

Pickard and Bonsall, 2004). Indeed, we bear strong doubts that the term had a precise meaning prior to pre-industrial fishing times. Although to our knowledge no consensus on the subject exists, archaeologists would probably define "deep-water" on an operative rather than a strictly bathymetric basis, to refer to any kind of fishing not accomplishable either from the shore or close to it (i.e. "inshore"). From such a standpoint, whether hake during pre-industrial times were mostly found below 100 m or not might thus be a secondary issue. Accessibility, not mere depth, would be the element to consider. Yet, when one acknowledges that the archaeozoological record of hake in Europe pales when compared with that of species such as Atlantic cod (*Gadus morhua*, L. 1758)(1), the fact that hake reaches into deeper waters than most of the commercial gadids is often taken as the explanation to account for its scarcity in the deposits (Pickard and Bonsall, 2004). The questions that need to be addressed at this point, however are whether hake could be regularly caught in shallow waters or not, and if such accessibility changed/diminished through time.

1.2- Distribution

With independence of reasons that explain the scarcity of hake remains in European sites, biases of various kinds need to be taken into account. One such bias is geographical, itself a combination of biogeographical and methodological constraints. In the NE Atlantic hake concentrates on the large shelfs of the Celtic Sea and the Bay of Biscay (northern stock) and in the narrow and steep shelfs around the Iberian peninsula (southern stock)(Figure 1). From a biogeographical standpoint, hake is a temperate water species able to reach into the high latitudes in Europe thanks to the Gulf Stream, and although most distribution maps convey a different impression (e.g. see Whitehead *et al.* 1984), hake is a rare item in the truly cold European seas, including the Baltic and the North Sea (2). On the other hand, its abundance along the sinusoid path of the continental shelf running from Southern Spain into the Cantabrian Sea, then following the Armorican shelf into the Celtic shelf and up again along the western coast of Ireland, the Orkney and the Shetland islands, is unfortunate in that many of these coastlines, in particular those of Portugal, Spain and Ireland, happen to feature among the archaeozoologically least documented ones of the European subcontinent.

1.3- Archaeological visibility constraints

A second bias hampering the archaeological visibility of the European hake could well be taphonomical. Most hake bones are extremely fragile and far more so than those of the commercial gadoids (Roselló-Izquierdo, unpublished). Chances of retrieving complete specimens in archaeological sites are thus hampered by such fragility and fractured bones are often difficult to identify to species level. The same applies to the scarcity of otoliths in the archaeological record whose calcium carbonate composition only allows to retrieve them under alkaline or neutral pH conditions (Wheeler & Jones, 1989). In Spain, one last bias that renders it difficult to track down hake in documents is nomenclatural. This relates to the fact that processed hake were often commercialised under ambiguous terms such as *pescado cecial* or *cecial* that included various kinds of dried fish (not necessarily salted), in addition to hake. Although when commercialised fresh, the documents refer to *hake* or well-known equivalents such as *pescada*, *pijota* or *pescadilla*, fresh hake remained a minor portion of hakes traded inland up until the twentieth century. For such reasons, any quantification of hake trade in the Spanish pre-industrial times' written sources might prove to be an underestimation of the real importance the species reached.

1.4- Outline of the project

A couple of years ago we initiated a project to study the origin and development of the hake fishery from a multidisciplinary perspective. Combining traditional zooarchaeological techniques, for instance the retrieval and analyses of hake remains from Iberian archaeological collections, with biomolecular techniques, including stable isotope analysis, we endeavor to systematically research the origins, nature and development of the NE Atlantic hake fishery. Alongside these methods we are also undertaking a systematic literature review to document the frequency of hake remains throughout Northern Europe and studying the historical evidence. We hope that through this combined approach we will be able to elucidate the shifting baselines the exploitation of the species has experienced through time.

In this paper we provide an overview of our archaeozoological research on Iberian assemblages and combine it with selected aspects of the species' biology. The aim is to set up a *Hindcasting-first-to-forecast-after* agenda that could shed light on issues where archaeozoologists might be able to join forces with fishery biologists in order to implement enhanced management protocols to ensure the conservation of this presently endangered resource.

2- The Iberian archaeological record of the European hake

2.1- The ichthyoarchaeological evidence

Although for most of the Upper Palaeolithic (≈45,000-13,000 cal BP) the record of marine fish is almost nil in the European subcontinent, no remains of hake have ever been reported from this time or in the ensuing Tardiglacial period (14,800-13,000 cal BP). Such absence does not necessarily mean that hake was not taken by hunter and gatherers. Indeed, a significant portion of the European continental platforms had emerged at that time so that the coastlines where fishing activities left their evidences presently lie underwater (Bailey and Flemming, 2008).

The earliest European records of hake appear in two Early Mesolithic sites from Southern Sweden and two Neolithic sites from Northern Iberia. The two Iberian sites are located in the Spanish Basque country (i.e. the Cantabrian Sea), lying barely 10 km away from one another (Figure 2A; Appendix: Table A1) and at both of them hake remains reach to the Bronze Age (Aranzadi and Barandarián, 1935; Arribas, in press; Barandarián 1965; López Quintana, 2011; Morales-Muñiz et al., in press; Roselló-Izquierdo and Morales-Muñiz, 2011). At the site of Lumentxa (Appendix; Table A1) the Neolithic has been radiocarbon dated at 5,180 +/- 70 BP (Ua-12662) (range: 6,054 - 5,825 cal. BP) and the Bronze Age at 3,560+/- 180 BP (I-15.451 range: 4,124 - 3,649 cal. BP) (Arribas, in press). At Santimamiñe (Appendix; Table A1) there are two radiocarbon dates for the Neolithic: 5,450 +/- 50 BP (Beta-240898) (range: 6,394 - 6,030 cal BP) and 5,010 +/- 40 BP (Beta-240897) (range: 5,892 - 5,653 cal BP), and one for the Chalcolithic/Bronze Age: 3,710 +/- 40 BP (Beta-240896) (range: 4,218 - 3,926 cal BP) (López Quintana, 2011). This temporal window is far too wide, thus the evidence far too coarse to specify whether or not throughout three millennia (i.e. 6,394 – 3,649 cal BP hake was fished regularly or just specific moments. Interesting here is that this temporal horizon coincides with the Holocene´s Climatic Optimum whose temperatures were roughly coincident with those found today in NE Atlantic waters (Roberts, 1998). As for the hake remains retrieved in the Swedish Early Mesolithic sites of Olmänäs and Huseby Klev, these date back to the Boreal chronozone (ca. 9,000 cal BP) that, although not as warm as the Climatic Optimum stage, nevertheless corresponded with a warm pulse at the start of the Holocene (Eriksson and Lidén, 2003). These climatic parallels of hake appearing on the archaeological deposits coinciding with temperate pulses constitute one first issue that needs to be explored in detail in the future.

Given the presumably deep-water nature of hake, two interrelated issues arising from these earliest European finds are: (i) whether or not the animals were fished in shallower waters than those in which they are presently found (i.e. >27.5 m), and, as a corollary of it, (ii) whether or not hake formerly ventured into brackish waters. In connection with the later, two facts need to be taken into account. The first one concerns the location of Santimamiñe that presently lies 5 km away from the coast, following the meanders of the Oca River. Given that during the Neolithic and Bronze Age periods this distance must have been very similar to the present day one, the fact that the site´s location coincides with that portion of the Oca where the influence of the tides is felt, suggest that a fishing of euryhaline (i.e. tolerant to shifting salinity conditions) fishes was possible for the cave´s inhabitants. In this context it is interesting to note that the dominant taxa at Santimamiñe, were either the Salmon (*Salmo salar*, L. 1758) or the sea trout (*Salmo trutta trutta*, L. 1758) that are both euryhaline species (Roselló-Izquierdo and Morales-Muñiz, 2011). A second possible piece of evidence of hakes formerly venturing into brackish waters is the presence of allelic frequencies in their genome that correlate, among others, with salinity and temperature shifts (Milano et al., 2014) features that reveal a high ecological plasticity for a presumably strict marine species.

After the Neolithic, hake has been reported in four Bronze Age deposits, the aforementioned Basque country sites plus those at Hornish Point and Baleshare in the Outer Hebrides (Jones, 2003) but, except for Iberia, hake apparently vanished from sight during the ensuing Iron and Roman periods (Morales-Muñiz et al., in prep.). This may reflect a mere construct, the result of incomplete archaeological surveys on the Irish, Spanish and Portuguese coasts. Still, given that hake must have been present along the shores of far better surveyed areas such as Southern England and western France, we suspect that such scarcity might reflect yet to be determined contrivances that resulted in a restricted accessibility of people to this particular resource at the time (3).

During the first millennium BC, and except for the Punic site of Camposoto in Cádiz (Southern Spain), almost all hake finds from Iberia appear in the region of Galicia, on the NW corner of the Peninsula (Figure 2A). As had been the case thus far, Iron and Roman Age hake was retrieved in coastal sites, suggesting a fishing carried out at a local, non-intensive, level reflecting subsistence. Although most of these fish assemblages are small (Appendix: Table A1) with NISPs (i.e. number of identified specimens) numbering above 100 remains, the contributions of hake fluctuated widely, even within a single site (e.g. 0.3% - 30% at Punta Atalaia). For such reason, the pooled mean contributions (Iron Age: 6.7 %; Roman: 26%) do not mean much even though they do hint at hake becoming a more important item of the catch through time, perhaps as a result of improvements at the level of tackle or possibility to move offshore (Table 1). What these values also hint at is that hake was neither an intensively fished item nor one regularly harvested throughout the year (4). Abundances, as expressed by NISP frequencies, on the other hand, might be simply taken to reflect an availability of hake in Galician waters that was nowhere to be seen in the Iberian littoral as is still the case today (Morales-Muñiz *et al.*, in press). Such availability would reflect a productivity of Galician waters that to this day rank among the richest for Iberia. The only Roman Age hake reported for Portugal (i.e. Troia; Appendix: Table A2) derives from the latest stages of the Roman occupation (4^{th}-5^{th} C AD) roughly coincident with the abandonment of the Roman fish factories and fish productions (Gabriel, 2013).

2.2 Historical evidence

In Medieval Iberia, there are a number of documents that demonstrate the importance of fishing and fish trade in Galicia, the major fished items now being hake, sardine (*Sardina pilchardus* L. 1758) and conger eel (*Conger conger* L. 1758) (Ferreira, 1988). From the standpoint of the archaeozoological record of hake, two major developments are documented (Figure 2B; Appendix: Table A2):

a) Coastal deposits featuring hakes no longer concentrate on Galicia as they include the site of Tabacalera (Gijón, province of Asturias), the Oficina do Sehnor Carrilho (Loulé, Algarve, Portugal) and the Pobla de Ifach (province of Alicante) that has yielded the earliest archaeozoological record of hake for the Mediterranean at this time (Morales et al., in press).
b) Contrary to the pattern seen thus far, more than half of the Medieval collections (54%) derive from inland sites, evidencing a transport of hake that reflects the trade that the documentary sources mention.

In relation with both issues two additional features need to be remarked at this point. The first one has to do with the earliest dates of hake in Medieval deposits since in all cases, coastal and inland alike, the earliest records are dated prior to 11th C AD that corresponds with the so-called *'Fish Event Horizon'*that presumably signaled the onset of the commercial fisheries in the NE Atlantic (Barrett *et al*., 2004, 2011). That Iberian hake might have travelled inland as early as 8th C AD (Curiel Castle; Appendix: Table A2) suggests a far earlier date for the onset of the fish trade in Northern Spain than that referred to by the written Iberian sources or evidenced by the English archaeozoological record. Noteworthy is that the earliest evidences of long-distance trade have not been recorded in Galicia but on the center of the Iberian Peninsula instead (i.e. Plaza de Oriente, Madrid; Appendix: Table A2). These hake finds date from a time when the city was still a Muslim stronghold thus reveal an activity that took place in spite of the continuous strife between the Christian kingdoms and the Muslim *taifa* kingdoms of the time. Whether Christians or Muslims, or perhaps both, were the developers of such trade and what routes the trade took cannot be settled on strict archaeozoological grounds. Fish with not too conspicuous scales, such as hake, might not have been an item most Muslims would consider halāl or Makrūk (i.e., allowed or no recommendable), although perhaps not necessarily dismissed as would be the case of species devoid of scales such as the conger eel, forbidden by Muslim precepts (Foltz, 2006; Morales et al. 2011)(5). In this context it is interesting to note that the Pobla de Ifach fish assemblage that harbours the earliest find of hake for the Mediterranean dates from 14th C AD, when the town was already in the hands of the Christians from the crown of Aragón. Likewise, even though hake was mentioned as a fished item in the Muslim documentary sources (Malpica, 1983) hake has been unreported in most of the archaeozoological fish collections from Muslim sites, such as Saltés, Alcazaba de Santarém, Calatrava la Vieja and Alqueria de Arge (Morales et al. 2009). But, again, matters might not prove so clear cut. The species has been reported in an ongoing fish assemblage from BNV (Tavira, Portugal; unpublished data). Fish trade inland has been additionally well documented during Almohad times at places such as Calatrava La Vieja and Mértola (Morales et al., 1994). In addition, an interim report on the 13th C AD fish assemblage from the aforementioned coastal Islamic site at Oficina do Senhor Carrilho has found three remains of hake (S. Gabriel, verb.com). Be it as it may, it seems clear that already by Early Medieval times evidence exists in Iberia of hake being shipped long-distance (i.e. presumably preserved) to inland sites. Such trade, in turn, would testify a more systematic (i.e. intensive?) fishing of hake one full millennium prior to the 18th C AD date postulated by Casey and Pereiro (1995) as the onset of a full-blown hake fishery in the NE Atlantic (Gutiérrez González (J.A.), 2003; Gutiérrez González (M.M.), 2003). The intensity of that early fishery is a pending issue that the documentary sources may help clear in the future.

The Iberian archaeozoological record of hake during Modern times is far more restricted than that from the Middle Age. Such phenomenon is probably another construct due to the scarce development of Modern and Contemporaneous Ages archaeology in Spain and Portugal. In fact, the written sources from the 17th and 18th C AD evidence hake to constitute a crucial resource for the Spanish (sic.) "Oceanic" fisheries of the time (Cornide 1788; Sáñez-Reguart, 1791-1795, 1796?; Graells, 1870). The faunal evidence in turn indicates that hake was often a relevant item of the fish collections both in coastal and inland deposits (Figure 2C; Appendix: Table A3). Although the proportion of inland sites featuring hake falls slightly below that from the Middle Age (i.e. 43% of the Modern records derive from inland contexts), these differences are neither quantitatively nor qualitatively significant given the small sample size of the Modern Age collections. What seems beyond question is that the pooled mean contributions of hake within the fish assemblages rose substantially from the level recorded for Medieval times (i.e. 66% vs. 41%; Table 1). Equally relevant, hake contributions in coastal and inland fish assemblages were identical (Table 2). In other words, it does appear that hake progressively became a more important item not only of the Spanish fisheries but also for the Spanish fish trade. Although due to their inherent limitations, the documentary sources are unlikely to reveal these and other aspects of the hake fishery and hake trade, the species is nevertheless more frequently mentioned in Modern Age (17th and 18th C AD) texts. Again, this may simply represent yet another construct given that in later times, and due to improvements in the transport among others, a greater proportion of hake were traded fresh, thus the shipments incorporate names one can clearly trace to the species.

One final aspect in which traded Iberian hake differed from traded cod in NE Europe is that, even when processed, complete specimens rather than be-headed ones or fishes devoid of most of their vertebral column, seem to have been transported at all times. In this way, the "*heads stay, tails travel*" proposal for commercial gadids of Perdikaris (1996) in the NE Atlantic does not seem to hold in the case of Iberian hake. Few reliable collections from inland sites are presently available to explore the issue in detail but the data from the ones at hand seem compelling beyond question (Figure 3). The archaeozoological data reinforce the Spanish documentary sources reporting hake being shipped as a dried, though not necessarily salted, product named "*pescado cecial*" or simply "*cecial*". As was previously mentioned, these terms are unfortunate in that many species prepared in this way would travel under the same commercial label (Figure 4). One is thus unable to infer from the documentary sources whether hake was in fact included under the label of specific shipments and, when so, what amount of the shipment the species represented. One way or the other, simply letting a fish to dry often generated a low-quality, short-lasting product that could spoil in a matter of weeks (6). Due to such deficient preparation, hake trade was, for all practical purposes, restricted to far smaller regional circuits than was the case for salted cod and other European fish productions. In other words, an essentially Iberian commodity. Add to it that hake flesh loses its quality faster when dried than the flesh of commercial gadids and one can understand why dried hake disappeared from the market by the 19th C AD. Various bromatological and organoleptic issues concerning dried hake remain open on the research agenda at this point that demand experimental analysis analyze.

3- The current European hake status

The European hake's archaeological record not only sheds light on the history of its fishing in the Iberian Peninsula but, more significant, might help address certain important issues currently facing this key resource. Indeed, hake fisheries management is confronting a number of challenges, some of which are due our still incomplete knowledge on the biology and ecology of the species, and others to exogenous anthropic phenomena such as overfishing and climate change. Understanding how hake ecology reacted in the past to shifting fishing pressures and different climatic scenarios should deepen our knowledge on how is hake currently responding to those same pressures. Such hindcasting exercise can prove fruitful to enhance our mechanistic understanding of crucial biological processes that constitute the basis for developing and testing new models to improve forecasting along with future management protocols.

The European hake is widely distributed throughout the North-East Atlantic, from Norway in the north to the Guinea Gulf in the south, and throughout the Mediterranean and Black Sea, being more abundant from the British Isles to southern Spain, occupying a variety of habitats with different temperature, salinity, productivity conditions, trophic resources, etc. This heterogeneity reveals the high adaptive capacity of the species, expressed also in terms of high phenotypic plasticity that results in a diverse and complex life history. This complexity underlies current management challenges of which, in our opinion, there presently exist four where zooarchaeological research might prove of help, namely:

1. For management purposes, ICES (International Council for the Exploration of the Sea) defines two stocks for the NE Atlantic, the so called northern stock being widely distributed throughout the shelves from Norway to the Bay of Biscay, while the southern stock inhabits the shelves surrounding the Atlantic sector of the Iberian Peninsula. The boundaries between both stocks have been always controversial and recent studies suggest a bi-directional pattern of connectivity with no evidence of stable differences in gene diversity between them (Pita et al., 2016). Still, the relative demographic independence of both stocks indicates the existence of sub-management units within a single metapopulation. This complex population structure and connectivity patterns seems to be changing in recent decades likely as a consequence of climatic changes, exacerbated by a differential exploitation rate that impinges on stock productivity. This is fostering shifts in the distribution, productivity and in the migration rate from northern to southern waters, impacting on the fate of the southern stock (Pita et al., 2016).

2. Since 2004, the southern stock of European hake is fully or over-exploited (i.e. operating at or close to optimal yield level with no expected room for further expansion; Korta et al., 2015). Despite the implementation by the EU of several technical measures and a recovery plan, the stocks remain outside safe biological limits. Lack of recovery is likely the consequence of reproductive potential lost and further resilience erosion, both caused by fishery exploitation (Cerviño et al., 2013). The observed decrease in the mean length of hake is most likely a consequence of a size truncation phenomenon that results from size-selective fishing (Hidalgo et al., 2014) and has been already observed in species such as Atlantic cod (*Gadus morhua*, L.1758) and Atlantic salmon (*Salmo salar*, L. 1758) (Olsen et al., 2004; Quinn et al., 2006). This truncation leads to temporal variation in gonadal development, resulting in earlier maturation at smaller sizes (Domínguez-Petit et al., 2008), diminishing the maternal influences thus reducing the positive effects of size-related reproductive traits on the survival of offspring. In addition, fishing also causes evolutionary changes in fitness-related traits such as growth and maturation (Olsen et al., 2004) by selecting for genotypes less affected by fishing (i.e. individuals with slow growth and early maturation at a small size);

these changes, in turn, undermine stock reproductive potential due to the adaptive juvenescence of the population (Saborido-Rey and Trippel, 2013; Hidalgo et al., 2014). More important, due to the genetic basis of these changes, their effects persist once fishing pressure is released (Saborido-Rey, 2016).

3. Although crucial data regarding hake growth based on tagging experiments and daily growth exist, there is no clear basis for age interpretation based on otolith rings (Cerviño et al., 2013) nor on any other skeletal element for that matter. It is nevertheless known that sex ratio at length/age is skewed towards males between 25 and 45 cm and afterwards the female fraction increases until about 70 cm when it reaches 100% (Murúa, 2007). Different maturation rates between the sexes lie behind the different growth rates, and the aforementioned size-selective fishing may also alter the sex ratio. Given the long term exploitation of hake (i.e. beginning of the Holocene, ca. 9,000 cal. BP) as well as the early date (i.e. 8^{th} C AD) that hints at an incipient trade in Iberia, it seems likely that these life history traits might have been already altered since the early times of the fishery. It is crucial to determine when fishing pressure started to modify significantly hake life history.

4. In a similar manner, overfishing of the largest individuals eventually results in a "fishing down the food web" scenario with a replacement of large fish by smaller ones, typically set at lower trophic levels (TL), setting in (Pauly et al., 1998). Whereas the decrease in mean length (ML) and TL have both been associated with over exploited species, such trends might also be explained in terms of phenotypic plasticity or through long-term environmental shifts.

4- Research agenda

Understanding hake population structure and resilience is challenged by the shallow temporal window that existing fisheries data provides. From such standpoint it is fortunate that historical and archaeological data are finally being recognized as essential for understanding long-term impacts of sustained exploitation on fisheries productivity (Braje et al., 2017, Schwerdtner-Mañez et al., 2014). Historic landing records can nevertheless be inaccurate or incomplete, and are usually only available for the last few centuries. But, again, considering that marine fishing intensification in the NE Atlantic dates back to at least 1,000 AD (Barrett et al., 2004, 2011), historical information from a relatively recent past may already yield ecological baselines far removed from 'pristine' or pre-industrial (i.e. non-intensive) conditions (Pauly et al., 2005).

In order to explore the human impact on Iberian hake fisheries in the long-term, we are currently pairing zooarchaeological and biomolecular analyses on archaeological fish bones to construct a baseline. The idea responds to the *Hindcasting first to forecast after* approach to enhance our perception of hake biology and ecology to improve population management. In terms of the four issues that have been highlighted in section 3, no less than six problems need to be addressed:

1. Validity of fishing stocks. Given the historical pattern of catches and recruitment pulses, the distributional and connectivity shifts have likely occurred in the past due to climatic events. Genetic analyses on archaeological bones should reveal the metapopulation structure and connectivity fluctuations across centuries. The latitudinal gradient along which the northern and southern stocks are presently set suggests that differences to spawning cycles, temperature and other environmental factors might be expected to

have had their genetic signature in the genome. Even though hake is assumed not to have been intensively fished until recent times, archaeological specimens may reveal haplogroups no longer existing today as has been the case of salmon comparatively (Consuegra et al, 2002).

2. 20,000 years ago the European continental platform was ca. 40% larger due to the emergence of the continental shelves (Flemming et al., 2014). Under glacial scenarios, underwater features such as the Biarritz trench, may have constituted formidable barriers that prevented hake from moving northwards limitating gene flow between the putative northern and southern stocks. Indeed, and given that the southeastern most corner of the Gulf of Biscay was an extremely cold area during glacial episodes, few hakes could have ventured beyond the Galician shelf during cold pulses (Ibáñez, 1990). If such were the case, a northern stock of hake would be questionable. As for the Gulf Stream, fluctuations in strength during the Late Glacial-Early Holocene transition have been monitored through the European eel (*Anguilla anguilla*, L. 1758), evidencing that only after the onset of the Holocene can one detect a current of equivalent features to the one we presently know (Kettle et al., 2008). These various lines of evidence indicate that the genealogy of NE Atlantic northern hake stock could well have been a recent development connected to large/regional climatic scale and geomorphologic cycles. The putative existence of refugia, as well as of local genetic variants within both stocks, needs to be explored with archaeological remains incorporating the biomolecular signatures of that phylogeographic history.
3. Overfishing. Size-selective fishing has induced adaptive changes in recent years due to a high fishing mortality (Braje et al., 2017). However, the dimension of such changes is difficult to estimate as we lack the aforementioned "pristine" baselines that can be revealed through the definition of genetic diversity shifts through history.
4. Despite the aforementioned problems with otoliths, fish bone measurements provide estimates of mean standard and total lengths and weight. Combined with the screening of specific genes related to life history features, measurements may shed light on life history regime shifts and modifications in the resilience of hake in the past. If mean size has changed through time, the ensuing step would be to correlate the shift with specific biological parameters such as maturation age or else fishing technology and strategies through time.
5. Fishing-down-the-food-web. The estimation of length, coupled with bulk collagen (carbon and nitrogen) and single compound isotopic data (nitrogen), should hint at specific environmental or anthropic factors as well as data on trophic level trends through time. Bone bulk collagen isotopic data has the potential to differentiate the geographical provenience of fish in the same way muscle samples can do (Barrett et al. 2011; Orton et al. 2011; Carrera and Gallardo, 2017). This would allow one to infer the trade routes that hake followed to reach inland markets in the past (Star et al., 2017).
6. Lastly, the possibility that hake started to be fished in estuaries and other shallow-water ecotones of which the Galician *Rías* might serve as models, would hint at an ecological plasticity to penetrate brackish waters for which no parallel exists today. Such eco-physiological plasticity might have left "fossil" genomic signatures on whether or not prehistoric hake populations ventured into brackish waters. Milano et al. (2011) described an approach to discover SNPs in modern European hake to distinguish Atlantic and Mediterranean populations as well as to differentiate stocks within them. Despite some drawbacks, such as sampling only adults or the use of a non-normalized cDNA library of skeletal muscle, they found SNPs significantly correlated with water surface temperature and salinity, environmental variables that seem to modulate genetic adaptation in other teleost fish (Bradbury et al. 2010; Guo et al. 2015, 2016; Jones et al.

2012; Norman et al. 2012). This was not so strange because some years before Cimmaruta et al. (2005), studying hake allozymes, described a genetic structure in European hake with strong correlation with temperature and salinity values of surface water. Using those SNPs could help us understand the archaeological populations and the nature of the adaptive capacities of hake to paleoclimatic changes. Finally, it might be possible to additionally investigate the brackish water character of archaeological specimens through the isotopic composition (carbon, nitrogen and sulfur) of the bone collagen.

5-Concluding remarks

How hake, one of the most important commercial fishes of the NE Atlantic, arrived to a status of an overexploited stock in its southernmost range is a complex issue for which no single approach may suffice. The combination of several lines of enquiry appears as the most sensible option. With independence of the difficulties of properly defining what a fishery (vs. a casual fishing) is in archaeological terms, many issues remain at the level of the physical evidences that archaeozoology may help bring into focus. Among these: (i) whether hake was at some point a more accessible resource due to it inhabiting very shallow waters it no longer occupies, (ii) whether the species started indeed to be fished only during the Holocene, coinciding with a NE shift in the Gulf Stream, and (iii) whether this fishing was brought about by a mere rise of the sea surface temperatures and other parameters, are questions likely to be answered only by an in-depth combined study of the archaeological evidences, the paleochemistry of the bones in particular, and a systematic tracking of certain biomolecular signatures. The presence and absence of hake from the archaeological deposits of the Holocene may bear implications for turning the species into an unsuspected bioindicator of climatic conditions.

Cultural issues such as when can one place the moment when the species started to be fished in an intensive way to feed the market (i.e. a “fishery” proper) may likewise be explored by a combination of biomolecules (revealing whether specific haplogroups disappeared at specific times) and archaeozoology *sensu stricto* (i.e. radiocarbon dating the evidences of hake shipped inland and recording mean TL values through time). All these are questions bound to generate many others in turn. Among these, experimental work to check the organoleptic properties of processed hake, in particular for how long certain products last, might help explain why hake always remained an Iberian production and why processed hake vanished from sight more than one century ago.

It is hoped that this paper will foster the interdisciplinary effort that is required to tackle these issues. Even if only partial success is reached, the future of the hake fishery might look a little less bleak than the scenario we are presently facing.

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7-Footnotes

(1) A dearth also seen in the European *still life* pictures and other artistic depictions from the Medieval to the Contemporaneous Period (in progress).
(2) This may explain the failure to depict hake in pictures that was mentioned in footnote 1 given that most of the artists were living in the shores surrounding the North Sea where hake had a probably anecdotic presence throughout the Holocene (Bødker-Enghoff, 1999, 2000).
(3) The European Bronze Age and the Iron Age up until the Roman period bear witness to a pulsating deterioration of the climate.
(4) Several historical sources bear witness to a seasonal fishing of hake in northern Spain. J. Cornide (1788) mentioned that, during winter, hake were fished inside the Galician *Rías* (name given to the local fjords) whereas Graells (1870) reported that the most productive fishing in the Cantabrian Sea took place from December to April, hakes caught in May and June being of poor quality.
(5) With regard to precepts, one should be reminded of stepping permanently over slippery ground. At the Jewish site of *Castro de los Judíos* (province of León), for example, within a clearly *kosher* food spectrum, conger eel was documented (E. González and C. Fernández, unpublished). One reckons that the scale-less nature of the processed fish might have rendered lack of scales more difficult to detect but this is just wishful thinking. Perhaps Christians were present in that community, etc.
(6) Hake penetrates into the Galician *Rías* using the highly saline waters found on the lower parts of the water column yet swims upwards on a daily basis to feed, reaching the less saline -often brackish- waters found at the surface.

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FIGURE AND TABLE LEGENDS (TEXT)

Figure 1- Distribution of the European hake (*Merluccius merluccius* Linnaeus, 1758) in the North Eastern Atlantic (the higher the density the darker the colour). Map compiled by us taking into account data from several authors.

Figure 2A - Location of Pre-medieval Iberian sites featuring hake. 1- Lumentxa (Lequeitio); 2-Santimamiñe (Kortezubi); 3- Punta Atalaia (San Cibrao); 4-Casa Martelo, La Franja 9-11 y Rego da Auga (A Coruña); 5-O Neixón (Boiro); 6-O Achadizo (Boiro); 7-A Lanzada (Noalla); 8-As Hortas (Islas Cíes); 9-Montealegre (Moaña); 10-Muiño do Vento (Vigo); 11-Troia (Setubal); 12-Camposoto.

Figure 2B - Location of Medieval Iberian sites featuring hake 1-Tabacalera (Gijón); 2-Castillo de Curiel (Gijón); 3-Punta Atalaia (San Cibrao); 4-Area (Viveiro); 5-Castillo de Moeche; 6-Porto; 7-Torre de Hércules (A Coruña); 8-Castelo da Rocha Forte (Santiago de Compostela); 9-Taramancos; 10-Torres do Oeste (Catoira); 11-A. Malvar y Ponte do Burgo (Pontevedra); 12-San Martín de Moaña; 13-Castillo de Pambre; 14-Castro de los Judíos (León); 15-Catedral de Vitoria; 16-Castillo de Arganzón; 17-Castillo de Treviño; 18-Castillo de La Bastida; 19-Plaza de Oriente (Madrid); 20-La Pola (Calpe); 21-Oficina S. Carrilho (Loulé).

Figure 2C - Location of Post-medieval Iberian sites featuring hake: 1-Punta Atalaia (San Cibrao); 2-A Palma (Baiona); 3-Seminario (León); 4-Convento de Santa Clara (Oporto); 5-Plaza de Oriente (Madrid); 6-La Cartuja (Sevilla); 7-Atarazanas (Barcelona).

Figure 3 - Skeletal spectra of Medieval and Modern periods hake collections from inland sites

Figure 4 – Stacks with dried conger eel in Galicia.

Table 1- Mean hake contributions in Iberian deposits through time. (N: number of deposits; □$\bar{y}$: Contribution of hake per period, expressed as the pooled mean of hake %NISP (Number of Identified Specimens) in each of the sites for that period. Check tables A1-A3 (Appendix) for additional features regarding each individual sample.

Table 2- Mean hake contributions in Iberian inland and coastal deposits from the Middle and Modern Ages. (N: number of deposits; □$\bar{y}$: Contribution of hake per period, expressed as the pooled mean of hake %NISP (Number of Identified Specimens) in each of the sites for that period. Check tables A1-A3 (Appendix) for additional features regarding each individual sample.

TABLE LEGENDS (APPENDIX)

Table A1 – Iberian Prehistoric and Early Historic sites (NISP: Number of identified specimens; P: Production site; Consumption site).

Table A2 – Iberian Medieval sites (NISP: Number of identified specimens; P: Production site; Consumption site).

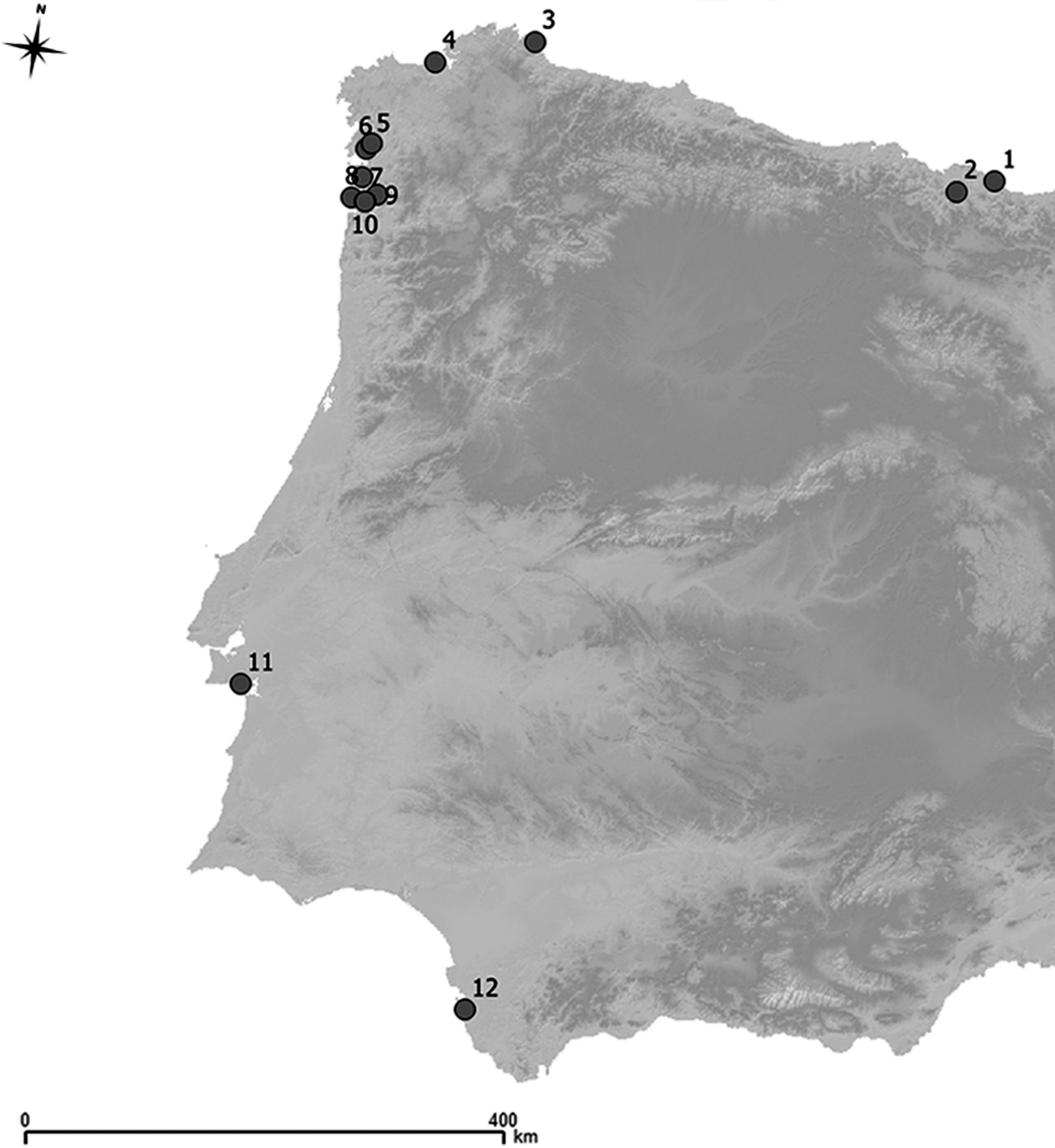
Table A3 – Iberian Post-Medieval sites (NISP: Number of identified specimens; P: Production site; C: Consumption site).

Table 1-

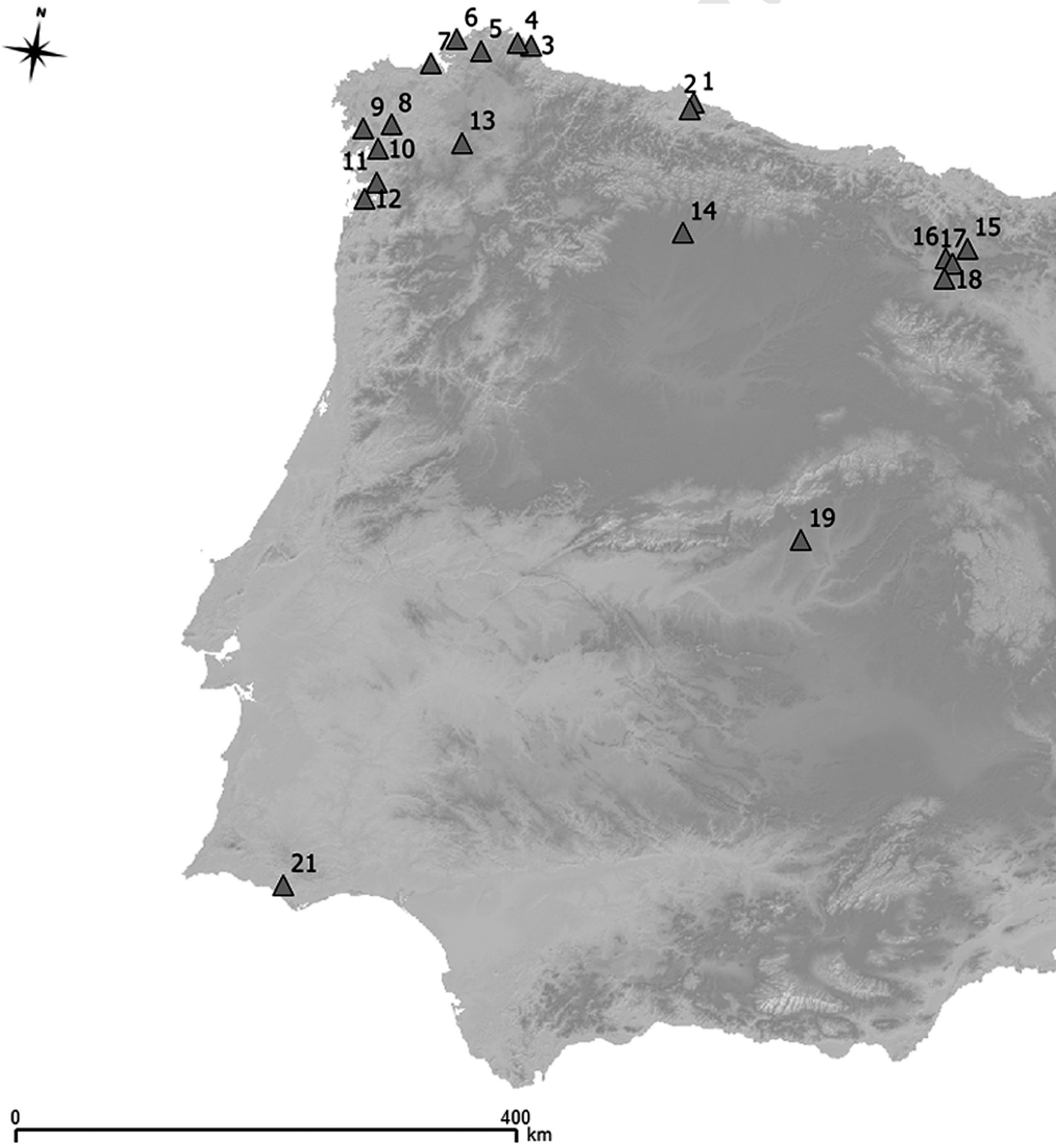
NEOLITHIC		BRONZE		IRON		ROMAN		MEDIEVAL		MODERN		TOTAL	
N	% (□ȳ)	N	% (□ȳ)	N	% (□ȳ)	N	% (□ȳ)	N	% (□ȳ)	N	% (□ȳ)	N	% (□ȳ)
2	43%	2	50%	8	6.7%	6	26%	22	40.8%	7	66%	47	35-37%

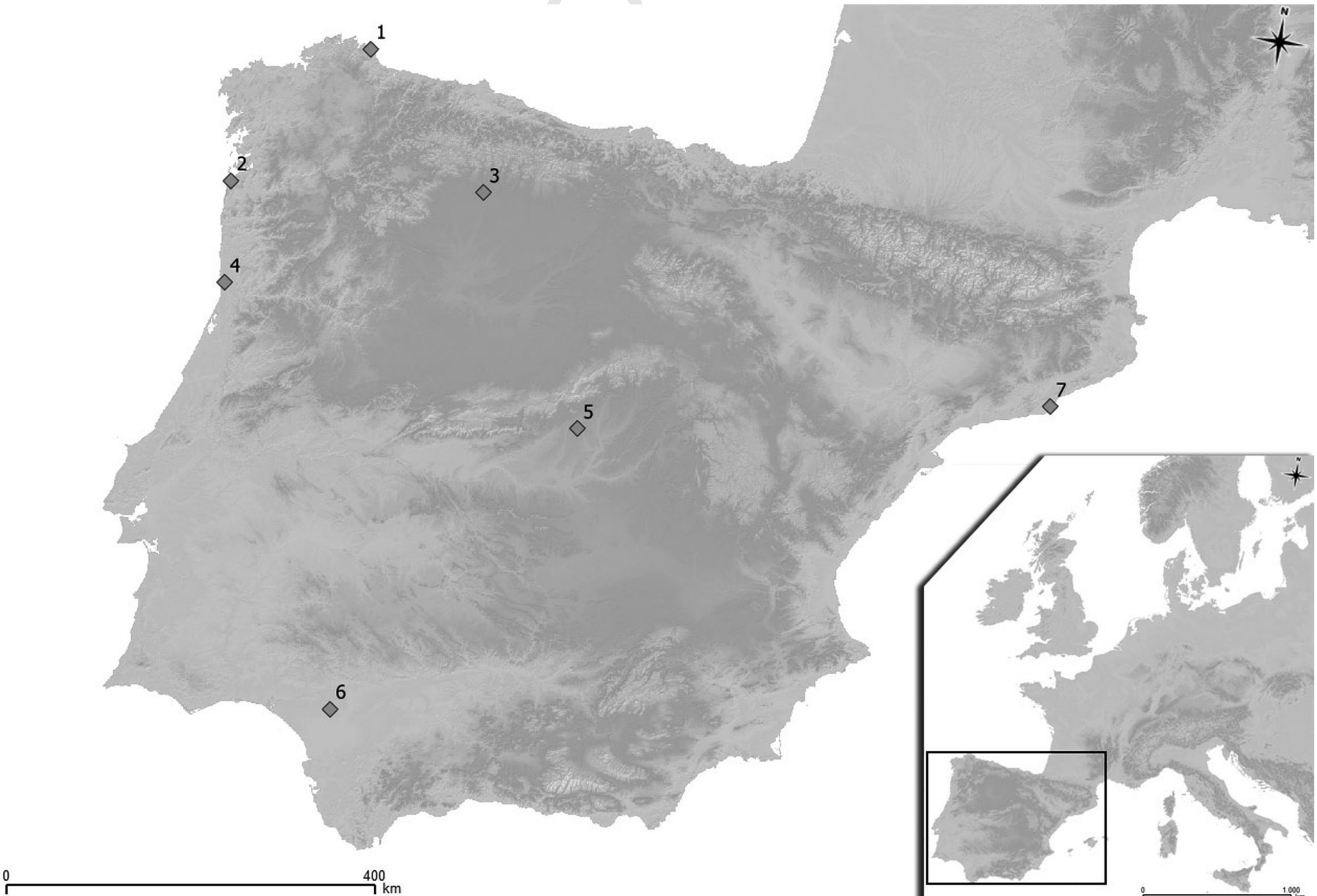
Table 2-

MEDIEVAL				MODERN			
INLAND		COASTAL		INLAND		COASTAL	
N	% (□ȳ)	N	% (□ȳ)	N	% (□ȳ)	N	% (□ȳ)
11	26.5%	11	55.2%	3	66%	4	66%



N
1
2
3
4
5
6
7
8
9
10
11
12
0
400
km


N
6
4
7
5
3
2
1
9
8
13
10
11
12
14
16
17
15
18
19
21
0
400
km


1
2
3
4
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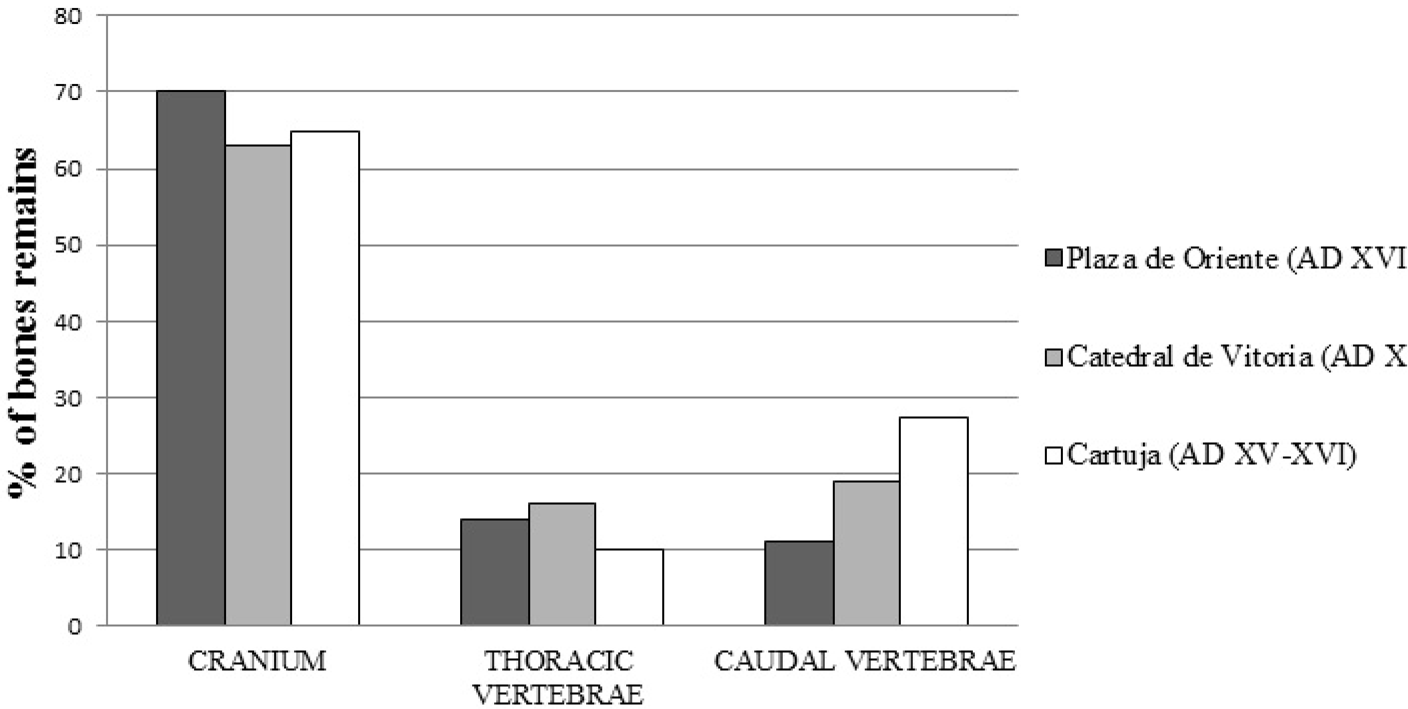
km



80
70
60
50
40
30
20
10
0
% of bones remains
CRANIUM
THORACIC VERTEBRAE
CAUDAL VERTEBRAE
Plaza de Oriente (AD XVI
Catedral de Vitoria (AD X
Cartuja (AD XV-XVI)

Highlights

1. Fisheries research traditionally addressed from a biological standpoint.
2. Such perspective is defective from a historical standpoint.
3. Increasing temporal depth of research fosters understanding of current problems.
4. A multidisciplinary research program for the European hake is presented.
5. Aim is to implement a model for a more correct management of hake stocks.