

Historical Ecology of the North Sea Basin: An Archaeological Perspective and Some Problems of Methodology

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The North Sea Basin is one of the most fertile marine environments in Europe. Its relatively shallow seabed, cool-temperate climate and winter storms ensure rapid recycling of nutrients, while the presence of land masses on three sides and large rivers draining extensive catchments, such as the Thames, the Rhine and the Elbe, bring additional inputs of nutrients from land. The geographical limits of the Basin are defined to the west by the coastline of Britain, to the east by the coastlines of southern Norway, western Sweden and Denmark, and to the south by the coastlines of northern France, the Low Countries and Northwest Germany. To the north, there is a broad opening to the North Atlantic, and to the coastlines of northern Norway and Iceland. To the south there is a much narrower opening through the English Channel to the Bay of Biscay and the southern Atlantic, and to the east a narrow connection between Denmark and Sweden to the progressively more brackish waters of the Baltic (Figure 1). With populous countries on every side, the North Sea Basin is also vulnerable to the pressure of human demand on its marine resources. In the past century, and especially in recent decades, it has become a byword for overexploitation of its fish stocks. Historical records suggest that the productivity and abundance of cod (*Gadus morrhua*) and herring (*Clupea harengus*) was much greater than today, but the accuracy or wider relevance of these records is unclear (Jackson et al. 2001). Certainly the present-day stocks of some major commercial fish are under serious threat, and a complete ban on fishing for cod has recently been advocated to avoid regional extinction. Given the acute and, more recently, chronic impacts on marine ecosystems of human activities, knowledge of the frequency and scale of past impacts on marine life is not only historically informative, but is also crucial for assessing the current crisis facing ocean fisheries.

The rim of the North Sea Basin has witnessed continuous occupation throughout the last 10,000 years with a succession of communities and cultures, who have variously interacted around its perimeter or across an east-west axis through colonization, trade, conquest, and competition for resources. The 'natural' baseline against which to judge present-day impacts is poorly known. Moreover, it was almost

certainly an ever-changing baseline, due both to climatic and environmental changes, both amplified in their turn by relatively high latitude and proximity to the Scandinavian ice sheet of the last glacial, and to a changing history of human interest in and exploitation of marine resources over the past 10,000 years.

Because of complex changes in palaeogeography associated with glacial isostasy, the archaeological record of long-term coastal settlement is fragmentary and subject to large uncertainties of differential preservation or visibility. Some of the best-preserved coastal sites, particularly for the Mesolithic period, are on the peripheries of the North Sea proper, in northern and western Scotland and the inner waters of Denmark. As far as marine subsistence is concerned, most of the emphasis has been on the Stone Age, and particularly the Mesolithic period (c. 9500–3800 cal BC [10,000–5000 radiocarbon years BP]) (Bailey and Spikins in press). For the later prehistoric and protohistoric periods (Neolithic, Bronze and pre-Roman Iron Ages, and Roman, Viking and Medieval periods), the emphasis on archaeological interpretation has been more on issues of trade and culture contact than on marine exploitation and subsistence (cf. Cunliffe 2001). This reflects both the relative rarity of coastal settlement, particularly around the southern rim of the basin, which has undergone long-term submergence and accumulation of marine sediments, and different research agendas in different periods of the archaeological sequence. For the later periods, in contrast to the Mesolithic period, the emphasis has generally been on social and cultural change rather than on palaeoeconomy, and on agriculturally based and urban societies rather than maritime ones.

The questions asked and specific evidence assembled vary tremendously between communities of scholars working in different periods and regions. Seasonality of resource scheduling remains a critical question in the Mesolithic, whereas studies of chiefdoms and states in the Middle Ages are more concerned with issues such as gender and ‘ideology’ (e.g. Barrett and Richards 2004). Mollusks are the subject of intensive study in Mesolithic contexts but are seldom given equally detailed treatment in later periods. This diversity is exacerbated by the fact that there appear to be only two periods in the postglacial history of the North Sea during which marine resources played a major role in daily routine, economy and social life. These periods, the Mesolithic and the Medieval (Barrett et al. 2004a; Enghoff 1999; 2000; Milner et al. 2004; Richards et al. 2003; Tauber 1981) occupy temporal extremes of the Holocene. Common ground between them, and those who study them, is hard to find. Thus, it is not possible to construct a single narrative of maritime historical ecology around the North Sea.

Whether this perceived emphasis on marine resources in the Mesolithic and the Medieval period reflects biases in the archaeological record and the different interests of archaeologists working in different periods is hard to judge. But it is worth noting that in both periods when marine resources seem to be particularly prominent, we are dealing with colonization processes involving the expansion of human populations into new territory — in the case of the Mesolithic, the entry of populations into

pristine territory newly exposed after the retreat of the ice sheets, and in the early Medieval period, the westward expansion of the Vikings from Norway across the North Sea and around the Atlantic coasts of northern Britain involving conquest and occupation of already populated territory. There are good reasons to suppose that marine resources played an important facilitating role in both cases.

Given these complexities, this chapter will focus on one issue that has been perceived as critical in both periods, and which also unites social and ecological concerns: the intensification of exploitation. We offer a broad overview of the evidence, in order to provide a long-term perspective on the history of human interaction with marine resources. Given the incompleteness of the evidence, we pay particular attention to methodological issues. We examine the large palaeogeographic and climatic changes that have affected the region, and the ways in which these have influenced both the visibility of archaeological evidence for coastal settlement and maritime activity and the ecological characteristics of the marine environment. We emphasize the extreme patchiness of the archaeological record, particularly for the earlier prehistoric period, because of factors of differential visibility and preservation, and focus on two episodes within this longer-term history: changes associated with the introduction of agriculture at the Mesolithic-Neolithic transition at about 4000 cal BC, and the so-called ‘fish event horizon’ at about AD 1000 associated with the early Medieval and Viking periods (see also Perdikaris and McGovern, this volume).

Methods

We begin with a brief discussion of methods used to assess changes in the dependency of human populations on marine resources and human impact on marine ecosystems. All the methods we refer to here have been used in discussion of the European archaeological evidence, and all are involved in the examples we discuss later. We distinguish between direct methods, which inform on the ecological impact of human subsistence on the exploited organisms, and indirect methods, which estimate the contribution of marine foods in human palaeodiet.

Direct Methods

These refer to the morphological, biological or biochemical characteristics of exploited organisms, which may be sensitive to human impact, and we identify four such indicators.

First and most commonly relied on is reduction over time in the mean size of organisms that grow continuously throughout their life span. This is especially popular in studies of mollusks, and assumes that size reduction is due to intensified exploitation that removes the older and larger individuals.

However, this measure is highly unreliable in the absence of data on age structure unless environmental changes affecting growth rates can be excluded (Figure 2). In other words, shells may undergo long-term reduction in size not because of increased human impact but because of other environmental changes that slow down rates of growth without affecting the overall age structure. Similar considerations apply to the study of fish bones. Here there is an additional caution, and that is that different age classes of fish may feed in different areas. Moreover, these may change from season to season, so that age and size classes of fish represented in archaeological deposits may reflect differences in the areas fished or the season of activity represented at that particular site. Differences in fishing methods can also affect the size of the caught fish, quite independently of any larger scale impact of human populations on fishing stocks.

Age at death, our second indicator, can be estimated for many mollusks and vertebrates by measurement of incremental growth structures in the shell or in fish-bone elements such as vertebrae and otoliths, and is an essential control on interpretation of changes in mean size.

Another indicator is change in growth rates, which is relevant for many mollusks and fish that are subject to density dependent controls on growth. Under conditions of crowding we should expect slower growth rates, whereas reduced density, for example thinning out by increased predation pressure, would result in increased growth rate. Growth rate information, like age at death, can be obtained from incremental growth structures. However, interpretation is complicated by other environmental changes, which may produce similar results. Change in growth rates, in its turn, is an additional confounding variable that can complicate assessment of size changes.

Finally, changes in the composition of stable nitrogen isotopes in higher-level predators may indicate changes in ecosystem structure and in particular evidence of ‘fishing down the foodweb’ under conditions of very heavy overall human predation pressure (Hirons et al. 2001; Pauly et al. 1998; Wainwright et al. 1993). We are just beginning to obtain results from this method, but it is clear that measurements on individual organisms need to take account of overall isotope ecology and of geographical variations in isotope ecology.

Indirect Methods

Indirect methods essentially comprise two types of analysis. The traditional method of palaeodietary measurement is to estimate differences in presence/absence or proportion of different food remains in archaeological deposits, using counts of specimens or minimum number of individuals, expressed in terms of flesh weight, calories, protein or some other measure of relative food value. These provide a measure of change in emphasis on marine versus terrestrial sources of food and hence expectations about increased/decreased impact on the marine sector. However, they should be used with extreme caution

because of problems of potential bias and confounding variables. For example, the apparent intensification of marine resource exploitation recorded in southern European cave sites from about 17,200 cal BC (16,000 BP) onwards and culminating in the concentrations of estuarine open-air shell mounds in Portugal, Denmark and Scotland from about 6500 cal BC (7000 BP) appears to be largely a function of differential visibility of evidence related to sea level rise, reinforced by stabilization of sea level and development of productive estuarine habitats from about 6500 cal BC onwards (cf. Bailey 2004a; 2004b; Bailey and Craighead 2003; Bailey and Milner 2002; Fischer 1995a). Problems of differential preservation of different types of food organisms are also a major source of uncertainty, as are problems of differential discard and differential spatial distribution of food remains, both at intra-site and inter-site scales.

Changes in processing methods, particularly of mammals and fish, as indicated by differential frequencies of different parts of the skeleton, provide an added refinement. For these may reflect changes in the ways in which the carcasses were prepared in response to increased demand. Systematic over-representation of the heads and other unwanted parts of fish, for example, might indicate mass processing of fish for drying or smoking and long-distance export and consumption elsewhere. However, as with other archaeological methods, it is necessary to allow for factors such as differential preservation or differential spatial discard of different parts of the skeleton. Under-representation of fish heads, for example, could equally well indicate preparation of fish carcasses for local consumption rather than for long-distance trade.

The second major measure of food consumption is stable carbon and nitrogen isotope measurements on human bone collagen, which can measure changes in the relative proportion of marine and terrestrial protein in the human diet. These techniques offer a powerful insight into human palaeodiet uncomplicated by the biases that afflict archaeological food remains. However, they have uncertainties of their own. Human skeletal material is often confined to limited geographical locations and may not be representative of the wider population. The precision with which the isotope data can measure the relative proportion of marine and terrestrial foods in mixed diets is also subject to controversy (Hedges 2004; Milner et al. 2004; 2006; Richards and Schulting 2006).

In summary, there are a variety of methods that can be deployed, but all are open to various uncertainties. The principal difficulty with direct methods is that all the indicators of increased impact can also result from other sorts of environmental changes not involving human activity, posing major issues of disentangling human and non-human effects. The principal difficulty with the indirect methods, quite apart from any uncertainties in the accuracy or reliability of palaeodietary measures, is that variation in the proportion of marine foods that contribute to the diet of coastal people does not necessarily correlate closely or at all with variations in their ecological impact on the exploited organisms.

Palaeogeography and Prehistoric Coastal Settlement

With respect to the earliest period of the sequence, Northwestern Europe enjoys several advantages as a region for testing models of initial human colonization of empty landscapes. Foremost is the certainty that humans were colonizing unoccupied landscapes. Northwestern Europe was undoubtedly unoccupied prior to late Pleistocene colonization since most of it had been covered by ice sheets thousands of meters. The region also has a long history of archaeological study and, hence, a comparatively fine-grained archaeological record, with numerous sites and a well-established chronological framework. However, the dynamics of the retreating ice sheet, rising sea levels in the Baltic and North Seas, and isostatic rebound greatly complicate characterization of the landscape and its coastal ecology—and even the extent of available land area and the position of the retreating coastline. Furthermore, the retreating ice simply expanded the area of the European subcontinent that was available for human habitation. No physical barriers (such as seaways, a narrow land isthmus, or ice sheets) precluded two-way movement between the newly available landmass and the Pleistocene refugia for human populations further south in Europe. Also, the differences between the environments of the source region and the colonized area appear to have been minimal. Fauna recolonizing the deglaciated zones would have had a long history of adaptation to (and avoidance of) humans. Colonization processes may have differed from those associated with first occupation of the continents of Australia and the Americas, which were separated from source

populations by oceanic or ice barriers, had flora and fauna that differed from those of the colonists' homeland, and included 'naïve' animals unused to human predation (Barton et al. 2004: 141–2). With these caveats in mind, we examine the archaeological data for colonization of northwestern Europe from about 13,000 years ago onwards, following the retreat of the Scandinavian ice sheet.

As on coastlines in most other parts of the world, there is a sharp increase in the evidence of coastal settlement and marine exploitation in the form of shell middens and other indicators of maritime activity from about 6500 cal BC onwards, the later part of the Mesolithic period in the European sequence. Most archaeologists now accept that this cannot be taken at face value as evidence of intensification on marine resources, but rather reflects the history of eustatic sea-level change and the loss of evidence on now submerged coastlines. In the North Sea, however, this picture is greatly complicated by isostatic effects, and there is evidence both of significantly earlier coastal settlement in the north on elevated shorelines, and significant loss of coastal evidence for later periods in the south because of ongoing submergence and coastal erosion.

The shallowness of the North Sea (~40–100 m depth), particularly the southern basin, means that it has a complex history of palaeogeographical change associated with progressive marine inundation by the late glacial and early postglacial sea level rise (Coles 1998; Fitch et al. 2005; Shennan & Andrews 2000). That history is further complicated by the proximity of the Scandinavian ice sheet, resulting in variable degrees of isostatic rebound or depression associated with local changes in the loading of sea and ice on the earth's crust. In general terms, the northerly regions, especially the Norwegian coastline, which had the largest mass of ice over it, are regions of isostatic rebound, which means that late glacial and early postglacial shorelines that elsewhere are now destroyed or submerged by eustatic sea level rise are exposed above modern sea level. This is also the case, though to a much more limited extent, in northern Britain and southern Scandinavia. However, that advantage is offset by the fact that bone and shell preservation over large areas of this territory, and especially in Norway and Scotland, is mostly very poor or non-existent, due to acid base rocks and soils (Bjerck 1995; Clark 1983; Hardy and Wickham-Jones 2002; Milner et al. in press (a); Waddington et al. 2003).

Conversely, the southern coastlines, particularly along the coast of eastern England and the Low Countries, have undergone progressive submergence, coastal erosion and loss or burial of earlier coastal settlements by marine transgression or burial under thick deposits of marine and alluvial settlements. These trends have continued into the historical period and in some regions up to the present day. The coastlines of Eastern England, particularly the low cliffs of the Yorkshire coast and parts of East Anglia, are under active erosion, and the collapse of houses and other property into the sea is a regular and dramatic witness to marine encroachment. Dunwich, on the Suffolk coast, once a thriving fishing town and harbor with a history extending back to at least the 11th century AD, is famous for its nine churches,

all of which are now underwater. Large areas of former coastal settlement are now almost certainly buried under many meters of alluvial and marine sediments. It is only rarely that major engineering works have allowed excavations on a scale that can give an insight into these deeply buried landscapes, as with the discovery of richly preserved Mesolithic settlements at Hardinxveld-Giessendam in the Netherlands, originally located in a coastal wetlands (Louwe Kooijmans 2003).

At the height of the last glacial Maximum, at about 20,000 cal BC, the North Sea Basin and its surrounding territories would have been a single landmass of uninhabitable ice and Arctic desert. Whether the British and Scandinavian ice sheets coalesced to form a continuous ice barrier is uncertain, but the North Sea would have comprised at most an inlet of variable extent accessible only from the north (Coles 1998) (Figure 1). In the earliest stages of deglaciation and sea level rise, that inlet would have widened somewhat and extended further south in the vicinity of the present-day Norwegian trench. Much of the Norwegian coastline was ice-free by 13,500 cal BC (13,000 BP years ago) and perhaps as early as 17,200 cal BC (16,000 BP) (Bjerck in press (a)). With the onset of the late glacial interstadials at about 13,500 cal BC (13,000 BP), populations of reindeer hunters spread out from glacial refuges in France and southern Germany into the lowland regions of northern Germany and Britain, and onto the still-dry bed of the North Sea. There are numerous dated occurrences of human occupation from about 13,500 cal BC onwards, and these include an antler harpoon dredged from the Leman and Ower Bank with an AMS date of 11,950–11,300 cal BC (OxA-1950), and a flint recovered by oil drilling from a submerged beach deposit on the Viking bank (located between the Shetland islands and the Norwegian coastline), which must be at least 11,000 cal BC on geological grounds (Long et al. 1986; Tolan-Smith and Bonsall 1999; Verhart 2004).

The activities of trawler dredges in the southern part of the North Sea have brought up many tons of terrestrial and marine fauna. These include land mammals such as mammoth and reindeer, which represent several different cold stages of the Pleistocene, when the North Sea would have been a dry basin (Glimerveen et al. 2004). Large quantities of marine mammals have also been recovered including a cold-adapted Pleistocene marine fauna of walrus, harp seal, ringed seal and various whale species (Van Kolfschoten and Van Essen 2004). These indicate periods of colder climate and submerged shorelines when glacial-period sea level was high enough for marine conditions to penetrate into the southern part of the North Sea Basin.

In the shallow waters of Denmark, there have been extensive and pioneer investigations of underwater archaeology, which have revealed over 2000 archaeological sites, mostly in the shallow waters of the Kattegat around the islands of Funen and Zealand between the Jutland peninsula and southern Sweden, with underwater excavations at Tybring Vig, the Argus Bank, Møllegebaet and Pihlaken (Fischer 1995a; 2004; in press; Skaarup and Grøn 2004). These sites are in shallow water (~10

m depth) on shorelines that have undergone isostatic submergence, so the majority belong to the Ertebølle culture (c. 5500–4000 cal BC) of the late Mesolithic period, and are not significantly earlier than the famous Ertebølle shell mounds on the isostatically elevated shorelines of the northern Jutland Peninsula. However, because of the excellent conditions of preservation underwater, these sites often provide detailed evidence of organic materials, especially wood. At Tybrind Vig there was a dugout canoe, a paddle with elaborate decoration, the remains of a landing stage, and large numbers of wooden stakes arranged in a line to form a fish trap extending out from the shoreline. Similar evidence of large-scale fish traps has been identified on other parts of the submerged shoreline, and suggests a major commitment to fishing. It is, however, clear from the faunal and other evidence of food remains, both from underwater sites and from the dry-land shell mounds, that while fish and to a lesser extent shellfish were major food sources, the overall economy was a mixed one that included hunting of terrestrial and marine mammals and some plant food exploitation. How much further back in time this marine-oriented palaeoeconomy can be traced in Denmark remains unclear, though Fischer (1995b) is optimistic about the possibilities of extending underwater exploration to deeper, and hence, earlier underwater locations.

For insight into earlier periods, we must turn to Norway and Sweden. Here, much of the coastline formed at about 13,500 cal BC is now above modern sea level because of isostatic rebound, especially in Norway (Bjerck 1995; in press (a); in press (b); Schaller Åhrberg in press). That ought to provide a unique insight into the use of marine and intertidal resources at a time when shorelines of equivalent date in other parts of the world are now 40–50 m below present sea level. However, there is no indisputable evidence of human presence on these elevated shorelines for another 3000 years. Then, at or shortly after 9600 cal BC (10,000 BP), numerous sites appear along the full 2000 km length of coastline as far as the far north of Finnmark, representing an expansion of coastal settlement that must have taken place within a few generations

One of the difficulties of evaluating these very early coastal settlements is the almost total lack of preservation of bone or other organic material. However, site locations on promontories and offshore islands with good views of the sea and nearby inlets providing easy access for boats are evidence of a strong maritime orientation. It seems probable but not demonstrable that fish, seabirds and sea mammals were all of importance, most probably in combination with hunting on land. Deep inlets like the Boknafjord in Southwest Norway or the Uddevalla and Götaälv Straits on the Bohuslan coast of Sweden had extremely high levels of marine productivity resulting from the meeting and mixing of nutrient rich seawater and glacial melt water. Narrow straits also provided good opportunities for trapping sea mammals, and further upstream narrow corridors of land and crossing points were good for intercepting reindeer. The location of the sites, the nature of the resources available, and the need for substantial intake of animal fats for human survival in these northerly regions, indicates that marine resources and

especially sea-mammals must have been a major source of subsistence. Flake adzes are a prominent tool type in the stone industries and would have been well suited for scraping blubber from seal carcasses (Bjerck in press (a)).

In the British Isles there appears to be a similar pattern, though the earliest sites seem to be slightly later than in Norway, most dating between about 8500 and 8000 cal BC. These are likewise confined to regions of isostatic uplift in northern Britain, on the Northumberland coastline of Northeast England, and in parts of Scotland and Northern Ireland, the latter requiring the use of boats and skilled navigation to cross the treacherous straits that separate Ireland and Southwest Scotland (Bailey in press; Tolan-Smith in press). Since the degree of isostatic uplift in northern Britain is much less than in Norway, it is possible that earlier coastal sites have been submerged. However, unequivocal evidence of hinterland occupation in northern Britain is also scarce in earlier periods. Thus, it seems that, as in Norway, this early phase of settlement indicates a new phase of population expansion, with heavy reliance on marine resources, perhaps linked as in Norway to changes in ocean currents and ecological conditions associated with the Preboreal period. Here too, however, actual organic remains of marine resources are sparse, and limited to some seal bones at Howick in Northumberland (Waddington et al. 2003) and salmon bones at the riverine site of Mt. Sandel in Northern Ireland (Woodman 1978).

The time lag in the human colonization of these rich marine environments following the exposure of ice-free coastlines can be explained in one of two ways. According to one view, the pre-existing human populations of southern Europe had no prior experience of exploiting marine resources. Moreover, successful movement along the Norwegian coastline and around the Western Isles of Scotland would have required seaworthy boats, most probably framed boats covered in animal skins, and investment in the necessary skills for the development of such a technology along with its attendant social costs and risks (Bjerck 1995; In press (a)), and there may have been a time lag before these skills were developed. The alternative view is that maritime skills and exploitation of marine resources have a much longer history on European coastlines mostly obscured by the loss of evidence associated with lowered sea levels, and that the more northerly coastal regions were too climatically marginal and risky for sustained human settlement until about 9600 cal BC, regardless of any existing technological skills in the exploitation of the sea (Fischer 1996; 2004; Bailey and Spikins in press). Bjerck (In press (a)), for example, has compared the marine environment on the late glacial Norwegian coastline to present-day Svalbard, with drifting pack ice and frozen fjords, polar bear, large populations of seal and maritime birds, but few fish apart from the small polar cod (*Boreogadus saida*). It is arguable as to whether this would have been an accessible or viable environment for year-round human survival, or whether marine resources by themselves in the absence of any alternatives on land would have been sufficient to support long-term human settlement. At about 9600 cal BC, the Scandinavian ice sheet, which had persisted in

close proximity to the coastline, finally disappeared, opening up the hinterland to herds of reindeer and elk that provided resources to complement those obtained from the sea. The polar front also shifted north to the latitude of Iceland and was replaced by the warmer waters of the Gulf Stream, creating a more productive environment at sea as well as on land, and providing an essentially modern marine fauna that included large stocks of cod and herring, which became key food staples in later periods. Under such conditions, the greater diversity and richness of resources, including land mammals, may have made a critical contribution to the sustainability of human settlement in otherwise quite extreme climatic conditions. Similar considerations apply to northern Britain.

How far back in time one can extend the deeper history of maritime exploitation on the Pleistocene coastlines of southern Europe beyond the immediate influence of the ice sheets is unclear. On all but the narrowest coastlines, the drop in sea level would have taken the shoreline at least 5–10 km out beyond the present position, so that any coastal settlements or archaeological evidence of marine exploitation must necessarily now be destroyed or submerged. Certainly, some of the long cave sequences on the north Spanish coast show the presence of marine shells as food remains in deposits extending back into the last glacial period, and although the quantities of shells are quite small, these are believed to be only the tip of a more intensive pattern of marine exploitation (Bailey and Craighead 2003; Straus in press; Straus and Clark 1986). In the Mediterranean, Upper Palaeolithic deposits in the site of Cueva de la Nerja in southern Spain, where the offshore shelf is steep and narrow, have yielded bones of seal and fish along with mollusk shells in deposits extending back to about 14,000 BP (Morales et al. 1998; Morales and Roselló 2004). On Gibraltar, the even earlier sequence of Vanguard Cave (Stringer et al. 2000) extends back to an earlier period of high sea level associated with the last interglacial period — another window of visibility for human use of marine resources — and recent preliminary excavations in these early deposits have produced small quantities of fish bones, a cut-marked bone of a porpoise, and marine shells (Clive Finlayson, pers. comm.). On the shallower continental shelves around the shorelines of northern France and southern Britain, last glacial shorelines would have been much further out to sea, and any archaeological trace of their use less easily visible.

At any rate, as far as the North Sea Basin is concerned, it seems certain that we can trace continuous interest in and exploitation of marine resources back to about 10,000 years ago. Whether an Inuit pattern of adaptation to and exploitation of marine resources existed in earlier periods on now-submerged northerly shorelines with Arctic conditions remains unclear.

For the later part of the Mesolithic period following cessation of eustatic sea level rise after about 6500 cal BC, coastal settlements with or without shell middens appear widely throughout much of the study area. Undoubtedly the largest and best-known group is the Ertebølle sites of Denmark and southern Sweden, which comprise some 400 known shell mounds, in which oysters are the most common

molluscan species, dated between about 5500 and 4000 cal BC (6500 and 5200 BP) (Andersen 2000; in press). Most of these are in the northern Jutland Peninsula and on the northern coastline of Zealand, where the slight elevation of the Litorina shoreline of the period above the present sea level has ensured optimal conditions of site visibility and preservation. Some individual mounds are several hundred meters long and 3–4 meters thick. Meilgaard alone comprises 2000 m³ of deposit containing an estimated 2,000,000,000 oyster shells (Bailey 1978), and other mounds are bigger. These seemingly astronomical quantities have sometimes given rise to the notion of human populations who lived primarily on mollusks, and who might thus have imposed considerable pressure on the available mollusk supply. It is, however, clear from a series of analyses carried out in Europe and elsewhere that these quantities do not warrant such a conclusion (Bailey 1975; 1977; 1978; Bailey et al. 1994; Clark 1975). Rather, they are the result of progressive accumulation over many centuries, combined with high levels of visibility and preservation of mollusc shells relative to remains of other food resources. In all those cases where adequate quantitative controls can be established, the marine molluscs appear to represent a relatively minor food supply, but one that was nevertheless of great significance to human subsistence in representing an easily accessible and predictable food resource (cf. Meehan 1982).

In Denmark, there are as many coastal sites again that are not shell middens, and the absence of shells appears to be due to the lack of local shell beds in the immediate vicinity of such sites. This is consistent with the idea that the oysters, though forming an important food supply, were only one of a range of resources exploited by these coastal populations. Some individual sites may have had quite specialized functions, for the exploitation of marine birds, whales or oysters (Rowley-Conwy 1983), but the overall economy comprised a wide range of resources including hunting of terrestrial and sea mammals, shellgathering, fishing and collecting of plant foods and a high degree of sedentism. Marine resources exploited included, in particular, oysters (*Ostrea edulis*) and cockles (*Cerastoderma edule*), gray seal (*Halichoerus grypus*), and cod (*Gadus morrhua*). Freshwater fish are also well represented in some coastal middens (Enghoff 1986).

In Britain, the best-known examples are in the north, particularly in Scotland. These include the Oronsay shell mounds (dominated by *Patella vulgata*), off the west coast of Scotland (5320–3800 cal BC) (Mellars 1987; Mellars and Wilkinson 1980), Morton (dominated by mollusks of *C. edule*) on the Tay estuary on the east coast (6600–3790 cal BC) (Coles 1971), and West Voe in the Shetlands, with a Mesolithic shell midden deposit with *P. vulgata*, *O. edulis*, and *Mytilus edulis* dated at 4320–4030 cal BC and a Neolithic midden stratified above it (Melton and Nicholson 2004; In press). Morton indicates a range of exploited food resources including land mammals, fish (with cod prominent), and plant foods. The Oronsay mounds suggest a more specialized marine economy dominated by fishing for saithe, *Pollachius virens*, like cod a member of the Gadidae family, shellgathering for limpets (possibly used for

baiting fishing lines) and hunting of gray seal. Seasonality data from fish otoliths suggest the use of different mounds on the island at different times of year, but it remains unclear whether these represent a specialized maritime community who lived permanently on the island (Mellars 2004) or people who visited the island for its rich marine resources from bases on the mainland or the large islands nearby (Mithen 2000).

In western Sweden and Norway, as noted, preservation conditions are generally poor. Remains of fishing for cod, sometimes of large size, and other gadids are present along with evidence of land-mammal hunting at a scattering of Mesolithic sites, including Skipshelleren and the Viste Cave in Norway, and Ölmanäs and Dammen in western Sweden (Bjerck in press (a); in press (b); Schaller Åhrberg in press; Wigfors 1995). Of these, Dammen is of particular interest in preserving quite a large assemblage of bones of cod and herring, substantial quantities of shellfish, particularly periwinkle (*Littorina littorea*) and a large artifact collection including numerous fish hooks, dated to about 7000 cal BC. Schaller Åhrberg (in press) interprets this as evidence of an organized fishery for cod using baited hooks on lines and for herring using seine nets.

There are few indicators from this scattered body of Mesolithic material that give insight into the nature of human impact on the marine ecosystem or provide us with a clear baseline from which to judge later impacts. It is clear that a wide variety of marine resources were exploited, and were of considerable importance as major sources of subsistence over many millennia, including resources such as oyster, cod and herring that have become of commercial importance in recent centuries. In reviewing the evidence for fish remains from these sites, Pickard and Bonsall (2004) have noted the considerable variation in size and age of specimens recovered in different sites, but have concluded that these represent variations in local topographic conditions relative to fish feeding areas and migratory patterns. They also specifically exclude the practice of deep-sea fishing from boats and argue that all the evidence is consistent with use of line fishing from the shore. We conclude that any impacts on the marine ecosystem were at best localized, and most probably moderated by the widespread practice of broad-spectrum economies not specialized or over-dependent on any one class of food resources, and by the confinement of marine exploitation, for the most part, to shore-based activities or at any rate a boating technology confined to inshore waters.

The Mesolithic/Neolithic Transition

The transition from the Mesolithic to the Neolithic is associated with the introduction of agriculture in the region, beginning at about 4000 cal BC in Britain and Denmark, and later further north. We might expect this major economic transition to show up in changes in the use of the marine environment, and a number

of lines of evidence have been brought to bear on this issue, in particular changes in size and age structure of exploited molluscan populations in midden sequences, and a new body of stable isotope results from human bone collagen.

A number of Danish shell middens contain Neolithic midden deposits stratified above Mesolithic levels, and these sites show a shift from a predominance of oysters in Mesolithic levels to cockles in the Neolithic, a transition especially well documented at the site of Norsminde (Andersen 1989) (Figure 3). This mound comprises ~ 270m³ of midden deposit and was occupied from 4500 to 3200 cal BC. The dominant species are oyster (*O. edulis*) and cockle (*C. edule*), with other mollusk species present in variable but generally low frequencies — mussel (*M. edulis*), periwinkle (*Littorina littorea*), carpet shell (*Tapes decussatus*) and whelk (*Hinia decussata*). The shift in taxonomic frequencies is well shown at this site, although the change involves a decline in oysters relative to cockles rather than the complete disappearance of oysters. Remains of other food resources are well represented in the Mesolithic levels, including bones of fish, seal and land mammals, while the Neolithic levels are composed mainly of mollusk shells, suggesting a change in the use of the site from a settlement to a specialized camp used for processing of shellfood by farming people who had their settlements further inland.

Detailed analyses of the size and growth characteristics of the principal mollusk species have been undertaken, informed by control studies of modern populations, to establish limits of accuracy in establishing patterns of growth as indicators of age and season of death. The Mesolithic evidence suggests that, after an initial size decline, interpreted as the initial impact of human gathering on a previously unexploited shell bed, there is a very stable pattern of exploitation with uniform size and age structures of the exploited mollusks, and no evidence that shellgathering activities were making significant inroads into the ecological viability of the mollusk populations (Figures 4 and 5). In the Neolithic layers, both size and age structure fluctuate, indicating intermittent periods of heavier exploitation pressure, while the shells also appear to have been collected over a longer part of the year (Figure 6), in contrast to the narrow season of collection practiced in the Mesolithic period (Bailey and Milner in press; Milner 2001; 2002). Similar trends have been identified in the cockles as well (Bailey and Milner in press; Milner and Laurie in press).

Comparison with stable isotope data from human skeletons suggests a more complicated picture (Figures 7 and 8). Sample data are now available from quite a large selection of human skeletons from Mesolithic and Neolithic burials throughout western and northern Europe including Britain and Scandinavia (Liden et al. 2004; Lubell *et al.* 1994; Richards and Hedges 1999a; 1999b; Richards *et al.* 2003; Schulting and Richards 2002). The results suggest a significant dietary shift from emphasis on marine protein in the Mesolithic to emphasis on terrestrial protein in the Neolithic. Some have gone so far as to suggest an actual avoidance of marine resources by Neolithic people (cf. Thomas 2003), but we do

not believe this is warranted by the evidence. Firstly, there is well-known evidence in Neolithic deposits for the continuation of shellgathering, sea-mammal hunting and fishing. This is true not only in the Danish sites, but also more widely in the North Sea Basin, notably in Norway, Sweden and Scotland (Bjerck in press (b); Clark 1977; Milner et al. 2004; Wickham-Jones in press; Wigfors 1995). Secondly, the baseline isotope ecology used to assess human measurements is likely to have varied from area to area and period to period. Until appropriate measurements of the isotopic composition of contemporaneous food organisms and environments have been undertaken, the isotope composition of human bone should be interpreted with caution. Thirdly, the stable-isotope technique may be insensitive to differences between diets lacking marine protein and diets in which marine protein makes a relatively small but nonetheless significant contribution (Hedges 2004; Milner et al. 2004; 2006; Richards and Schulting 2006).

Nevertheless, it seems reasonable to infer a general shift over time to greater emphasis, proportionately, on terrestrial protein in the human diet. But this leaves us with the paradoxical result that marine resources appear to have been subject to less pressure from human impact when they formed a larger part of the diet (in the Mesolithic), and more pressure when human populations were apparently less dependent on them (in the Neolithic). That paradox might be resolved in five ways.

Firstly, we might suggest that the results in Figures 7 and 8 are a biased sample, reflecting individuals that are not representative of all the local populations from which they are drawn. In this regard it should be noted that there are no stable isotope results on human bone from the Norsminde site, which could conceivably be atypical in relation to the other locations from which human skeletons have been recovered and analyzed. However, it seems unlikely that such a relatively large and diverse sample is systematically biased in this way.

Secondly, it is possible that marine resources declined in abundance because of environmental change and thus became more vulnerable to overexploitation even in the absence of changes in the pattern of human activity. Analysis of sediment cores in the Norsminde estuary suggests a considerable increase in rate of sediment accumulation during the Neolithic period, quite likely related to agricultural land clearance, which would have improved substrate conditions for cockles at the expense of oysters. In addition, there is independent evidence for minor climatic change at this time, and in particular a reduction in temperature, marking the end of the mid-Holocene climatic optimum. Oysters would have been more sensitive to both these types of environmental change than cockles, and the oyster habitat may well have reduced considerably as a consequence. However, a similar argument cannot be applied to the cockles. On the contrary the evidence seems to suggest that their habitat expanded, and yet they too came under increased pressure of human exploitation, judging by reductions in size and age of the mollusk shells in the Norsminde midden.

Thirdly, we could argue that Mesolithic populations, being more dependent on marine resources, were more careful to avoid damaging ecological impacts that could have a major effect on human survival and well being than Neolithic populations, who could afford to be less conservation-minded, knowing that their livelihood did not depend to the same degree on the continuation of a minor resource. However, we think this unlikely, if only because mollusks appear to have been a relatively minor resource in the Mesolithic period too. Yet they played an important role as a stopgap and an alternative resource at times of year when other food resources were in short supply, and this applies as much to farming populations as to hunter-gatherer ones (cf. Deith 1988).

Fourthly, it is possible that Neolithic populations, though less dependent on marine resources than their Mesolithic predecessors, were larger overall because of changes in the economic base, including the probable addition of domestic livestock and crops, and thus had a bigger impact on a fixed marine resource base. Thus, changes in economic scheduling of different resources during the course of the year, and in particular a prolongation of the season over which mollusks were collected, as is clearly shown by the seasonality results at Norsminde, exposed the shell beds to increased levels of human impact independently of any other factors.

We cannot at present discriminate with any confidence between these alternatives, not least because analyses of changes in age structure and growth rate need to be applied to a much larger and more diverse sample of food remains in archaeological deposits. It may be that several if not all of these factors have contributed to the patterns visible in the archaeological record. As far as human impact on the molluscan populations is concerned, the main interest of this example is to demonstrate two patterns. The first is an initial reduction in size and age following initial exploitation of a pristine shell bed, followed by a period of stability. The second, apparent in the later part of the Norsminde sequence, is a greater impact on the mollusk population, indicated by episodic reductions in the size and age of the shells with occasional periods of recovery, reflecting wider changes in the organization of the human economy and most probably a larger human population. The details of these changes in human impact are difficult to pursue further in this case, because of relatively small sample sizes, low chronological resolution, and also the ongoing problem of disentangling human impacts on mollusk populations from other environmental changes (Bailey and Milner in press).

The Medieval to Modern Transition

A diversity of opinion continues to exist regarding the state of Europe's political economy following the collapse of the Roman Empire (Collins and Gerrard 2004). Nevertheless, it remains clear that the intensity of economic production and market trade declined in the middle centuries of the first millennium AD —

the years once referred to as the Dark Ages. Documenting the re-emergence of intensive surplus production, market trade and urbanism (sometimes referred to as the commercial revolution of the Middle Ages) is a well-trodden scholarly path (e.g. Anderton 1999; Hodges 1982; Prestell and Ulmschneider 2003). Perhaps the only significant controversies remaining are the chronology of this development and its causes. Some scholars suggest an early, even 8th century, development (Hill and Cowie 2001) whereas others would place significant economic changes only around or after the year 1000 (Griffiths 2003).

Within this debate, the North Sea has long been a focus of discussions of trade and its corollary, piracy (e.g. Myhre 1993; Sawyer 1971). The significance of intensified exploitation of marine animals, however, has only been recognized comparatively recently (e.g. Barrett 1997; Benecke 1982; Ervynck and Van Neer 1994; Heinrich 1983; Jones 1981). Hoffmann (1996), in a seminal paper, used historical evidence to hypothesize that Medieval population levels, land use practices, and fishing efforts had depleted freshwater fish resources by the early centuries of the second millennium AD. Since then, wider syntheses have convincingly demonstrated that marine fishing increased tremendously around the North Sea at this time, replacing the former dominance of freshwater species in the fish bone record (Barrett et al. 2004a; Enghoff 2000). The question of causation remains complex, but Hoffmann's hypothesized shift from freshwater to marine species appears to be real, whether to increase the absolute supply of fish or to replace dwindling freshwater resources. Many of the marine fish are found as bones in inland towns so it is highly probable that they represent traded commodities (or indirect subsistence to use Hoffmann's terminology) rather than locally organized provisioning.

To illustrate this trend one can consider the evidence from different parts of Britain likely to have been net 'producers' and 'consumers' of traded fish, particularly cod, over the millennium from AD 600–1600, namely the Northern Isles of Scotland (Orkney and Shetland) and England (Figure 9). The former were the focus of a semiautonomous Scandinavian, then Scottish, earldom (Thomson 2001) whereas the latter transformed from a patchwork of small Anglo-Saxon chiefdoms to the English state over the millennium in question (Hinton 1998).

In the Northern Isles, fish and sea mammals were exploited at very low levels prior to the 9th–10th centuries. Regardless of recovery method and preservation conditions, cetacean and seal remains are rare finds (e.g. Mulville 2002). Fish bones are more abundant, but represent small inshore species easily caught using traps, nets or lines and with minimal risk or technological investment (Barrett et al. 1999; Colley 1983; Nicholson 1998). Stable isotope analysis of human bone collagen also indicates that marine protein was a negligible component of the Northern Isles diet at this time (Barrett and Richards 2004; Barrett et al. 2001). The most common fish species is saithe, *Pollachius virens*, also the species that dominates the fish remains at Mesolithic Oronsay (see above). Based on ethnohistoric analogy from later centuries, it is likely that in the 9th–10th centuries saithe served principally as a source of lamp oil,

although they may also have formed a minor dietary supplement (Nicholson 2004); but it is doubtful that the same analogy can be extended as far back as the Mesolithic period, when it is assumed that saithe were exploited mainly for food.

With the first appearance of burials with Scandinavian grave-goods in the Northern Isles (between AD 850 and 950), there was a significant increase in sea fishing, particularly for large cod. This may be evidence for the introduction of a marine-oriented diet, knowledge base and worldview by Scandinavian migrants (Barrett et al. 1999; 2001; Cerón-Carrasco 2005). Large cod and related species were widely fished in Viking Age Norway (e.g. Barrett et al. forthcoming; Hufthammer 2003; Perdikaris 1999; see also Perdikaris and McGovern, this volume).

In the 11th or 12th centuries, however, the intensity of fishing for cod and related species increased far more. In many zooarchaeological assemblages, fish bones outnumber (and occasionally even outweigh) cattle, caprines and pigs combined (Barrett et al. 1999; 2001; Harland 2006). Many fish were clearly being eaten locally. However, some sites were producing cured fish based on the evidence of cut marks and element distributions and these may have been intended for export (Barrett 1997; Barrett et al. 1999; Cerón-Carrasco 1998; Harland 2006). The intensity of bait collection probably also increased, as indicated by a reduction in the size and age of limpet (*Patella vulgata*) shells found in 11th to 13th century strata at the site of Quoysgrew in Orkney (Figure 10 and 11) (Milner et al. in press (b)). Limpets can be eaten, but isotopic evidence suggests that marine carnivores were preferred (Barrett and Richards 2004). These mollusks were utilized as fish bait in later centuries (Fenton 1978), and the same may be true of the Quoysgrew limpets. Stable isotope evidence suggests that some individuals ate more marine protein than is known since the Mesolithic (Barrett and Richards 2004) (Figure 12, compare Figure 7).

Turning to England, eight taxonomic groups dominate the fish bone record. The marine fish are herring and gadids (cod family fish, in which the closely related hake is included for present purposes). The freshwater fish are cyprinids (carp family) and pike (*Esox lucius*). The migratory fish are European eel (*Anguilla anguilla*), salmon and trout (salmonids), smelt (*Osmerus eperlanus*) and flatfish (including both flounder, *Platichthys flesus*, which enters fresh water, and marine species). When these taxa were compared using Correspondence Analysis, it became clear that all ‘catches’ from the seventh to the tenth centuries were dominated by freshwater and migratory species (particularly cyprinids and eels). In the eleventh and later centuries, however, herring and gadids became dominant (Barrett et al. 2004a).

Simply put, the major change through time was an increase in the abundance of herring and gadids. Both became far more abundant in the eleventh to twelfth centuries (Figure 9). Herring was found in some earlier sites, particularly proto-urban centers such as York and London (e.g. Jones 1988; Locker 1988), but its importance increased fourfold at this time. For gadids, different species show slightly different patterns. Cod itself first appeared in more than nominal numbers in the eleventh to twelfth

centuries. Later, however, its proportion of the total declined as it was joined by related species such as haddock, ling, saithe and hake. Surprisingly, the few assemblages that can be tightly dated suggest that the initial increase in herring and cod abundance occurred within 50 years of AD 1000. Some corroboration of these observations comes from the limited historical evidence available from this period (see Barrett et al 2004a; Pauley 2004).

Attempts have been made to assess the impact of this early process of increased fishing activity on the dynamics of the fish populations in relation to the more recent impact of heavily industrialized fishing in the 20th century. Bolle et al. (2004) have used otoliths from archaeological sites of the 11th century and later to compare age, size and growth-rates of ancient and modern catches of cod, haddock, saithe and plaice. The expectation is that intensification of fishing activity should show up in a general shift to younger fish and higher growth rates (see Figure 2). The results are equivocal. Modern data show a clear shift to younger fish and increased growth rates of juveniles in cod and haddock, some change in plaice and none in saithe. However, interpretation is complicated by a two factors. Firstly, there are no data for fish assemblages that precede the fish event horizon to provide a baseline for assessing later changes. Secondly, juvenile fish of some species are subject to predation from the adults. Thus increased predation of adult fish, with consequent increase in growth rate of the surviving adults, may result in greater overcrowding and reduced growth rate of the juveniles, But this effect will be absent if the nursery grounds for the juvenile fish are separate from the adult feeding areas.

Stable Isotope Analysis and Food Web Structure

Another approach to the investigation of human impact is the analysis of the stable nitrogen isotope composition of the exploited organisms. In the North East Atlantic fisheries, statistical data on catches over the last 50 years indicate that smaller individuals and species have become increasingly abundant. Essentially, short-lived invertebrates and planktivorous pelagic fish of low trophic level have replaced long-lived carnivorous bottom fish of high trophic level. Pauly et al. (1998) have analyzed these effects in recent fisheries data and describe such disturbances of ecosystem structure and function as ‘fishing down the foodweb.’ However, a more complete understanding of this process and particularly its longevity is hampered by the limited data available (Polunin and Pinnegar 2002; Watson and Pauly 2002). Records of fishery landings and fish dietary data rarely extend beyond the past fifty years. Morales & Roselló (2004) have attempted to extend the record further back in time by calculating the mean trophic level of archaeological fish assemblages in a chronostratigraphic sequence that spans thousands of years at the Cueva de la Nerja in southern Spain. However, this approach relies heavily on the availability of extremely well preserved assemblages, which reflect the original, true proportions of fish of different

trophic levels, and these are rare in the archaeological record. A technique that offers a more reliable approach is the measurement of the ratio of the stable isotopes of nitrogen (^{15}N and ^{14}N), expressed as $\delta^{15}\text{N}$, in archaeological marine fauna, as a means of tracking changes in the diet of marine predators (Hirons *et al.* 2001, Wainwright *et al.* 1993). Nitrogen isotope ratios show clear enrichment of ^{15}N (~2–4‰) in the tissues of a consumer organism relative to its prey, and hence progressive enrichment of ^{15}N with increasing trophic level. Disruptions to the food web such as loss of medium/high trophic level fish should show up as a progressive reduction in $\delta^{15}\text{N}$. Comparing prehistoric, historic and modern nitrogen isotope data should therefore provide valuable insights into temporal trends in North Sea and Northeast Atlantic ecosystem structure in relation to recent human impacts.

Changes in the nitrogen isotope composition of predator species may also be the result of long-term environmental changes that have affected organisms at the base of the food web. In order to demonstrate that shortening of the food web is due to overexploitation, it is essential to compare $\delta^{15}\text{N}$ measurements of organisms at different trophic levels and at different time periods and in different geographic locations. We have begun to collect stable isotope data from a number of Danish shell middens of Mesolithic and Neolithic date. An initial comparison of data from pinnipeds (gray and harbor seals) recently beached on the southern coastlines of the North Sea (Das *et al.* 2003) and archaeological specimens (Craig *et al.* 2006) shows that the modern specimens actually have higher $\delta^{15}\text{N}$ values than their prehistoric counterparts, which is the reverse of what would be expected if recent shortening of the foodweb had occurred (Figure 14 now 13). One hypothesis to account for this unexpected result, albeit based on our very small sample sizes, is that there has been an overall shift in the $\delta^{15}\text{N}$ values of organisms at the base of the foodweb due to environmental changes, and we are currently testing that hypothesis by comparing measurements in modern and archaeological mollusk shells. In another example from central California (Figure 13), Burton *et al.* 2001 have shown that there are no significant differences in the mean $\delta^{15}\text{N}$ between ancient and modern pinnipeds, suggesting that ecosystem structure has remained stable over the time period in question, although analysis of lower trophic level ancient and modern marine species would be needed to confirm this.

Conclusions

Human intervention in the North Sea marine ecosystem has been taking place for at least the last 10,000 years and possibly longer. Moreover, there have been major environmental changes affecting marine organisms both at the large scale of the North Sea as a whole, and at a more localized geographical scale, as well as changes in the configuration and size of human populations. There is thus no single baseline

against which to judge recent human impact, but rather a constantly shifting baseline subject both to geographical variation and episodic change in time.

There have been at least four periods when intensification of human exploitation of marine resources may be inferred: an early period of late glacial intensification associated with the earliest human colonization; a later postglacial intensification associated with the Mesolithic period; further intensification under the pressure of expanding agricultural populations from the Neolithic period onwards; and the 'fish event horizon' of ca. AD 1000, which anticipated the further expansion of the North Sea fisheries to Iceland and Newfoundland in the 15th century AD and the industrialization of fishing activity in the 20th century. There may have been many more such episodes. The evidence of intensification in the prehistoric periods is controversial, especially in the prehistoric periods mentioned, because it is possible that the apparent changes in the archaeological record could equally well be explained by changes in the visibility of coastal archaeological deposits or changes in environmental conditions. The record that we currently have is at best patchy, and we should beware of glossing over the gaps in the record to construct a narrative of long-term progressive and increasing human impact. Equally unwarranted is the assumption that there was no human impact on marine ecosystems before the modern period.

Evidence of increased human pressure on resources is not necessarily evidence of *over*exploitation on the resource, let alone of resulting food stress on the human population. Resources with limited geographical distributions that are easily accessible, for example intertidal mollusks, might seem to be most vulnerable, but even these are likely to be resilient in the face of intensified predation provided that there are reserve stocks on less accessible coastlines or in subtidal locations, capable of replenishing locally depleted shorelines. Moreover, the thinning out of shell beds and the removal of larger specimens may lead to a relaxation of human predation pressure and a switch to other food supplies because of the resulting increase in the cost of locating and collecting edible-sized specimens, long before the risk of local extinction. This is the marine resource that we might expect to have been the earliest to come under pressure of human exploitation, but archaeological records indicate minimal evidence of human impact and none that we would consider threatening to the viability of mollusk populations, not even at a local scale.

A variety of methods can now be brought to bear on issues of human dependency on marine resources and human impact on them, including a new generation of stable isotope techniques. However, all of these techniques are subject to uncertainties and potential biases. A major difficulty is that changes that might be taken as evidence of increased human impact might equally well be produced by environmental changes unrelated to human activity (or at best only indirectly so). Changes in the methods used to capture resources can also produce 'false' evidence of intensification in the form of an apparent

reduction in size or age structure, for example a change in the mesh size of fishing nets or the size of fishing hooks, or a change in the season or location of capture. Nevertheless, it is clear that these techniques, used in combination, open up rich possibilities for tracking long-term changes in human use of and impact on marine resources, subject only to limitations imposed by the availability of archaeological samples and the resources to analyze them.

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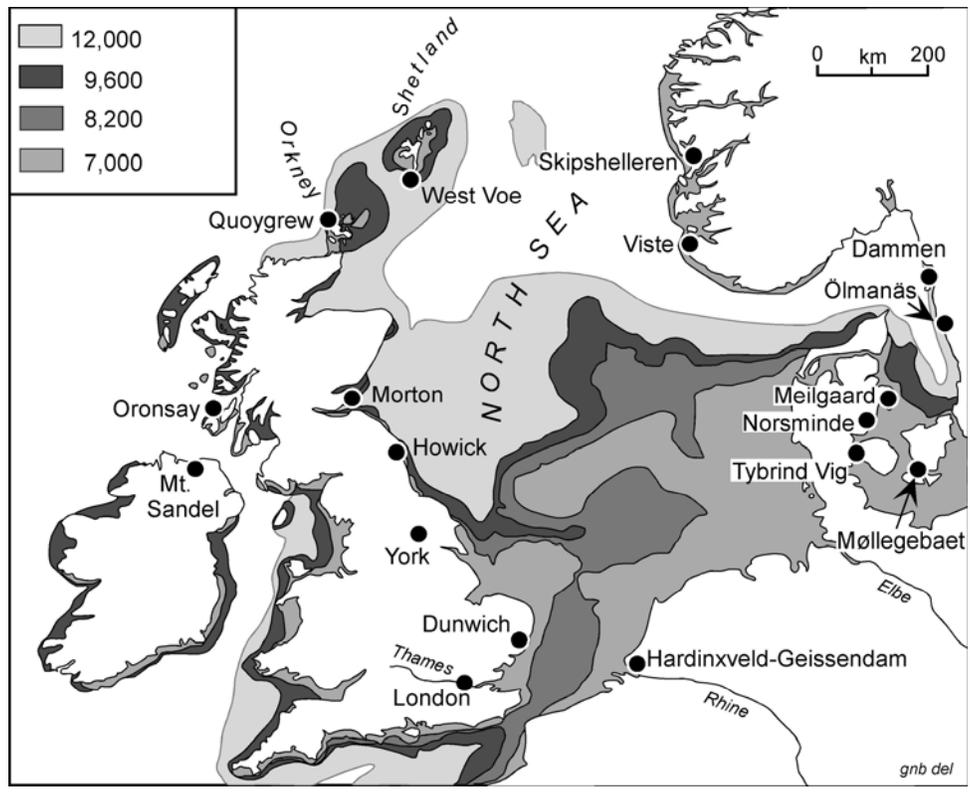


Figure 1. Map of North Sea region indicating position of coastline at different periods, sites and places mentioned in the text. Shoreline positions are based on data from Shennan & Andrews (2000).

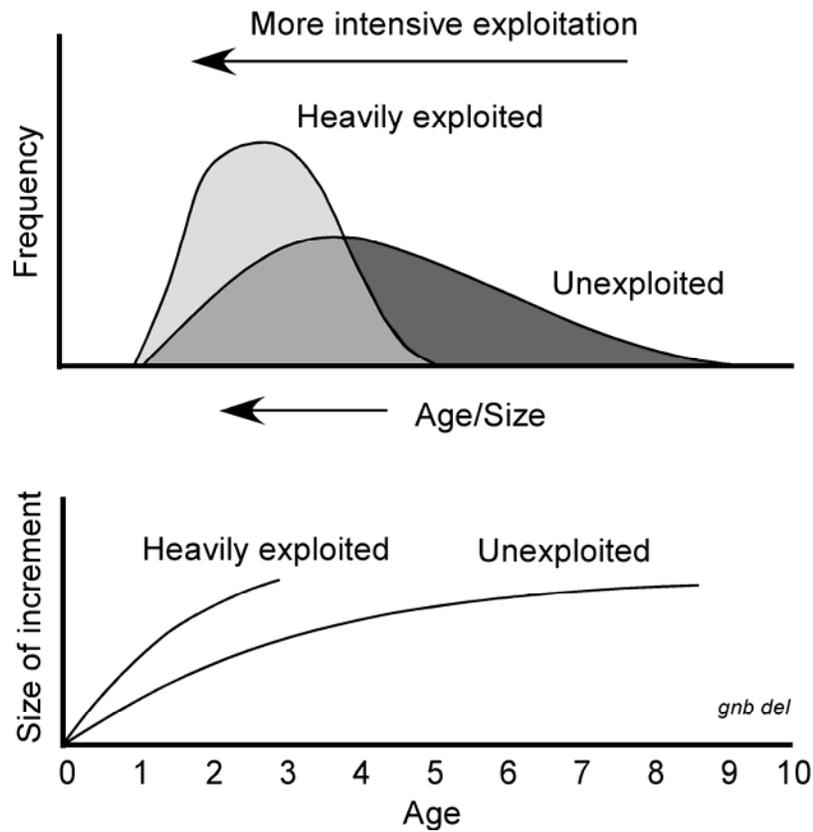


Figure 2. Effect of human impact and environmental change on age structure and size characteristics of marine organisms. The example given here is for molluscs. Similar effects are likely with all marine organisms that grow continuously throughout their life span such as fish, but are likely to be moderated by differences in feeding areas and behavior patterns of different age cohorts.

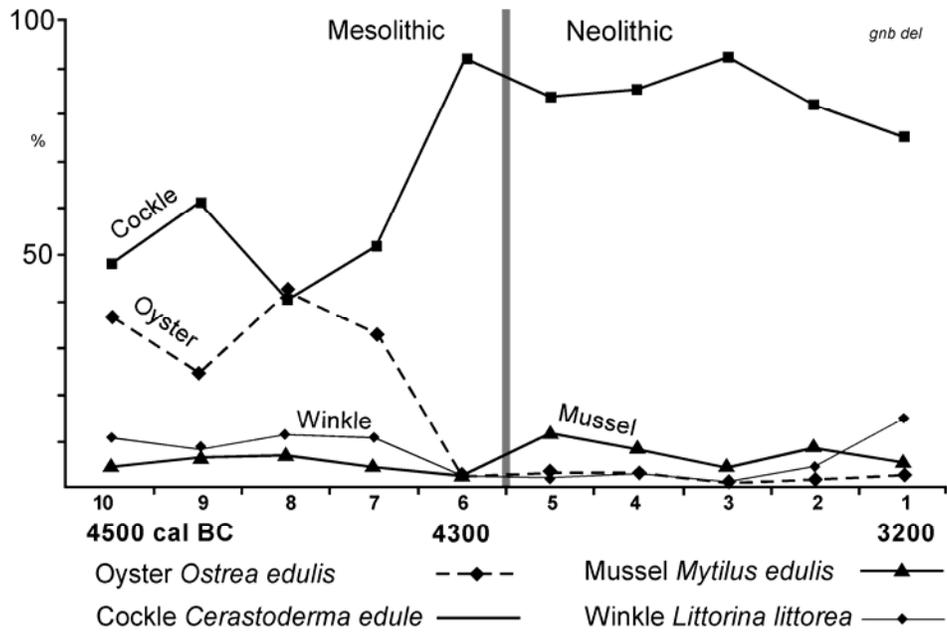


Figure 3. Change in frequency of molluscan taxa at the Danish shell midden of Norsminde. Data from Bailey & Milner (in press).

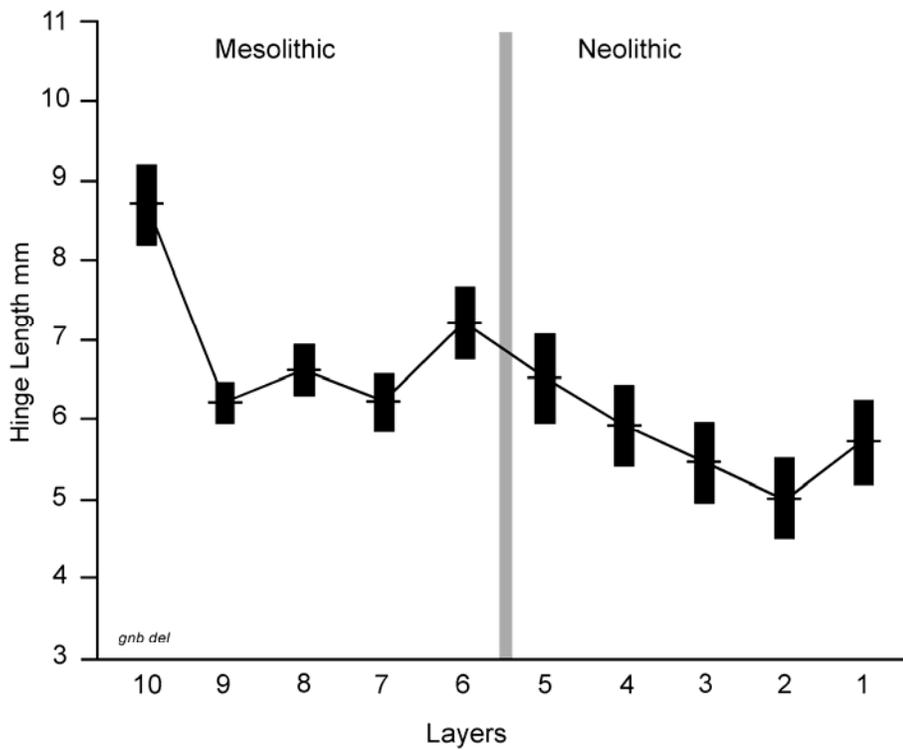


Figure 4. Change in size frequency of oyster shells in the Norsminde sequence. Data from Bailey and Milner (in press).

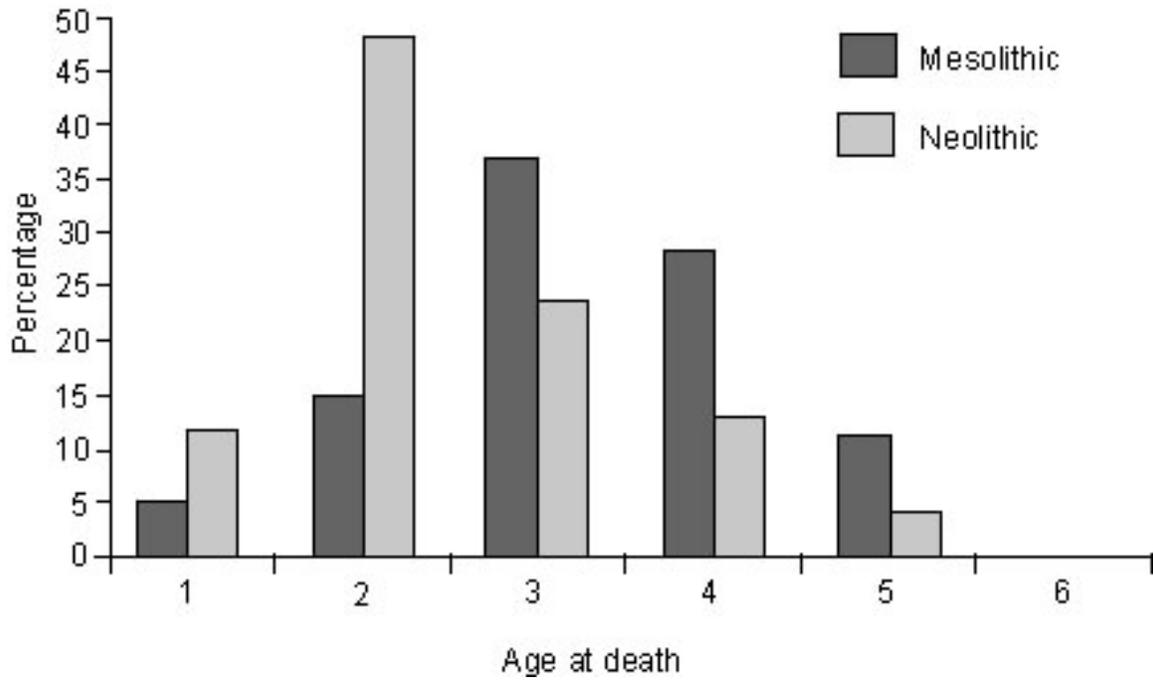


Figure 5. Change in age structure of oyster shells in the Norsminde sequence. Data from Bailey and Milner (in press).

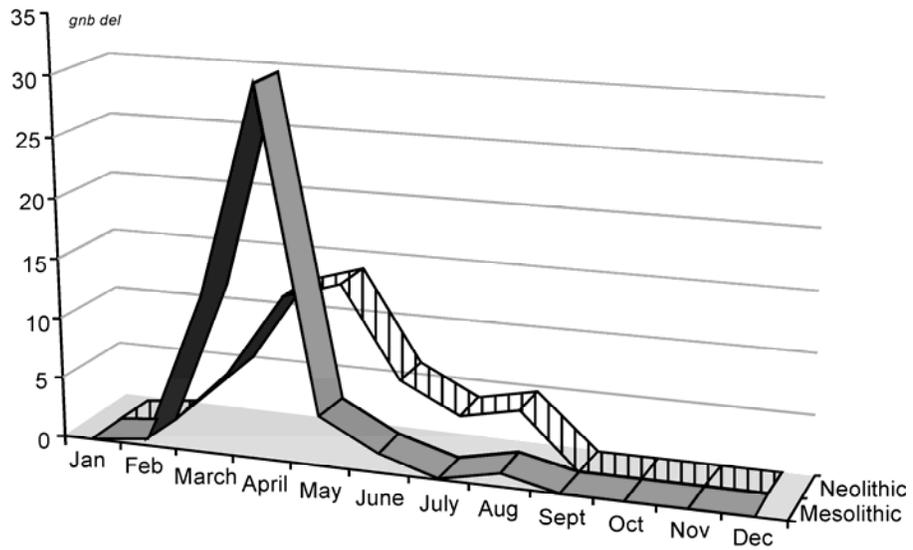


Figure 6. Seasonality of oyster gathering in the Norsminde sequence. Data from Bailey and Milner (in press).

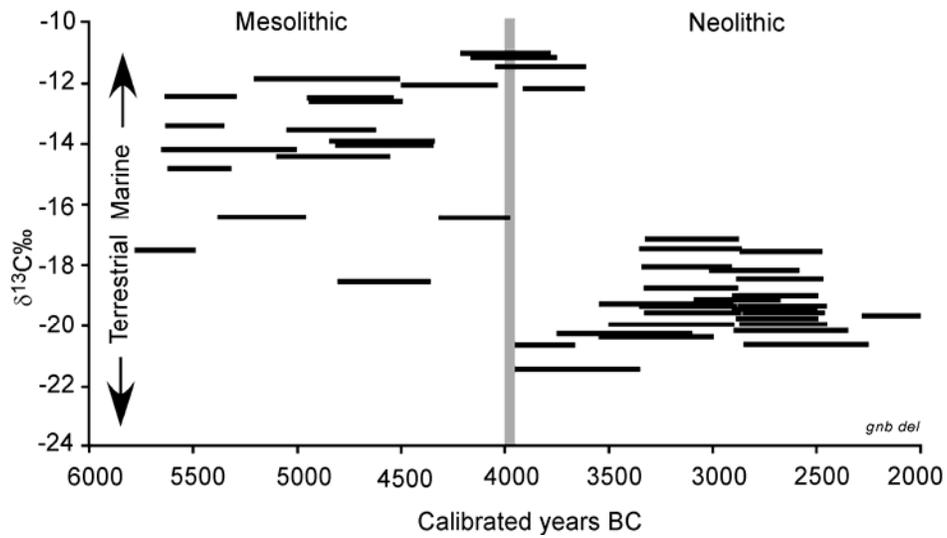


Figure 7. Stable isotope composition of human skeletal material from Mesolithic and Neolithic contexts in Denmark. Data from Milner et al. (2004)

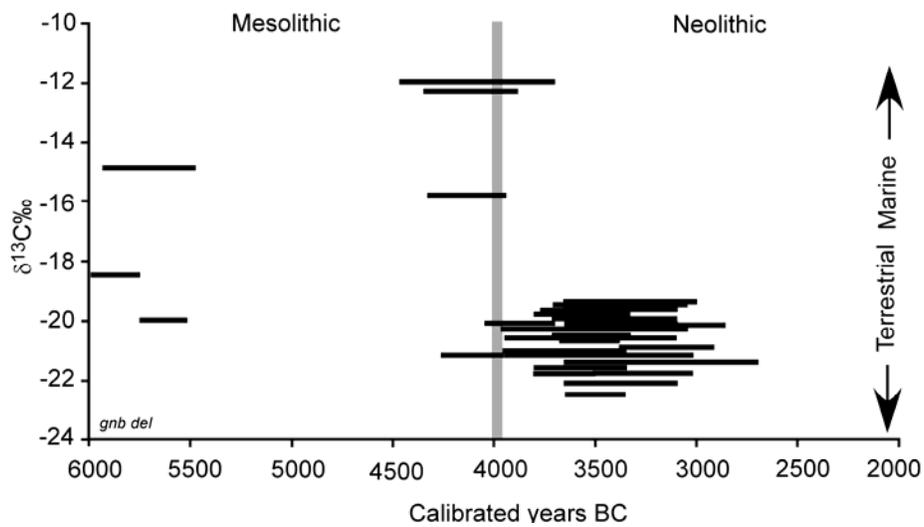


Figure 8. Stable isotope composition of human skeletal material from Mesolithic and Neolithic contexts in Britain. Data from Milner et al. (2004)

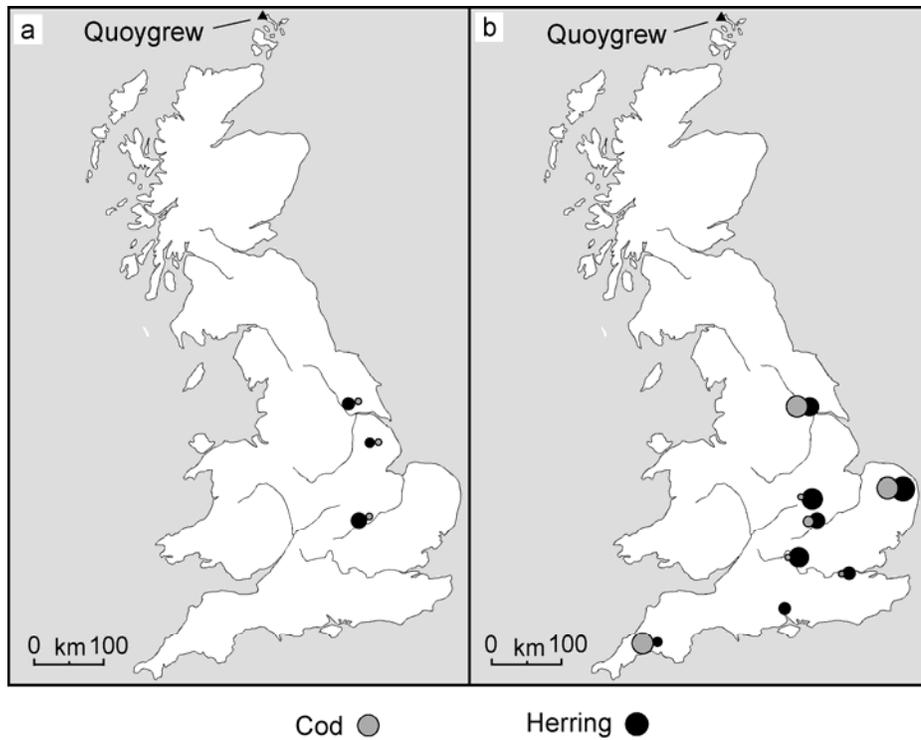


Figure 9. Map of Britain showing location of Quoygrew and changes in patterns of inland fish consumption: a. 9th and 10th centuries AD; b. 11th and 12th centuries AD. Size of circles indicates relative proportion of cod and herring in fish bone assemblages of the two periods. In the earlier period, freshwater fish dominated fish consumption at inland centers. Data from Barrett et al. (2004a). See text for further discussion.

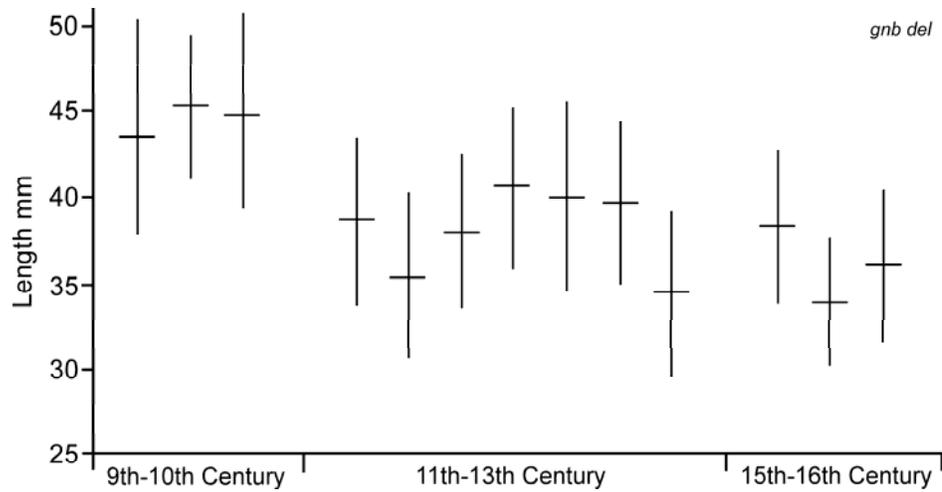


Figure 10. Change in size of limpets in the Quoygrew sequence. Horizontal bar is the mean, vertical bar the range. Data from Milner et al. (in press (b)).

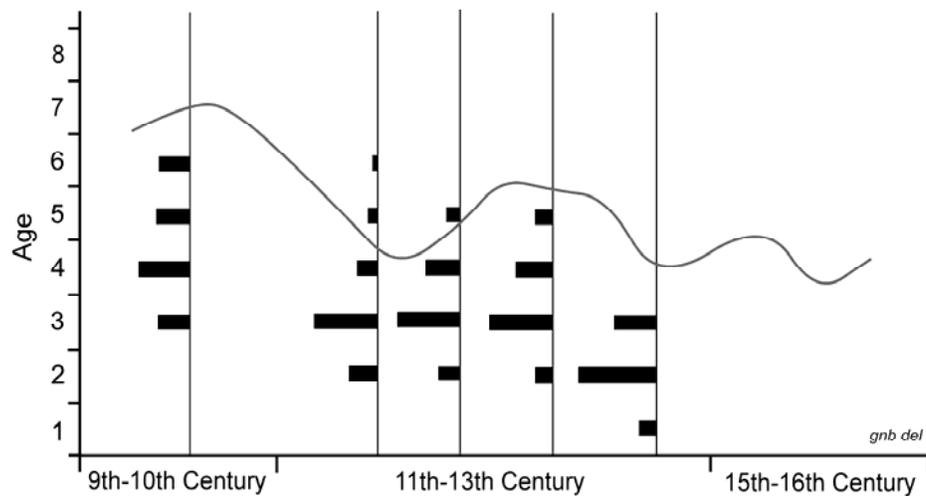


Figure 11. Change in age structure of limpets in the Quoygrew sequence, using the same horizontal scale as in Figure 10. Each age distribution is based on a sample of 30 measurements. The continuous line shows the size trend of Figure 10 for comparison. Data from Milner et al. (in press (b)).

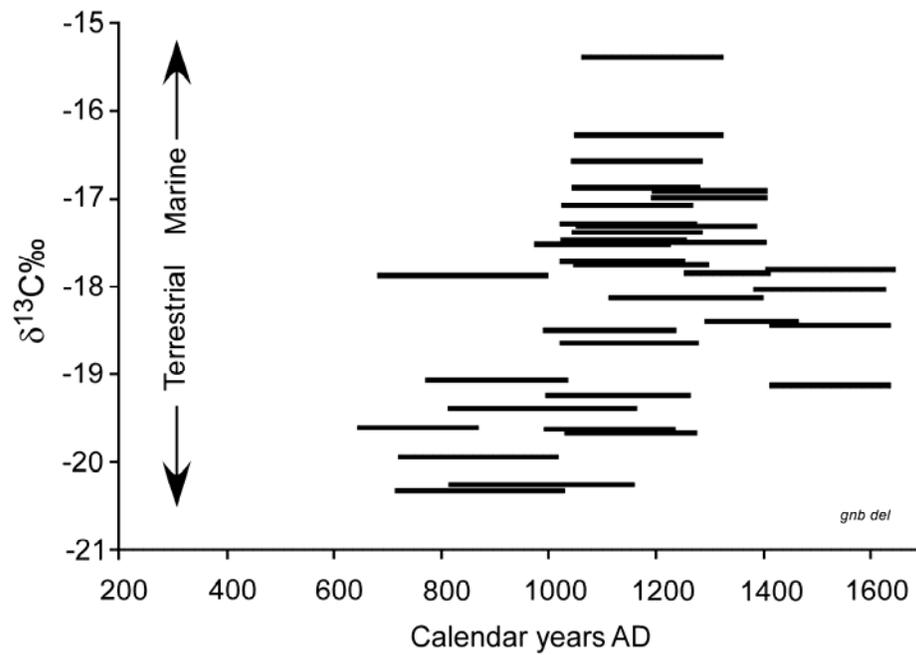


Figure 12. Stable isotope composition of human skeletal material at Newark Bay, Orkney, showing changes associated with the fish event horizon. Data from Barrett & Richards (2004).

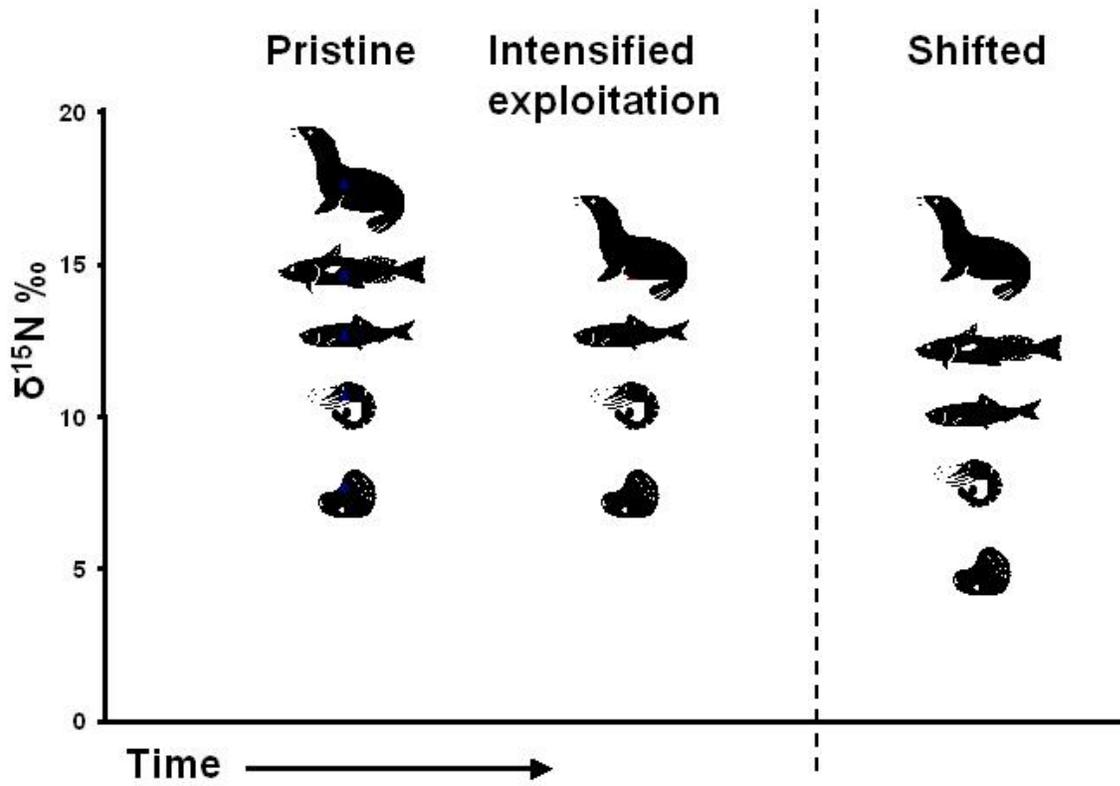


Figure 13. Model of changes in $\delta^{15}\text{N}$ composition of marine organisms in response to fishing down of the food web.