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An environmental (pre)history of European fishing: past and future archaeological contributions to sustainable fisheries

James H. Barrett^{1,2}

¹McDonald Institute for Archaeological Research, Department of Archaeology, Downing Street, Cambridge, CB2 3DZ, United Kingdom. [Tel. +44 (0) 1223 339287, e-mail, jhb41@cam.ac.uk]

²Trinity Centre for Environmental Humanities, Room A6 003 6th floor, Arts Block, Trinity College Dublin, College Green, Dublin 2, Ireland

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Abstract

This paper explores the past and potential contribution of archaeology to marine historical ecology. The primary focus is European fishing of marine and diadromous taxa, with global comparisons highlighting the wider applicability of archaeological approaches. The review illustrates how study of excavated fish bones, otoliths and shells can inform our understanding of: (a) changes in biogeography – including the previous distribution of ‘lost’ species; (b) long-term fluctuations in the aquatic environment (including climate change); (c) the intensity of exploitation/impacts; (d) trade, commodification and globalization. These issues are also relevant to informed fisheries conservation and/or management targets. Equally important, the long (pre)history of European fishing raises awareness of our ecological heritage debt – owed for centuries of wealth, sustenance and well-being, and for which we share collective responsibility. This debt represents both a loss and a reason for optimism, insofar as it is a reservoir of potential to be filled by careful stewardship of our rivers, lakes, seas and oceans.

Introduction

Marine historical ecology is an increasingly established approach to understanding past human impacts on aquatic ecosystems, and it provides an important guide to long-term ecosystem baselines for fisheries management and conservation efforts (e.g. Rick & Erlandson 2008; Pinnegar & Engelhard 2008; Holm et al. 2010; Schwerdtner Máñez et al. 2014; McClenachan et al. 2015; Thurstan et al. 2015; Engelhard et al. 2016; Schwerdtner Máñez & Poulsen 2016). Its toolkit is diverse, ranging from quantitative palaeoecology (e.g. time-series data regarding water temperature) to the qualitative assessment of anecdotal documentary sources and oral history (e.g. regarding the distribution, abundance and/or size of particular taxa). To date, the most extensive literature, and that most closely engaged with fisheries biology, has drawn predominantly on historical sources and thus relatively recent centuries – particularly the last 100 to 500 years. Yet archaeological remains of aquatic organisms harvested by humans in the past are potentially one of the most directly relevant sources, with the greatest potential time-depth. Much can be learned from fish bones, otoliths and shells, recovered from the coastal middens of fishers themselves and from the consumption waste of sometimes distant consumers (Fig. 1). These remains are very informative even in the absence of other evidence. When they

coexist with contemporary textual records, the potential of interdisciplinary research is greater still. Thus, although it focuses mainly on archaeology, this paper does not draw a fundamental distinction between marine historical ecology based on written and archaeological sources.

At the most fundamental level, archaeology provides a unique window onto the challenging problem of demonstrating very long-term changes in ecosystem baselines (Jackson et al. 2001; Orton 2016). Ecological conservation and restoration initiatives rest on the aspiration to move degraded ecosystems in the direction of ones that are undisturbed by humans. But what is 'undisturbed' when, for example, a fishery has been industrially exploited since before the advent of fisheries statistics, and commercially exploited for centuries before that (Barrett et al. 2004a; Pinnegar & Engelhard 2008; Thurstan et al. 2015)? And what level of variability existed within the 'natural' state, due to long-term environmental fluctuations, including climate change (Jackson & Hobbs 2009; Alagona et al. 2012)? In many instances these questions may only be answerable using archaeological and related palaeoecological evidence.

The distinctive potential of archaeology does not, however, come without challenges. Although surviving fish bones, otoliths and shells exist for longer than historical records, their distribution is discontinuous across time and space. Ironically, the archaeological record is often least comprehensive for recent centuries. Systematic waste disposal became widespread in early modern times and (although this is changing) archaeological research has traditionally been focused on the distant past. In meta-analyses of archaeological fish bones from York and London in England, for example, there was little data post-dating 1600 CE and 1900 CE respectively (Harland et al. 2016; Orton et al. 2016; 2017). Thus the integration of archaeological and historical evidence must sometimes bridge a knowledge gap, making cross-calibration of the different sources difficult.

It can also be problematic to know what archaeological fish bones, otoliths and shells represent, as is well-rehearsed within the specialist field of zooarchaeology. As a proxy for natural populations, fish bone assemblages have been filtered by human choices (e.g. Ervynck 1997; Barrett & Richards 2004), fishing-gear selectivity (e.g. Owen 1994; Plank et al.

2018), non-human piscivores (e.g. Nicholson 2000; Russ & Jones 2011), and by a myriad of other preservation factors (e.g. Butler & Chatters 1994; Nicholson 1996; Russ 2013). This proxy is further affected by how comprehensively the bones were recovered during excavation (e.g. Partlow 2006; Enghoff 2016), how precisely the remains were identified after excavation (e.g. Wouters et al. 2007; Nikulina & Schmölcke 2016) and how the data were quantified (Lyman 1994; Nicholson 1996; Domínguez-Rodrigo 2012). Universal archaeological concerns about preservation and recovery are particularly acute for fish remains (Wheeler & Jones 1989; Reitz & Wing 2008). Otoliths, for example, are unusual finds in all except alkaline and/or waterlogged burial environments (Van Neer et al. 2002; Disspain et al. 2016). In very aggressive (e.g. acidic) burial environments even bones may not survive, although the taphonomic pathways to complete destruction are complex and variable (Nicholson 1996; Collins et al. 2002). Thus regions with acid soils, including the interior of peninsular Scandinavia for example, yield archaeological fish bones only in special circumstances. Moreover, unless sediment is sieved using fine mesh, larger fish bones will be preferentially recovered compared to smaller bones. Sieving is now becoming commonplace across Europe, but it is a recent development in many countries so data quality remains uneven.

Preserved fish or fish products were also sometimes traded or transported over great distances (e.g. Barrett et al. 2011; Star et al. 2017). Trade is of great archaeological and historical interest in itself – and may have ecological significance as either a consequence or cause of resource depletion – but it means that species distributions must be interpreted with caution. A selection of early examples include finds of Nile perch *Lates niloticus* (Linnaeus, 1758) in Bronze Age Hala Sultan Tekke on Cyprus (Van Neer et al. 2004), of barracuda *Sphyraena sphyraena* (Linnaeus, 1758) at Roman Nijmegen in the Netherlands (Enghoff 2000) and of north African catfish *Synodontis* and Atlantic chub mackerel *Scomber colias* Gmelin, 1789 (originally published under the synonym Spanish mackerel) in Roman deposits in England (Locker 2007). Less straightforward are bones of species that do occur in local waters but may nevertheless represent fish traded over long distances; dried cod *Gadus morhua* Linnaeus, 1758 and salted herring *Clupea harengus* Linnaeus, 1758 are examples from medieval and post-medieval Europe (see below).

Lastly, in the past it has been variable to what degree archaeological data regarding fish bones and shells could be systematized and brought into the public domain.

Archaeoichthyology is unusual and highly specialized research, kept alive by a very small number of expert enthusiasts in diverse professional contexts. Many of these researchers are supported commercially by rescue archaeology, with the funded end-product being an archival report that may or may not be publically accessible. It is to the enormous credit of this community that archaeological fish bone research is done and published, and that formal consortia (e.g. the Fish Remains Working Group of the International Council for Archaeozoology; the Oceans Past Northern Seas Synthesis of the COST Action Oceans Past Platform) are acting to realize its potential. Overall, fish remains represent both a critically important source for marine historical ecology *and* one that has been underutilized due to a diversity of challenges.

In overcoming these challenges (e.g. Nicholson 2000; Nims & Butler 2018), we are cautiously learning more about the environmental (pre)history of sea fishing in Europe and globally – yielding insights that are of direct relevance to sustainable fisheries today. This paper aims to provide a brief overview of the potential for archaeological analyses to inform our understanding of: (a) changes in biogeography – including the previous distribution of ‘lost’ species; (b) long-term fluctuations in the aquatic environment (including climate change); (c) the intensity of exploitation/impacts; (d) trade, commodification and globalization. It draws predominantly on examples regarding marine and diadromous fish in Britain and elsewhere in Europe, reflecting the research focus of the author. Global comparisons have been included where methodologically pertinent and it is hoped that the paper’s thematic observations will be of general relevance.

Biogeography

One of the most straightforward and important roles of fish remains in marine historical ecology is demonstrating changes in biogeography – due to anthropogenic drivers such as overfishing and habitat loss, to natural drivers such as prehistoric climate change, or a combination of both. For example, both archaeological and historical data show temporal changes (major reductions) in the distribution of anadromous fish such as sturgeon (*Acipenser*) and salmon *Salmo salar* Linnaeus, 1758 in the rivers around the North Sea

(Desse-Berset 2011; Lenders et al. 2016; Nikulina & Schmölcke 2016; Thieren et al. 2016). In the case of sturgeon, comparison of past and present further demonstrates that both *Acipenser sturio* Linnaeus, 1758 and *Acipenser oxyrinchus* Mitchill, 1815 once occupied European waters.

Reintroduction efforts are now unfolding for both sturgeon and salmon in European waters. History alone could justify elements of this conservation policy, insofar as declines are demonstrable even within the 19th and 20th centuries (Lotze & Worm 2009; Dickson & Pinnegar 2010; Nikulina & Schmölcke 2018). However, only archaeological evidence revealed the long-term presence of an extirpated sturgeon species, and the study of excavated fish bones has helped demonstrate that the distribution of anadromous fish had already been affected by habitat reduction (via dam building, for example) in the Middle Ages. For salmon, the convergence of historical and fish bone evidence has been particularly revealing (Lenders et al. 2016). These studies employing archaeological and historical evidence indicate that baselines necessary for informed targets in ‘rewilding’ the rivers around the North Sea need to go back much further than currently anticipated, requiring approximately a millennium to see systems without significant human impact.

Of fish with at least partly marine life histories, anadromous and catadromous taxa show the clearest patterns of long-term anthropogenic changes in biogeography, based on both archaeological and historical evidence (e.g. Clavero & Hermoso 2015; Lenders et al. 2016; Thieren et al. 2016). Freshwater fish, also susceptible to human impacts on bounded aquatic ecosystems, reveal similarly stark extirpations. Burbot *Lota* (Linnaeus, 1758), for example, was once present in the Thames or one of its tributaries based on the fish bone record (Coy 1989), despite having no such record in the National Biodiversity Network database (NBN Atlas website at <http://www.nbnatlas.org> Accessed 10 July 2018). This species is considered extinct in Britain, at least partly due to water pollution (Worthington et al. 2010).

Shifts in the biogeography of fully marine fish are less absolute, but no less important when observed. Haddock *Melanogrammus aeglefinus* (Linnaeus, 1758), for example, must once have been common in the coastal waters of the southern North Sea (Beerenhout 1994; Holm 2005). Its present scarcity can be attributed to fishing pressure and benthic habitat

alteration. In comparative perspective, a meta-analysis of the archaeological fish bone record from the northwest coast of North America concluded that modern range contractions and fluctuations in the distribution of Pacific herring *Clupea pallasii* Valenciennes, 1847 may be a result of industrial fishing (McKechnie et al. 2014). The taxon's distribution was more widespread and predictable in the distant past.

In other instances, shifts in marine species distributions serve as proxies for climate change. For example, the climatic significance of the recent abundance of anchovies *Engraulis encrasicolus* (Linnaeus, 1758) in Danish waters is made clear by knowledge that this species is otherwise only evidenced in the Mesolithic, during the Atlantic warm period (Enghoff et al. 2007; Enghoff 2016; Fig. 2). Archaeological examples of other warm-water taxa are also known at surprisingly high latitudes. Bones of seabream taxa (*Pagellus bogaraveo* (Brünnich, 1768) and perhaps also *Spondyllosoma cantharus* (Linnaeus, 1758)), now mainly restricted to the south coast of the UK, have been found in Orkney, especially during the Viking Age (9th-11th century CE) (Barrett et al. 1999) within the period of comparatively warm air and seawater temperatures known as the Medieval Climate Anomaly (e.g. Asteman et al. 2018). Discoveries like these provide a window onto possible future changes in fish distributions, in the context of anthropogenic global warming. In methodological terms these unanticipated finds also illustrate the potential for palaeoclimatic meta-analysis of the archaeological fish bone record. As the evidence-base grows it will be increasingly possible to reveal past (and thus infer future) climate-driven shifts in the distribution of multiple fish taxa. A similar approach has been used to track changes in the salinity of the Baltic Sea through time (Schmölcke & Ritchie 2010).

Long-term changes in the aquatic environment

With these last examples the discussion of biogeography has merged into a consideration of fish remains as proxies for long-term changes in the aquatic environment. Evaluating the presence and absence of indicator species – be they susceptible to changes in temperature, salinity or water pollution – is clearly one relevant approach. However, it is also possible to measure parameters of the aquatic environment through direct biomolecular analysis of fish remains. The most common approaches are ancient DNA (aDNA) and stable isotope analysis.

As in all aspects of archaeology, aDNA is poised to play an increasing role in marine historical ecology. Changes in the aquatic environment, especially temperature, have already been inferred. For example, shifts in the genetic structure of cod in Icelandic waters during the 15th and 16th centuries CE have been attributed to climatic cooling (Ólafsdóttir et al. 2014). The power of this kind of analysis will only increase as temperature-selective SNPS (single nucleotide polymorphisms) and other genomic signatures of cold-water ecotypes continue to be identified in modern fish populations (Bradbury et al. 2010; Star et al. 2017; Lait et al. 2018). Changing salinities may also be traceable based on analysis of adaptive genomic architecture (Berg et al. 2015; Barth et al. 2017).

To date, however, stable isotope methods (also common in modern fisheries ecology) have been most used – to provide proxies for changes in water temperature, salinity, nutrient sources and food web complexity (trophic level). When measured sequentially on incremental growth structures such as otoliths or mollusc shells, they can provide such proxies within the lifetime of a single animal. Studied across multiple otoliths, fish bones or shells, stable isotopes can track environmental changes over centuries or millennia (Misarti et al. 2009; Disspain et al. 2016; Butler & Schöne 2017).

Continuity and change in water temperature has been inferred from oxygen isotope analysis. In an example using oxygen isotope analysis of mollusc shells of 10th-12th century CE date from Orkney in Scotland, Surge and Barrett (2012) deduced that the Medieval Climate Anomaly may have been associated with both warmer summer sea surface temperatures and higher seasonality. In another study, this one using cod otoliths from Arctic Norway, researchers observed a decrease in water temperature in the 17th century CE, during the Little Ice Age (Geffen et al. 2011; Fig. 3). Intriguingly, an Icelandic study of growth patterns in archaeological otoliths of the same date shows a reduction in juvenile cod growth; this too may imply cooling (Ólafsdóttir et al. 2017). Research of these kinds has now become widespread, with ongoing methodological refinement (Disspain et al. 2016; Butler & Schöne 2017). Combined with biogeographic information, this work is providing a stronger foundation for inferences regarding climatic impacts on fish and fishing in the past, with implications for modelling the future.

From an archaeological point of view, intra-annual fluctuations in oxygen isotope values within incremental growth structures also facilitate an assessment of the age and seasonality of seafood harvesting (e.g. Hufthammer et al. 2010). This information is of considerable significance for interpreting past socioeconomic practices, but also has ecological implications – vis-à-vis the age of sexual maturity and time of spawning, for example – if fish were caught consistently before reproducing. Many fisheries of the past targeted spawning migrations and aggregations. In the case of once superabundant taxa (e.g. cod and herring), this practice may or may not have had detectable biological outcomes (e.g. fisheries-induced evolution or resource depletion) in premodern times. For anadromous fish, conversely, the threat may have been greater. One must ask, for example, whether mill dams were the only factor influencing the reduction of salmon in medieval European rivers (cf. Lenders et al. 2016). Fish traps designed to target upriver migrations (Murphy 2009) may also have played a role, by both direct mortality and preventing successful spawning.

We do not yet have good age and seasonality data directly from excavated salmon remains. Otoliths of this species are seldom recovered from archaeological deposits. However, the method of isotope analysis has been successfully applied to incremental growth structures in the vertebrae of masu salmon *Oncorhynchus masou* (Brevoort, 1856) from Japan (Matsubayashi et al. 2017). The resolution of this method may never be sufficient to determine season of catch, but it can reveal important life-history information of relevance to reproductive success, including whether or not individual fish made multiple migrations between freshwater and the sea.

Stable isotope analysis is also widely used to provide a proxy for changes in nitrogen source (including land-derived nutrients) and food web complexity in aquatic ecosystems. The relevant archaeological remains include bones of fish and fish-eating taxa such as seabirds and marine mammals (Bailey et al. 2008). At its most basic, bulk nitrogen isotope analysis ($\delta^{15}\text{N}$) of organisms near the base of the food web can serve as a proxy for temporal and/or spatial variability in nutrient inputs (including that from anthropogenic landscape change and pollution) and nitrogen fixation. Animals of higher trophic level also carry this signal,

combined with information regarding their trophic level given the increase of $\delta^{15}\text{N}$ from prey to consumer. In food web analyses, nutrient source/nitrogen fixation and trophic level can be disentangled empirically by comparing bulk analyses of different taxa and/or by stable isotope analysis of single amino acids (e.g. Jennings & Warr 2003; Layman et al. 2012; Ramos & González-Solís 2012; Ostrom et al. 2017; Trueman et al. 2017).

In Europe, nitrogen isotope studies of archaeological fish bones have thus far been more important in establishing continuity within major water bodies (and thus the efficacy of stable isotope signatures for sourcing the origin of traded fish products – see below) than in demonstrating temporal change (e.g. Barrett et al. 2008; Barrett et al. 2011; Hutchinson et al. 2015). However, this view of long-term stability is being nuanced as comparisons begin to include post-industrial archaeological and modern remains. For example, a mid-20th century decrease in $\delta^{15}\text{N}$ has been observed in a study of (fish-eating) harbour porpoise *Phocoena phocoena* (Linnaeus, 1758) remains from the southern North Sea dating between 1848 and 2002 (Christensen & Richardson 2008). This discovery could imply either a change in nitrogen source at the base of the food web or a reduction in the trophic level of available prey – fishing down the food web.

An example from the Pacific Ocean using stable isotope analysis of single amino acids illustrates how this ambiguity is being overcome. Employing bones of the fish-eating Hawaiian petrel *Pterodroma sandwichensis* (Ridgway, 1884) as their proxy, Ostrom et al. (2017) used amino-acid-specific $\delta^{15}\text{N}$ analysis to differentiate the roles of changing nitrogen sources and trophic level in the isotope signatures of the Pacific food web over the last millennium. Results show it was possible to infer a recent drop in trophic level (rather than a change in nitrogen fixation) that may be attributable to industrial fishing. Amino-acid-specific $\delta^{15}\text{N}$ analysis is an emerging field with its own methodological challenges (O’Connell 2017), but one with considerable potential.

Intensity of exploitation/impact

When nitrogen source and trophic level can be differentiated, as in the Hawaiian petrel study just discussed, isotope ecology using archaeological remains clearly serves as one proxy for the intensity of fish exploitation and potential human impacts on aquatic

ecosystems. Interpreted with caution, other parameters of excavated material can also illuminate these issues. Important examples include shifts in target species and changes in fish size, age and/or growth rate. Fluctuations in the role of fish protein in human diet (as assessed from stable isotope analysis of human bone) may similarly indicate trends in the intensity of fishing. Lastly, losses of genetic diversity, as inferred from DNA, may provide evidence of human impacts on fish populations.

Shifts in target species, a classic symptom of serial depletions in modern times (Pitcher & Lam 2015), are characteristic of some archaeologically fish bone data. This phenomenon can unfold in differing ways. One is a trend towards use of lower trophic level taxa, in a process that may imply fishing down the food web. In a now-classic case study, Reitz (2004) argued, based on taxonomic patterns within fish bone evidence, that colonial overfishing of mullets and sharks in 17th- and 18th-century Florida reduced the trophic level of what had been a sustainable pre-contact fishery. European applications of this taxonomy-based approach to inferring trophic level and fishing down the food web have been cautious because of the many sources of variability that characterize archaeological fish bone data – and ontogenetic trophic-level changes within fish of a single species (Morales & Roselló 2004). The value of the method may increase, however, if taxonomic patterns in archaeological material can be evaluated concurrent with trophic-level assessments based on stable isotope analysis.

Past shifts in target species have also entailed a transition from freshwater and/or diadromous fish to fully marine taxa. A reorientation of fishing effort of this kind has been thought to characterize much of Britain and some other areas of northern and western Europe in the decades around 1000 CE – the so-called ‘fish event horizon’ (Barrett et al. 2004b). What was first recognized as a rapid transition is now known to exhibit regional variability, but the general trend remains evident (Barrett 2016; Orton et al. 2017). Opinion differs regarding the causes. Overfishing and habitat reduction have been blamed for impacting the availability of freshwater and migratory fish (Hoffmann 1996; Barrett et al. 2004a; Lenders et al. 2016). Alternatively, social and economic changes have been implicated (e.g. Fleming 2001; Barrett & Richards 2004; Kowaleski 2016; Reynolds 2016; Van Neer & Ervynck 2016). All these factors are potentially inter-related (Barrett et al. 2004a;

2011; Barrett 2016). The argument for or against overfishing hinges in part on how one interprets the discovery that (in London) freshwater fish did continue to be caught – in increasing numbers – in the years after 1000 CE, concurrent with the increase of marine fish (Orton et al. 2017). One plausible interpretation is that wild freshwater fish *were* under pressure by the turn of the 10th and 11th-centuries CE, with increasing catches thereafter due to increased effort despite decreasing availability. This interpretation is justified by historical evidence for the emergence of an increasingly elite monopoly on freshwater fish consumption and of a new emphasis on aquaculture to meet this aristocratic demand (Dyer 1988; Serjeantson & Woolgar 2006; Woolgar 2010). It is also supported by a reduction in the size of freshwater and diadromous fish species consumed in York, England, during the 11th century CE (Harland et al. 2016).

This last observation leads discussion to studies of fish size, age and growth rate. When diachronic trends in growth have been studied it is typically clear that fish reached larger sizes and/or older ages in pre-industrial times than is observed today (e.g. Hales & Reitz 1992; Limberg et al. 2008; Betts et al. 2014; Turrero et al. 2014). Although environmental factors will have played a role, especially in growth *rates* as inferred from incremental growth structures (e.g. Van Neer et al. 2002; Ólafsdóttir et al. 2017), it is inescapable that radical changes in size distributions between the distant past and the present highlight the impact of modern industrial fishing. To provide one example (although allowances must be made for all the filters of archaeological fish bone evidence) the difference is striking between the total length distributions of cod from the modern North Sea and from carefully sieved medieval archaeological deposits in Britain. During a sea-fishing boom of the 11th-12th centuries CE, the mode of cod total length estimates for excavated fishing settlements in Orkney, northern Scotland, is typically greater than 80cm (Barrett et al. 1999; Harland & Barrett 2012). In 11th- to 13th-century York, England, the mode of estimated total lengths for cod is smaller at between 50cm and 80cm (Harland et al. 2016). Nevertheless, both of these examples far exceed the modal size of cod in the North Sea (15-30cm total length) as determined by International Bottom Trawl Surveys conducted in modern times (e.g. Speirs et al. 2010; Fig. 4). Temporal shifts in fish size distributions *within* the archaeological record may also reveal human impacts on aquatic ecosystems – implying sequential removal of the largest individuals (e.g. Plank et al. 2018).

Nevertheless, one must exercise caution when interpreting archaeological fish size evidence. In some instances changes in the estimated length of fish harvested may relate to social and economic factors unrelated to the characteristics of the prey population. The most plausible cases of prehistoric or medieval overfishing in European waters involve freshwater and diadromous taxa. Within a given watershed they are inherently more vulnerable to human exploitation than marine fish. Thus we see – importantly given debate regarding the causes of the ‘fish event horizon’ – that both pike *Esox Lucius* Linnaeus, 1758 and eels *Anguilla anguilla* (Linnaeus, 1758) declined in length in medieval York, with the observable reduction having occurred in the decades around 1000 CE (Harland et al. 2016). Cases regarding marine fish are more equivocal. In coastal and island northern Scotland, for example, a shift from large to small cod family (Gadidae) fish in the 13th-15th centuries CE was not caused by overfishing. On the contrary, it was associated with a reduction in fishing intensity and a shift to coastal fishing methods – driven by socio-economic and demographic crises (Harland & Barrett 2012; Barrett 2012). Thus archaeological examples of declining fish size through time (e.g. Jackson et al. 2001) may have multiple explanations, even if methodological factors such as excavation recovery methods are controlled for.

This is an important caveat, but despite the complexities of archaeological interpretation, meta-analysis of long-term trends in fish size has the potential to provide a key indicator of changing ecological baselines. The survival of large fish in a marine ecosystem is formally recognized as an indicator of Good Environmental Status – within the EU Marine Strategy Framework Directive (MSFD) for example (Modica et al. 2014; Engelhard et al. 2015). One definition of the “Large Fish Indicator” used in assessments of the North Sea is the “proportion of fish greater than 40 cm length in bottom trawl surveys” (Engelhard et al. 2015). Archaeological fish bones do not derive from bottom trawling, but empirical or modelled comparisons with catches using relevant gear (e.g. hook and line for many pelagic fish) can and should be attempted (cf. Plank et al. 2018).

The intensity of exploitation can also be explored using modern and ancient DNA. Estimating changes in effective population size is one approach, although interpretation is not always straightforward vis-à-vis environmental and anthropogenic drivers (Ólafsdóttir et

al. 2014; cf. Roman & Palumbi 2003). DNA analysis of archived otolith samples has been used to raise the possibility that local populations of even a widely and contiguously distributed species can be eradicated by fishing pressure. For example, Hutchinson et al. (2003) argue that between 1954 and 1998 the Flamborough Head population of cod was eliminated through reduced spawning stock biomass and in-migration of genetically distinct fish stocks.

Detecting early fisheries-induced evolution is another promising line of inquiry (Heino et al. 2015). It has been observed from optical study of otoliths, for example, that the growth rate of juvenile North Sea plaice *Pleuronectes platessa* Linnaeus, 1758 increased incrementally between the 15th and 20th centuries (Van Neer et al. 2002). It is not possible at present to say whether this resulted from environmental change, density-dependent growth (in the context of increased mortality from fishing) or fisheries-induced adaptation for faster maturation. The possibility of fisheries-induced evolution has also been raised to explain discovery of a reduction in mean body size for age between archaeological (Upper Palaeolithic) and modern salmon and trout *Salmo trutta* Linnaeus, 1758 from the Iberian Peninsula (Turrero et al. 2014). In this example, the potential role of selection for smaller size could not be differentiated from poorer growth caused by environmental change. It is in suggestive but ambiguous contexts such as these that aDNA may come to play a complementary and pivotal role.

The intensity of fishing can also be inferred using indirect archaeological evidence. The possibilities are diverse, ranging from documenting increasing harvests of shellfish for bait (Milner & Barrett 2012) to assessments of the role of marine protein in human diet based on stable isotope analysis (Barrett & Richards 2004). The latter method is now both routine and powerful, being used for studies of subsistence, economic and social differences within and between human societies (Britton 2017). It has also substantiated major temporal shifts in the importance of marine resources. British examples include a relative turn from the sea at the onset of agriculture in the Neolithic (Richards & Schulting 2003; Milner et al. 2004) and the 'fish event horizon' of the Middle Ages (Müldner 2016). The method may not, however, be sufficiently precise to use in isolation. Trends in the consumption of marine fish

that are known from zooarchaeological and historical records sometimes remain undetected based on stable isotope data from human skeletal remains (Ervynck et al. 2014)

Commodification & Globalization

It is widely recognized that commodification and globalization are critical factors in expanding the range, depth and severity of human impacts on marine ecosystems (see Pitcher & Lam 2015). It is also increasingly acknowledged that these developments are not unique to post-industrial times (Roberts 2007; Pinnegar & Engelhard 2007; Fagan 2017). Very large-scale commercial fisheries existed in the distant past, often spatially far removed from consumers in areas of urbanism and high population density.

In a European setting, this kind of ecological globalization is clearly evident within the Roman world. Fish sauces (e.g. *garum* and *hallex*) and *salsamenta* (salted fish) were traded across the Empire from large coastal factories, especially those around the Mediterranean and Atlantic coasts of the Iberian Peninsula. Fish sauces are observable archaeologically, from the remains of ceramic amphora in which they were transported and the fish bones of exotic species sometimes found in them (Van Neer et al. 2010). Traded *salsamenta* is also recognizable from finds of fish bones of taxa outside their southern European range. Van Neer et al. (2010) tabulated 35 examples – the northernmost being five finds of Spanish mackerel from Roman sites in Britain.

Fishing and fish trade declined in most areas of post-Roman Europe, to increase again around the end of the 1st millennium CE (Barrett 2016; see above). The decline is evident mainly from archaeological evidence. The increase is known from both archaeology and history – with textual sources becoming increasingly important through time. From c.1000 CE we can begin to reconstruct the outline of an inexorable process of ecological globalization, in which increasing demand for preserved marine fish was partly served by trade from distant waters. Two species, herring and cod, provide illuminating examples. At the time of the Domesday Book (1086 CE), it is estimated (from this historical source) that the eastern English catch of herring exceeded 3,000,000 fish (Campbell 2002). It has been argued that many were already being traded to Continental Europe for wine – as is historically demonstrable by the 13th century (Barrett 2018). By the 15th century, the North

Sea and (particularly) Øresund export trade of preserved herring had reached c.35,000 metric tonnes, more than the contemporary Anglo-French wine trade (Holm 2016). The best years of the medieval Øresund fishery actually produced catches two or three times greater than those documented in the early 20th century.

Concurrently, the medieval trade of dried cod (stockfish) from Arctic Norway to towns around the North and Baltic Seas probably reached c.6000 metric tonnes (equivalent to c.25,000 metric tonnes of wet fish) based on customs records (Nedkvitne 2016). The stockfish trade had expanded to include Iceland already in the 13th-14th centuries (Vésteinsson 2016), and in the years around 1500 a salt-cod fishery began in Newfoundland (Candow 2009a). Historical sources show the remarkable scale of this preindustrial development. Already in the 16th century, the Newfoundland fishery is thought to have involved 350-380 European ships and 8,000-10,000 men. It may have produced 200,000 metric tonnes (wet weight) of cod (Pope 2004; Candow 2009b). Cod bones from fishing settlements, such as Red Bay in Labrador and Ferryland in Newfoundland (Betts et al. 2014), document the catches themselves. The preserved fish were consumed in European centres, with the specific markets for Norwegian, Icelandic and Newfoundland products differing through time (Jones 2000; Candow 2009a; Nedkvitne 2014; da Silva 2015).

Although the late-medieval and subsequent apogee of these developments is mainly known from historical documentation, archaeology plays a role in illuminating their reach. For example, based on stable isotope and aDNA analysis, preserved cod of North Atlantic (e.g. Icelandic) and possibly Newfoundland origin was discovered on the wreck of the Mary Rose (1545 CE) in England (Hutchinson et al. 2015). Cod of North Atlantic origin has also been discovered during excavations of deposits associated with enslaved Africans in the Caribbean – illustrating another important (and tragic) aspect of globalization (Klippel 2001)

It is in revealing the *origins and early growth* of long-distance fish trade that archaeology comes into its own. In particular, it was previously unknown when the long-range trade of North Atlantic cod had begun. Research using a combination of stable isotopes, aDNA and more traditional zooarchaeological studies of taxonomic and anatomical patterning in fish bone assemblages has helped solved this puzzle. The earliest long-range transport of Arctic

Norwegian stockfish can now be traced to Haithabu, Germany – an important Viking Age (9th-11th-century CE) trading centre, then part of the Danish kingdom (Star et al. 2017; Fig. 5).

Traditional zooarchaeological evidence (taxonomic and anatomical representation) and stable isotope provenancing show that this trade subsequently expanded around the North and Baltic Seas, especially in the 13th century (Barrett et al. 2011; Orton et al. 2011; Orton et al. 2014; Barrett 2016). Archaeological evidence then merges with what is known from historical sources. Increasing demand in the late Middle Ages led to the emergence of salt-cod fisheries in south-west England (Kowaleski 2016), western Ireland (Breen 2016) and off Iceland (Jones 2000; Gardiner 2016). Following the discovery of Newfoundland in 1497, the process of ecological globalization quickly spanned the North Atlantic (Candow 2009a; 2009b).

In methodological terms, archaeological research demonstrating the trade of a widely distributed species such as cod depends on recent advances in aDNA analysis (e.g. Boessenkool et al. 2017; Star et al. 2017) and the creation of baseline isoscapes to which stable isotope data from archaeological specimens can be compared (Barrett et al. 2008; 2011; Hutchinson et al. 2015). Early developments in the isotopic provenancing of fish emerged from within archaeology, but are now being augmented greatly by isotope ecologists to trace predator migration and to source marketed fish products (e.g. Trueman et al. 2017; St. John Glew et al. 2018). The resulting methodological advances are likely, in turn, to enhance archaeological studies of fish trade – and of long-term anthropogenic and environmental impacts on the aquatic environment (see above).

Discussion

How can studies of marine historical ecology based on archaeological fish bones enhance the sustainable use and exploitation of fishes? First, we can come to know that the magnitude, spatial reach and antiquity of human fishing pressure is even greater than text-based historical ecology has revealed. In particular, understanding the millennial time depth of commercial fishing and commodification alerts us to the possibility that the earliest anecdotal historical baseline data (to which we are wisely turning as a complement to 20th-

century fisheries statistics) will measure populations that were already exploited. The potential of undisturbed (and recovering) ecosystems may thus exceed our greatest expectations. This is reason for optimism, even accepting that fisheries-induced evolution and fisheries-environment interactions (relating to climate change and prey availability, for example) may reduce the capacity and/or rapidity of recovery (Dunlop et al. 2015; Rose & Rowe 2015).

Second, observations from archaeology can provide data of direct relevance to contemporary conservation and fisheries management objectives. Examples include information about the former range, size and genetic diversity of species, which inform our understanding of biogeography, fluctuations in the aquatic environment and the intensity of exploitation. Genetic diversity may not be recoverable, but reintroductions (of anadromous fish, for example) and careful management can aspire to Good Ecological Status based on indicators such as biodiversity and size distributions (e.g. Modica et al. 2014). As discussed by Alagona et al. (2012), it is sometimes asserted that (pre)historic baselines are unachievable or irrelevant to contemporary conservation objectives. I would argue that they reveal a world of sometimes unanticipated possibilities (cf. McClenachan et al. 2015). For example, the comparison of modern data with archaeological and/or long-term historical evidence regarding the size of fish in past catches can provide a guide to the real potential of properly regulated marine protected areas, avoiding under-ambition in conservation targets (e.g. Plummeridge & Roberts 2017; Fig. 4).

Third, analysis of archaeological materials can reveal long-term patterning in the aquatic environment. In this way, we can model the degree to which present and future environmental changes, especially global warming, are likely to impact fish stocks (e.g. Enghoff et al. 2007; Clavero et al. 2017). The potential benefits are both pedagogical (promoting climate-change mitigation) and pragmatic (planning for the management of altered ecosystems) (Pinnegar et al. 2013; Jackson et al. 2018).

Lastly, the long history of commercial fishing across many European countries (including Britain) – for cod, herring, salmon, sturgeon and many other species – creates a shared cultural responsibility for the present state of the seas. It has been observed that both

traditional ecological knowledge and learned grassroots “ocean literacy” can enhance support for careful stewardship of shared natural resources – and vice versa (e.g. Drew 2005; Pitcher & Lam 2015; Engelhard et al. 2016). In a European context, it will be crucial to the future of aquatic life that we recognize the *ecological heritage debt* owed for centuries of wealth, sustenance and well-being. This debt is both a loss and a reservoir of potential to be filled.

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Fig. 1. A subsample of fish bones excavated from a medieval coastal settlement at Quoygrew, Orkney, Scotland. Archaeological remains of aquatic vertebrates and invertebrates offer unique potential for study of long-term changes in fish biogeography, the aquatic environment, human impacts on aquatic life and the commodification of aquatic products. (Photo: James H. Barrett)

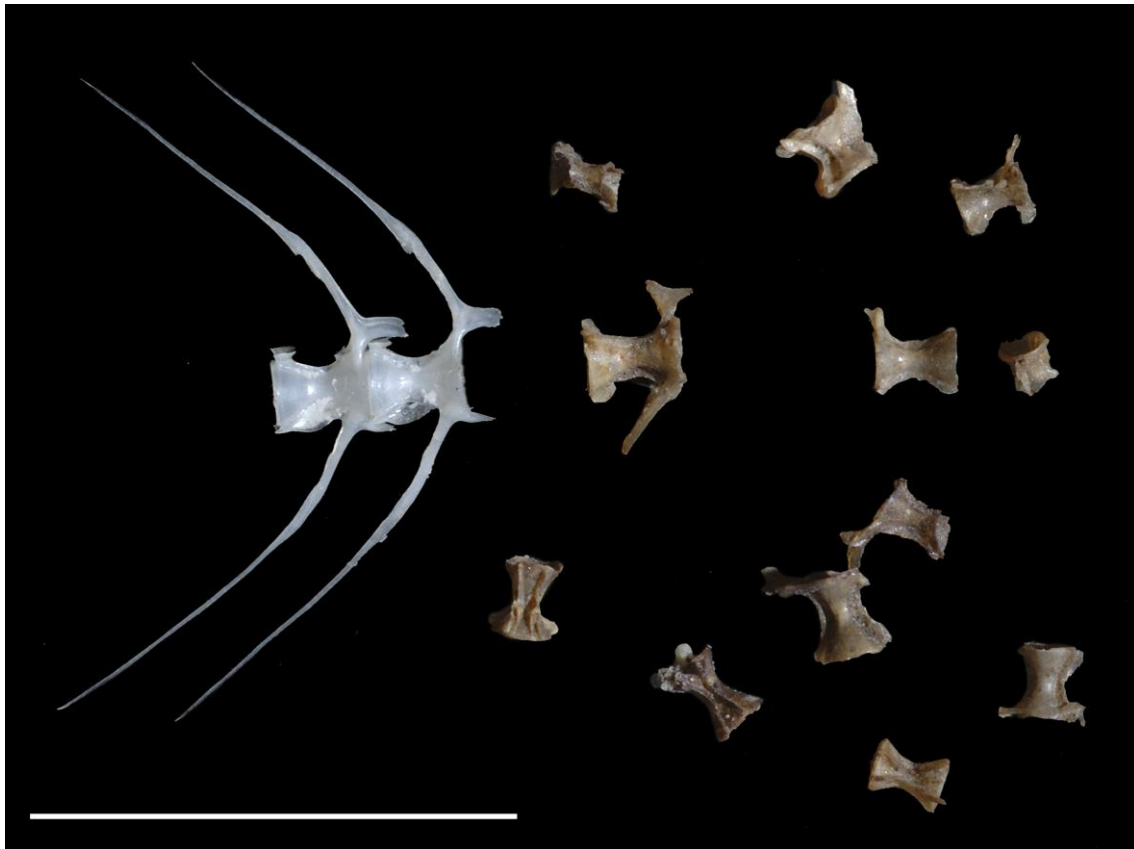


Fig. 2. Anchovy vertebrae excavated from the Ertebølle culture (5400–3900 BCE) site Krabbesholm II in Denmark. Two modern vertebrae (left) are shown for comparison. The distribution of this species has changed during past and present climate fluctuations. Scale 1cm. (Photo: Geert Brovad; after Enghoff et al. 2007 with permission from Elsevier and Inge Enghoff)

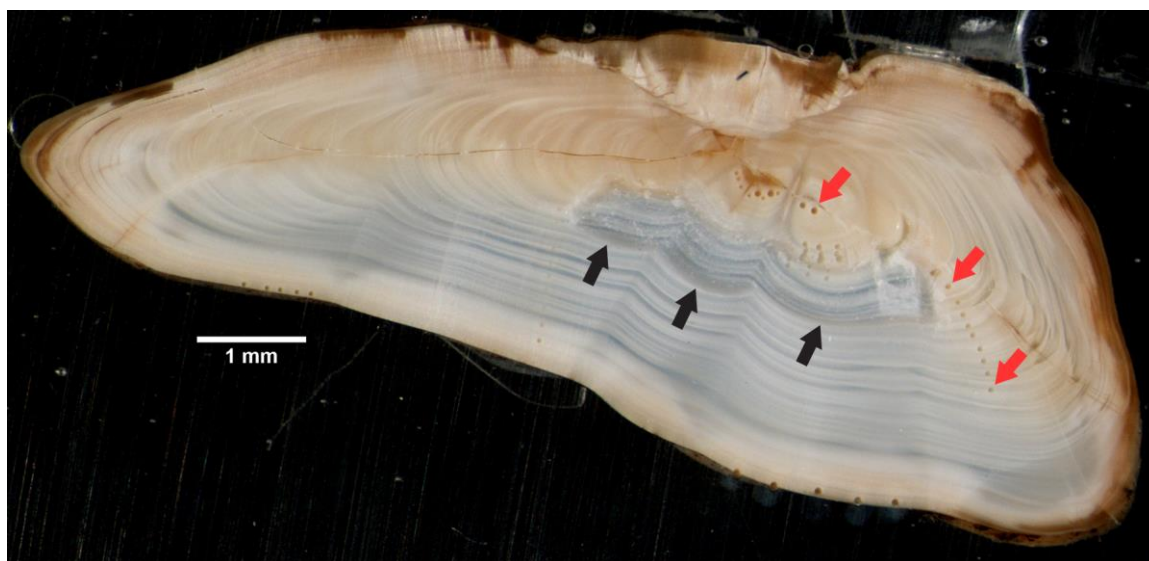


Fig. 3. A cod otolith of c.18th-century CE date excavated from the site Vanna in Troms County, northern Norway. The central furrow following the contours of incremental growth results from micromilling for oxygen isotope analysis, in order to infer temperature history. The small pits are from laser ablation-inductively coupled mass spectrometry (LA-ICPMS), to infer elemental composition (see Geffen et al. 2011). (Photo: Julie Skadal, courtesy of Audrey Geffen)

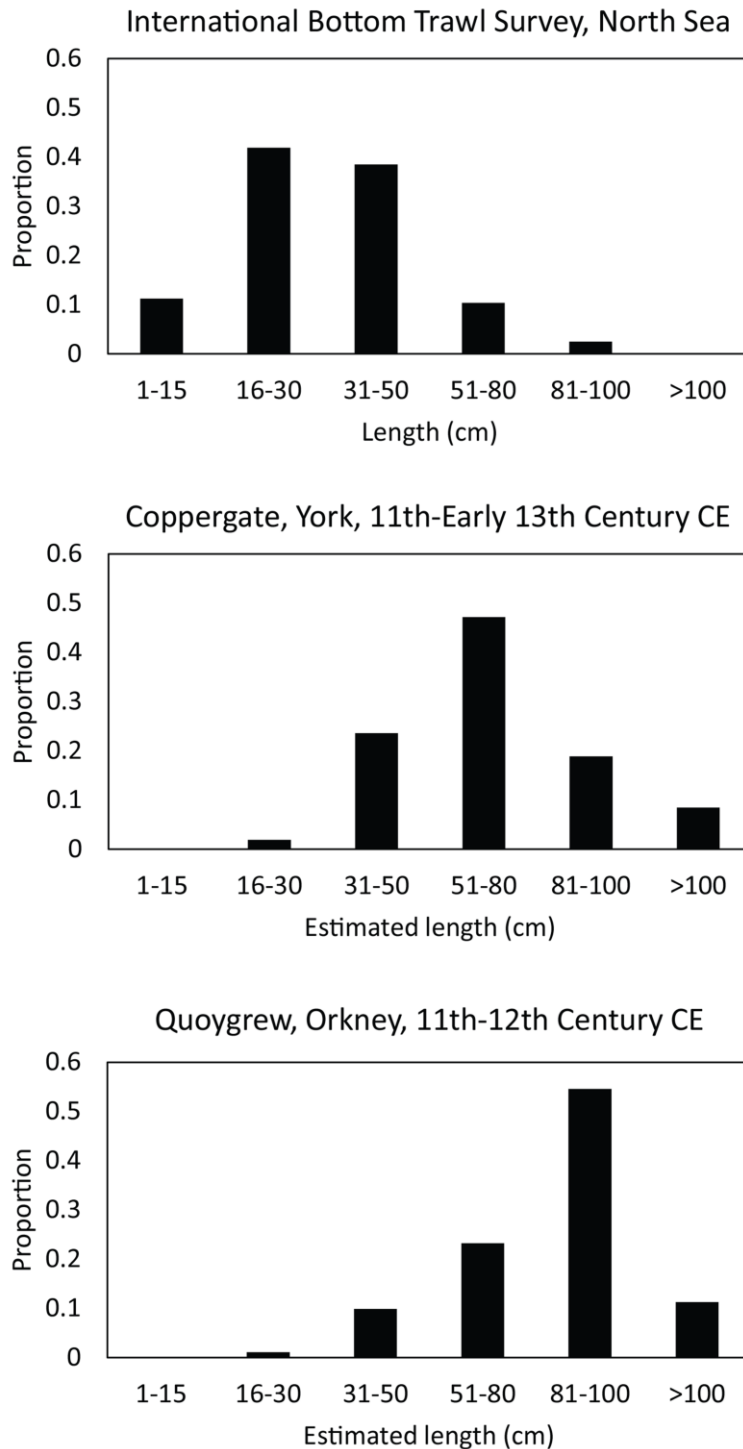


Fig. 4. Proportion of cod by length group. Top: Modern North Sea data from the 1991 International Bottom Trawl Survey (Spiers et al. 2010); Middle: 11th to early 13th century data ($n=106$) estimated by comparison of excavated bones from Coppergate, York, with reference specimens of known size (Harland et al. 2016); Bottom: 11th to 12th century data ($n=1006$) estimated by comparison of excavated bones from Quoygre, Orkney, Scotland, with reference specimens of known size (Harland & Barrett 2012).



Fig. 5. Left: stockfish (air-dried cod) in Lofoten, northern Norway (Photo: James H. Barrett); Right: cod bone (cleithrum) of 9th-11th-century date from Haithabu, Germany, having the distinctive genotype of the North East Arctic population which feeds in the Barents Sea and spawns along the Norwegian coast, especially in Lofoten (Star et al. 2017). (Photo: James H. Barrett)