J Mari Arch (2006) 1:9–28
DOI 10.1007/s11457-005-9004-5

ORIGINAL PAPER

Coastal environments and their role in prehistoric migrations

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Abstract In recent years, increased attention has been turned towards the role of coastal environments in facilitating the global dispersal of humans. Previous approaches have focused on locating, dating and linking coastal archaeological sites, in order to create an overall impression of population movement across continents. When considerations of the actual process of colonization have been presented, they have been predicated on a series of assumptions regarding the nature of the coastal environment. The most important of these is that the coastal zone is homogenous and stable, on space and time scales relevant to human migration. This paper aims to test this and other assumptions by considering the true nature of the palaeo-coastal zone on global to continental scales and on timescales commensurate with migrating populations. Evidence is presented from Pleistocene and Holocene palaeo-environmental and archaeological records, so covering the major migrations of the Palaeolithic and Mesolithic. The principal conclusion of this study is that the coastal zone is in fact characterized by a significant degree of environmental heterogeneity and instability on a multitude of spatio-temporal scales. This in turn has significant implications for how we interpret the actual process of colonization.

Keywords Coastlines · Palaeolithic · Colonization · Palaeo-environment · Timescales · Pleistocene

Introduction

For several decades, the dominant perspective in Palaeolithic and Mesolithic archaeology has been that maritime and coastal adaptations were a Late Pleistocene and Holocene

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development, and hence only appeared once global colonization was largely complete (see Erlandson 2001 for review). Recent work has started to question this view and indeed coastal environments are increasingly regarded as having been important routes for the large-scale dispersal of humans across the world (e.g. Fladmark 1979; Stringer 2000). However, actual archaeological evidence for this assertion is sparse, primarily due to the submergence of palaeo-coastlines and coastal zones by the sea level changes of the Quaternary. Consequently, the limited evidence that is currently available to us actually insufficient to unravel the complexities of the colonization process. This paper therefore aims to move away from the archaeological record by arguing that there are certain key environmental aspects of the coastal zone that, if examined in sufficient detail, may provide greater insights as to the role coastlines played in prehistoric migrations. These aspects include changes in climate, sea level, oceanographic conditions, geomorphology and resources. These issues have to be dealt with in order to resolve basic issues of defining the coastal environment, determining its stability in both space and time, and to hypothesise how past humans interacted with it; all of which are central to ideas of coastal migration. This approach should be seen as complementary to traditional archaeological studies and indeed it purposefully seeks to build on the work of both archaeologists (e.g. Flemming et al. 2003) and other Quaternary researchers (e.g. Broecker and Hemming 2001).

Background to colonization

The 'Out-of-Africa' model of human and hominid evolution suggests that *Homo sapiens sapiens* and their hominid ancestors evolved first in Africa before dispersing and colonizing the rest of the world (Klein 1999). Although this model has yet to gain universal acceptance (e.g. Hawks and Wolpoff 2001; Klein 1999; Straus and Bar-Yosef 2001 for reviews), the balance of archaeological and genetic data (e.g. Underhill et al. 2000; Renfrew et al. 2000; Gamble 2001; Rightmire 2001; Forster and Matsumura 2005) currently supports it. The obvious consequence of this theory's acceptance is that humans (from this point on the term 'human' will be used with reference to both *H. sapiens sapiens* and earlier hominid species), having dispersed out of Africa, were capable of traversing large areas, until, by the start of the Holocene, the planet was almost entirely populated.

In recent years, various strands of evidence, coupled with a growing interest in the potential underwater archaeological record of inundated continental shelves (e.g. Flemming 1998), have stimulated interest in the idea that some of these dispersals may have been accomplished by using coastlines as migration corridors. For example, Stringer (2000) outlined a potential coastal migration route from Africa to Asia, while Flemming et al. (2003) have advocated prospecting for sites in the vicinity of areas that would have been crossing points at times of lower sea level (e.g. the Straits of Gibraltar).

While the impetus behind studying coastal migration routes is recent, the idea that coastlines represent potential migration corridors is not. As early as 1960, Heusser proposed a coastal route for the initial entry of humans into North America. This view was later coherently formulated by Fladmark (1979) who argued that humans did not enter North America via an ice-free corridor dividing the Laurentide and Cordilleran ice sheets, as commonly perceived, but instead moved along ice-free refugia situated on the Pacific Northwest coast. Although originally regarded with some scepticism by the majority of North American researchers there is now greater acceptance of Fladmark's coastal route (see Dixon 2001 for review). This is the result of direct palynological, faunal and geological evidence of coastal refugia on the continental shelf (Josenhans et al. 1995; Mandryk et al. 2001; Hetherington et al. 2003) and the identification of sites that pre-date the opening of the ice-free corridor (e.g. Monte Verde: Dillehay 1997). In other parts of the world, coastal routes have been considered in less detail, though a number of glimpses of potential coastal/marine adaptations are known from the archaeological record. Recent work in East Africa has provided evidence for coastal adaptations as early as 125 ka (Walter et al. 2000), whilst entry into Australasia, even at times of lowered sea level, is believed to have required a sea crossing of several tens of kilometres (Van Andel 1989).

Current approaches to understanding the colonization process

Existing approaches to the study of coastal colonization operate on the basis of what could be described as a 'site-oriented' method. That is, they aim to locate, excavate and date sites and then link them to demonstrate a route (e.g. Flemming et al. 2003) or use them to suggest potential colonization processes (e.g. Mannino and Thomas 2002 who describe migration driven by the availability of shellfish). These studies are supported by local palaeo-environmental evidence (e.g. Hetherington et al. 2003), while the patterns of migration are further constrained by genetic research (e.g. Forster and Matsumura 2005). Due to issues of preservation and the sheer difficulty of locating primary context archaeology in submerged environments (see Flemming 1983) there is arguably a limit on the volume of archaeology that may be discovered in the near future. Consequently, this 'site-oriented' method presently provides more information about the products of colonization rather than the actual process. In effect, it provides detailed information about what happened at sites A and B, but little information as to how humans actually moved between them.

Attempts to resolve the processes of colonization through the coastal zone are also hindered by the actual temporal and spatial scales involved. Even some of the most rapid colonization events would still have taken several hundred to several thousand years given that the distances in question spanned thousands to tens of thousands of kilometres (e.g. Macaulay et al. 2005). Note for example, that predicted rates of human dispersal into the Americas (albeit utilizing inland rather than coastal routes, and based on modelled assumptions) are of the order of 6–10 km/yr (Hazelwood and Steele 2004). Therefore, considering that the approximate distance from Beringia to the tip of South America is 13–14000 km, even the most rapid migration would take 1300–1400 years. Consequently, if sites A and B are far apart in space, they are also distant in time, thus increasing uncertainty as to the nature of the connection between the two.

Further issues arise over the fact that archaeological evidence of coastal use may not always present a clear-cut picture as to the nature of the coastal environment and the activities of past humans. For instance, evidence of prehistoric coastal use is often based on the existence of shell middens. However, as Bailey and Milner (2002: 6) have pointed out, "*the distribution of shell mounds is probably a poor predictor of the distribution of coastal populations or marine oriented economies*." This stems from the fact that shells tend to preserve well in the archaeological record, while those of other resources, such as fish bones, do not (see also Erlandson and Moss 2001 for further taphonomic issues). In addition, stable isotope analysis, a technique that is commonly regarded as providing secure evidence of dietary patterns (e.g. Schulting and Richards 2001), requires its interpretations to be approached with some caution (Bailey and Milner 2002).

Ultimately this site based approach means that the coastal environment between sites is treated in a rather perfunctory manner. This is reflected by the fact that a number of key assumptions about the coast continually find their way into the research literature. These can be summarized as follows:

1. Coasts provide more equable climatic conditions than inland areas (e.g. Fladmark 1979).
2. Coasts provide more stable habitats than inland areas (e.g. Yesner 1980; Stringer 2000).
3. Coastal environments are relatively uniform along the length of a coastline (e.g. Stringer 2000; Mannino and Thomas 2002).
4. Coasts have a diverse, and often more productive, array of resources compared to inland routes due their ecotone (boundary between two ecosystems, hence combining characteristics of each) status (e.g. Bailey and Parkington 1988; Flemming et al. 2003).
5. The restricted topography of coasts (i.e. the presence of the sea) focuses migration routes and simplifies navigation (e.g. Mithen and Reed 2002; Kelly 2003)

Some of these qualities are believed to have attracted humans to the coast in the first instance (e.g. points 1, 2 and 4; Flemming 1996), while others are believed to have had greater implications in facilitating large-scale dispersal along coastlines (e.g. points 2, 3 and 5; Stringer 2000; Mannino and Thomas 2002; Mithen and Reed 2002).

Given the predominant focus on individual archaeological sites, this instantly raises questions as to whether these assumptions are valid down the entire length of a coastline. In fact, the spatio-temporal stability and homogeneity of coasts implied in much of the previous work seems to be at odds with views expressed by other coastal researchers. Coastal geomorphologists and engineers, for instance, frequently state that the coastlines are dynamic, rapidly changing areas. As Sherman and Gares put it, "*coastal areas are among the most dynamic in terms of physical processes*" (Sherman and Gares 2002: 1). Therefore, if we are to obtain an improved understanding of the role that coastlines played in prehistoric migrations, there is a clear need to test these assumptions.

An environmentally oriented approach

Rationale

The importance of the palaeo-environment is well known to archaeologists; Flemming et al. (2003) have stated the importance of understanding the palaeo-environment at potential crossing points, while Hetherington et al. (2003) have examined in detail the coastal refugia of the Pacific Northwest coast. However, what has not been done is to utilise coastal palaeo-environmental data to answer the more general question as to why the coast may have been a viable and important route for prehistoric migrations and thus test the assumptions outlined in the preceding section. Further, by looking first at environmental data, it may also be possible to avoid some of the biases inherent in the archaeological record, as described by Bailey and Milner (2002).

Examining coastlines in this manner results in a perspective that is large in scale and scope. Nonetheless, this should be regarded as an advantage when dealing with potential colonization routes that spanned large expanses of time (millennia) and space (trans-continental), particularly if undertaken in parallel with more detailed analyses of local-scale sites. Indeed, this adoption of a nested hierarchy of scales parallels current thinking in palaeo-environmental research (e.g. Shennan et al. 2000; Barron et al. 2003a). The approach as detailed in this paper therefore represents the largest scale in this hierarchy. As more archaeological and palaeo-environmental information becomes available, then increasingly smaller scales of investigation can be initiated.

Defining the coastal zone

As well as testing assumptions of coastal stability and homogeneity, another important issue to consider is the spatial extent of the coastal zone. In effect, this should determine where a ‘coastal’ adaptation begins and an ‘inland’ or ‘terrestrial’ one ends. However, defining the coastal zone is a notoriously difficult exercise (Woodroffe 2003). Most coastal researchers agree that the coastal zone is the area in which marine processes influence terrestrial ones, and vice versa. In reality, its exact dimensions vary depending on the needs of the user and the particular environmental features that one uses to delimit it (Finkl 2004). For example, if proximity to marine waters is the primary feature used to define a coastal zone, its dimensions will be a product of the tidal range (which can range from a few decimetres in micro-tidal environments to tens of metres in macro-tidal ones) and the adjacent topography and geology. Hinterland areas with steeper gradients and more resistant geology will restrict the areas over which tidal inundation operates, hence ‘coastal zones’ of hundreds of metres are typical. Conversely, shallow gradients and poorly/un-consolidated geology will be characterised by extensive tidal flats, marshes and halophytic vegetation which may extend up to a kilometre from the shoreline. In extreme cases, particular topographic features such as estuaries and fjords can result in the marine influence extending kilometres inland of the nominal coastline.

By comparison, if one takes a maritime influenced climate as the primary characteristic, then the coastal zone could be taken to extend several hundred kilometres inland depending on regional circulation patterns and topographic features (e.g. mountain barriers). For instance, climate modelling of Northwest Europe has identified that the transition between ameliorated ‘maritime’ and more variable ‘continental’ climates is located several hundred kilometres inland, during both the last glacial stage and at present (Barron et al. 2003a). The maritime climate stems from the continent’s proximity to the North Atlantic, and the fact that in winter, prevailing winds transfer heat from relatively warm water masses (the North Atlantic Drift current), thus increasing winter temperatures up to tens to hundreds of kilometres inland (Barron et al. 2003a; Rahmstorf 2003a).

From the human perspective there are similar problems in terms of defining the “coastal zone.” Erlandson (2001: 301) suggests that modern coastal hunter-gatherers, “*rarely travel more than about 5 or 10 km from a home base to collect food*” suggesting a very restricted relationship with the coastline. When foraging takes place further afield, the remains of marine resources (e.g. shells, skeletons) may not be transported back to the home base. This in itself implies the presence of processing sites located in close proximity to the coastline. This is arguably supported if one considers the attraction of the coastal zone to be purely driven by proximity to maritime resources. In contrast, other ethnographic studies of Arctic foragers suggest they have accurate knowledge of very large parcels of land (Kelly 2003). For instance the Aivilingmuit (Iglulik) knew 52000 km^2 of Southampton Island, Canada (Carpenter 1955), whilst the Central Eskimos could recall an area of 650000 km^2 (Boas 1888).

At present there is therefore no consensus of what should actually be described as “the coastal zone” for colonization purposes. Further, even if a single definition could be found, the area amenable to a coastally oriented adaptation can vary considerably in a cross-shore direction, depending on regional topographic, oceanographic and climatic conditions. Consequently, when considering potential colonization routes, hypotheses of both a spatially restricted coastline hugging zone and a more expansive maritime influenced zone must be considered.

Temporal ranges of perception

If we are to test the importance of the temporal variability of coastal environments, it is vital to consider whether the variability occurs on timescales appropriate to human perception, i.e. was the coastal zone perceived as a stable entity by the migrating population? At the level of analysis presented in this paper, only the most basic or universal principles of perception will be considered.

The overwhelming evidence on the temporal range of perception for hunter-gatherers argues for scales relating to human life spans—i.e. biographical timescales. This can be initially argued on the basis of the simple ecological principle that individuals of all organisms are adapted to cope with climatic variability that occurs within their lifetimes, while longer term (i.e. more persistent) climate changes are dealt with by some combination of adaptive evolution and migration (Huntley 1999). This implies that changes on biographical scales are actively perceived and responded to by behavioural action, while those on longer timescales are responded to by virtue of almost unconscious biological processes. From an ethnographic point of view, an individual hunter-gatherer's repertoire of knowledge is built up over their lifetime through their experience and interactions. As Ingold puts it, "*the world as perceived by hunter-gatherers is constituted through their engagement with it, in the course of everyday subsistence related practices*" (Ingold 2000: 58). This therefore highlights the role of short-term, biographical scale perception when dealing with hunter-gatherer societies.

Nevertheless, the human ability to receive information over longer timescales cannot be discounted. This may takes the form of myths and stories that encode information for coping with environmental change, in the form of generalized and transferable schemes relating to weather, animal behaviour and ecological relations (Kelly 2003). As a result 'social' information about the environment can be built up over timescales longer than a human lifespan, depending on the recurrence time of the climatic or environmental change being recorded (Rockman 2003). For example, oral traditions of the Tareumuit and Nunamuit (both Arctic hunter-gatherer societies) encode oscillations between marine and terrestrial faunal abundances on cycles of 120–200 years by describing them in terms of the movement of animal spirits. "*When wolves starve on land they go to their relatives in the sea and turn into killer whales; conversely, killer whales, when unable to find food in the sea, travel inland and become wolves.*" (Minc and Smith 1989: 20 quoted in Rockman 2003: 6). While it has been argued that oral traditions can transmit information over timescales of several millennia, we must also recognise that the verbal durability of narratives relies on the principle of memorability (Echo-Hawk 2000). In essence, only the most memorable aspects of an event will be transmitted over multiple generations. Thus, environmental oscillations and cycles operating over millennial or greater scales will have small incremental effects from a human point of view and are hence less likely to be remembered and recounted.

In summary, biographical-scale changes would no doubt have been perceived by hunter-gatherers, while oscillations on timescales slightly longer than this (e.g. up to 200 years) may have been recorded in cultural memory. Conversely, very slow oscillations (i.e. hundreds to thousands of years or more) relative to the human perceptual range would have appeared to be invariant, or have such small effects that they were considered to be unimportant.

Structure of coastal environments

The complex structure of coastal environments means that simply assessing the stability and homogeneity of resources and climate in isolation is not a viable option. This stems from the fact that they are intricately linked to other aspects of the coastal system; namely sea level, oceanographic factors and geomorphology. In many instances, these links operate in two directions. Climate, for example, strongly influences oceanographic conditions (e.g. wave regimes), but is in turn heavily influenced by the interaction between the oceans and the atmosphere. Therefore, separating out resources and climate for analytical purposes will lose a sense of the overall patterns of change within the coastal zone.

Consequently, to examine the way in which the environmental factors fluctuate over space and time, the evolution of coastal environments over the course of a transition from a sea level lowstand to a highstand shall be described. These large-scale sea level changes were a fundamental part of the Pleistocene glacial-interglacial cycles, and were the product of the exchange of water between ice sheets and oceans. During cold glacial phases ice sheets expanded and sea levels fell, by up to 140 metres at times of maximal ice build-up (Rohling 1998). During warm interglacials, such as the present day, the ice sheets melted and sea levels rose (see Pirazzoli 1996; Lambeck and Chappell 2001 for comprehensive overviews of sea level change mechanisms).

Lowstand phases

At lowstands, continental-scale ice sheets would have dominated the landscape in areas such as Northern Europe and North America, the climate would have been cold while ice (either sea ice or icebergs) would have extended further (e.g. as far south as the French Atlantic coast during the Last Glacial Maximum—LGM: c.22ka) into the oceans than it does under present conditions (COHMAP 1988). Since coastal climates are heavily determined by sea conditions, this ice, in conjunction with onshore winds, would have played a major role in depressing coastal air temperatures below the commonly assumed ameliorated winter conditions. For example, during the Younger Dryas (12.7–11.5 ka) in Northwest Europe, annual temperature ranges in coastal areas (e.g. Ireland) were up to 34°C (i.e. enhanced seasonality), a value comparable to contemporary inland areas (e.g. Poland). As a point of comparison, the present day annual temperature range for Ireland is around 9–11°C (Isarin et al. 1998). Conversely, the presence of ice may have also proved to be beneficial to a migrating population in that it could have formed part of a coastal adaptation, in effect providing a seaward extension of the coastal landscape, allowing access to otherwise inaccessible areas and resources.

The presence of the continental ice sheets themselves would have also influenced ocean-atmosphere interaction to the point that regional atmospheric circulation patterns would be significantly different to interglacials. This in turn would have created spatial variability in coastal climates on regional scales within the overall global glacial pattern. In the Pacific for instance, the Laurentide ice sheet influenced prevailing wind patterns such that at glacial maxima, the cold California current, which today flows equatorwards along the California coast, was much weaker (Herbert et al. 2001). This in turn created increased sea surface temperatures (SSTs) off the California coast and changing patterns of precipitation and hence vegetation, up to tens of kilometres inland (see also Pisias et al. 2001; Barron et al. 2003b).

Coastal landscapes would also have adopted a particular morphology contingent on the cold, lowstand conditions. For instance, depending on the length of the lowstands, deltas rather than estuaries would have been the most likely geomorphological formation where rivers entered the sea, this being a consequence of their tendency to form under conditions of falling or stable sea level. Note that the majority of the world's current delta systems were initiated only when sea level rise slowed sufficiently in the mid-Holocene (Stanley and Warne 1994). Further, delta environments are typically highly fertile and could have provided significant spatially delimited resources along a single colonization route.

Obviously, these conditions would have impacted on the resources exploited by coastal hunter-gatherers. Temperature differences, such as between glacials and interglacials, are known to affect the distribution of terrestrial plant and animal species (e.g. Davis and Shaw 2001; Schreve 2001), and also coastal or marine species. For instance, as is currently being seen as a consequence of global warming, small changes in water temperatures can have significant effects on fish distribution patterns. Perry et al. (2005) have reported that a 1.65°C change in North Sea bottom temperatures over twenty-five years has resulted in latitudinal shifts in fish stocks of tens to hundreds of kilometres. Therefore, when considering coastal resource stability we also have to take into account that different water temperatures and distribution of water masses would have ensured varying patterns of species distribution. Due to very poor preservation in the geological and archaeological record, data on such distribution changes in prehistory is limited, though some examples do exist. For instance, fish remains from cores off the British Columbia coast indicate that during the late Pleistocene, fish were sparse due to the influx of cold glacial outwash. This contrasts with mid-Holocene evidence of skate, dogfish and sharks, whose presence implies increased water temperatures (Tunnicliffe et al. 2001).

Finally, access to some types of coastal resource may also have improved under lowstand conditions. Recent research has demonstrated that lower sea levels draw down and steepen the coastal water table gradient. This has the effect of enhancing groundwater flow, potentially leading to the development of coastal springs, oases and wetlands on exposed continental shelves (Faure et al. 2002).

Transition phases

It is in the transitional periods between highstands and lowstands, when climate and sea levels were fluctuating, that much of the evidence against coastal stability can be found. Given the amount of evidence to be discussed, it will be divided into climate change, sea level change and oceanographic factors.

Climate change and associated effects

Ice cores from Greenland show that at least 20 rapid (decadal-scale) climate fluctuations took place during the Last Glacial (i.e. 10–80 ka BP) (Fig. 1; Taylor 1999; Alley 2002; Rohling et al. 2003). These 'Dansgaard-Oeschger' (D/O) oscillations were characterized by air temperature warming of greater than 10°C in decades or less (Cuffey and Clow 1997), followed by centuries of gradual cooling, then decadal collapse to an approximately 500 year long stadial (cold period). This sequence then repeats approximately every 1500–3000 years (Rahmstorf 2003b). These D/O oscillations were also possibly present between 340–500 ka BP (Oppo et al. 1998). The coldest parts of D/O oscillations are also characterized by iceberg rafting events, extreme examples of which appear every 6–7000 years (Alley 2002; Rohling

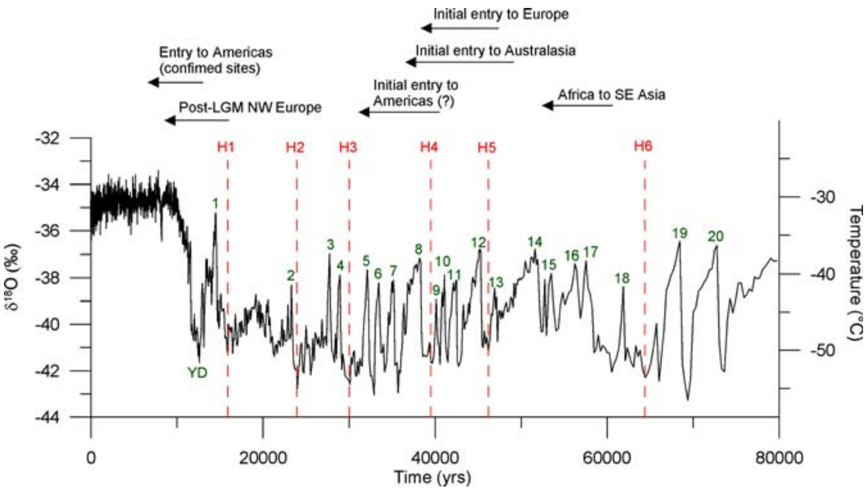

Fig. 1 Record of δ^{18}O isotope fluctuations from Greenland (GISP-2 core). This provides a proxy for ice volume and air temperature over Greenland. Green numbers indicate D/O oscillations, red lines indicate Heinrich events. YD refers to the Younger Dryas event (after Grootes and Stuiver 1997; Cuffey and Clow 1997; Rohling et al. 2003). Superimposed are approximate timings of colonization events undertaken by *H.sapiens sapiens*. The date for the earlier American colonization event is based on Gonzales (2005), the later date on Dixon (2001). The timings of the remaining events have been obtained from Klein (1999); Bowler et al. (2003); Gamble et al. (2004); Forster and Matsumura (2005)

et al. 2003). During these ‘Heinrich events’, ‘armadas of icebergs’ would have choked the North Atlantic as far south as 40°N (Hemming 2004). Antarctic ice cores also record similar, albeit more symmetrical (i.e. slower warming and faster cooling) events, which also precede the Greenland events by c.1500 to 3000 years (Blunier and Brook 2001). While these events are best recorded in the Greenland and Antarctic records, their effects can be seen in palaeo-climatic records from across the globe (Broecker and Hemming 2001; Rohling et al. 2003). Further, in the stadials at least, the palaeo-environmental record suggests that the D/O oscillations were also characterized by regionally dry, dusty and windy conditions (Rohling et al. 2003) which would have impacted strongly on vegetation growth.

The D/O oscillations are also reflected by dramatic shifts in sea surface temperatures (SSTs). For example, during D/O stadials, SSTs off the Portuguese coast fell by between 3–9°C. In the same area, extreme cooling has also been noted for Heinrich events, during which summer SSTs fell to as low as 4°C, compared to average Holocene (i.e. interglacial) measurements of 19°C (de Abreu et al. 2003). These results should not be treated as universally applicable, since different areas may have experienced different degrees of warming/cooling depending on local sea ice extents and circulation patterns. Nevertheless, they do provide an indication of the magnitude and nature of change that was possible under these circumstances.

These oceanic temperature fluctuations would have a direct effect on marine ecology and hence the resources available for human consumption. In particular, it has been suggested that North Atlantic plankton stocks decreased by more than 50% over c.500 years during D/O oscillations (Schmittner 2005). Due to their position at the bottom of the food chain, there would have been a direct and almost instantaneous (i.e. annual timescales or less: Stenseth et al. 2002) knock-on effect on species higher up the chain (e.g. fish). Consequently, oceanic temperature change can be linked directly to marine resource availability in a time frame appropriate to human perception.

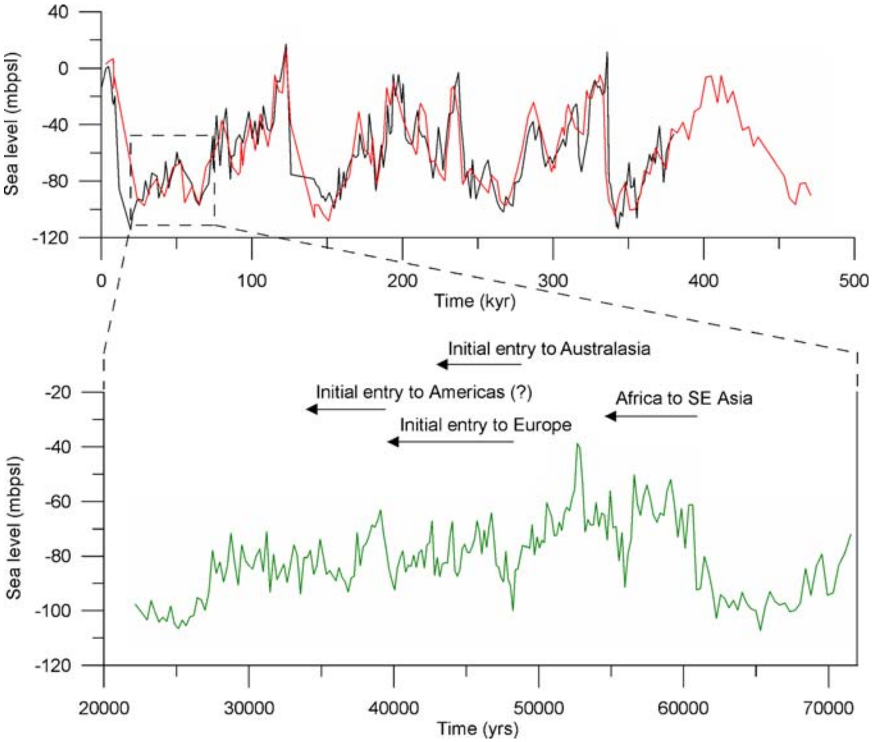

Fig. 2 Sea level curves from Red Sea foraminifera showing estimates of glacio-eustatic change relative to present sea level. Top) Low resolution record showing transitions between glacials and interglacials. Red and black lines represent data from two different cores. Bottom). High resolution record showing millennial-scale fluctuations during the Last Glacial. Both curves have error margins of ±12 m (after Siddall et al. 2003). Superimposed are approximate timings of colonization events undertaken by *H.sapiens sapiens*. The timing of initial entry into the Americas is based on Gonzales (2005), Africa to SE Asia on Forster and Matsumura (2005), Australasia on Bowler et al. (2003), initial entry to Europe on Klein (1999)

Sea level change and associated effects

The dramatic temperature shifts occurring during transitional phases would also have provoked glacio-eustatic change through melting or growth of the continental ice sheets. Recent evidence indicates complete reversals in sea level of up to 30 m on very short timescales (Fig. 2), potentially within the human perceptual range (e.g. Chappell 2002; Siddall et al. 2003; Rohling et al. 2004). These fluctuations have been identified through, and beyond, the last glacial stage as far back as 240 ka BP (Thompson and Goldstein 2005). The speed of these fluctuations has been estimated as between 1–2 cm/yr. As a point of comparison, present day rates of sea level rise, as determined by satellite altimetry, are estimated as 2.4 ± 0.4 mm/yr (3.1 mm/yr after correction for postglacial rebound: Cazeneve and Nerem 2004).

Even more rapid rates of sea level rise could have occurred during these fluctuations since it is unlikely that meltwater release was constant. Examples of these phenomena include rapid rises in sea level at around 14.6 ka BP and 19 ka BP that are believed to represent meltwater pulses (Fairbanks 1989; Weaver et al. 2003; Clark et al. 2004). The magnitude of the former is estimated to be 20 m in less than 500 years (c. 4 cm/yr: Clark et al. 2002;

Weaver et al. 2003; Tarasov and Peltier 2005), and c.10–15 m in less than 500 years for the latter (Lambeck et al. 2002; Clark et al. 2004). It must be emphasized that these rates are estimates of the change in global eustatic sea level and that they would have been modulated on local to regional scales by isostatic, sedimentary, gravitational and tectonic influences. These factors have the capacity to either accentuate or moderate the eustatic component, and should not be ignored as they can result in relative sea level changes of similar or even greater magnitudes; for instance relative sea level falls of 8 cm/yr in areas experiencing considerable isostatic re-adjustment such as eastern Sweden (Berglund 2004).

Whether these changes were perceived or considered important lies not just in the actual vertical change in sea level, but the rate and extent of the resulting coastal flooding/exposure. This is dependent both on the rate of sea level change and the topography of the coastline in question. This can be simply illustrated by the production of hypsometric curves for three contrasting sections of continental shelves: NW Europe, Western North America and the Indian Ocean Rim (Fig. 3). Hypsometry consists of producing a surface-elevation distribution in which the areal percentage of the surface lying in a given elevation interval (bin) is calculated, throughout the whole domain of elevation (Rosenblatt et al. 1994). The cumulative frequency curves presented in Fig. 3 are based on ETOPO-2 (Smith and Sandwell, 1997; U.S. Department of Commerce 2001) data binned at 2 m elevation intervals and give an indication of the percentage of the total area that is represented by each elevation interval. The elevation range has been chosen to represent an even distribution of altitudes about current mean sea level (0 m) and easily encompasses the minimum attained eustatic sea level drop (−120 m) recorded during the Quaternary. Effectively, the steeper the gradient of the curve the greater areal percentage of land a particular band of elevations occupy.

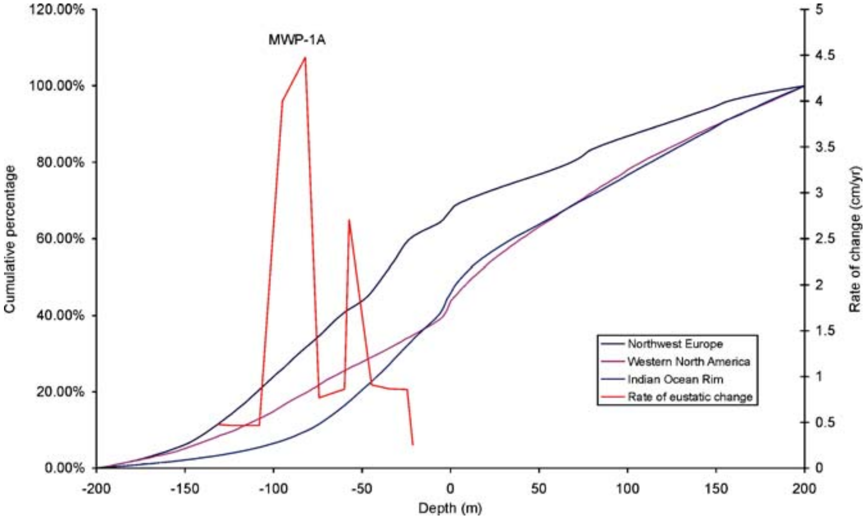

Fig. 3 Hypsometric curves for three different continental coastlines. These curves depict the percentage of continental shelf area at a particular depth/altitude, and demonstrate the variation in continental-scale coastal topography between different regions. Hypsometric plots are derived from the ETOPO2 dataset (U.S. Dept. of Commerce 2001). Superimposed is the estimated rate of eustatic sea level rise for the post-LGM as inferred from Barbados coral data (Fairbanks 1989). Note the obvious increase in rate of rise which correlates to meltwater pulse 1A (MWP-1A; c. 14.6ka). The rate increase at −50 m is present in the Barbados data but not in a number of other records (see Lambeck et al. 2002) and hence will not be considered here

Superimposed on the hypsometric curve is the estimated rate of eustatic sea level rise for the post-LGM as inferred from Barbados coral data (Fairbanks 1989).

It is not the purpose of this paper to present a detailed analysis of these data, but the broad implications of Fig. 3 are that increased rates of flooding would have taken place when shorelines were located between c. −100 and −75 m due to MWP-1A. However, its impact would have been largest along the Northwest European coastline where a greater proportion of the shelf (∼11.6%) is situated at this depth compared to Western North America (∼7.3%) and the Indian Ocean rim (∼5.6%). It should be noted that neither the use of modern day bathymetry nor the purely global eustatic curve will provide a detailed insight to coastal change (Westley et al. 2004) but they can provide gross comparative trends when utilized on a continental scale.

In addition to gross changes in coastline location as a response to sea level rise, it is also important to understand more local geological controls on the rate of coastal change. Work by Pethick (2001) for instance suggests that estuaries can migrate landward at speeds of up to 10 m/yr, whereas open coast landforms can move alongshore at 50 m/yr and ebb-tidal deltas can extend along the coast at up to 300 m/yr; all in response to a sea level rise of just 0.6 cm/yr. Furthermore, research in the Caspian Sea has indicated rates of shoreline movement of several tens of metres in response to a sea level rise of c.10–15 cm/yr (Kaplin and Selivanov 1995; Kroonenberg et al. 2000).

Finally, rising sea levels would also have had direct implications for the terrestrial component of the coastal ecosystem, and hence resources, via increasing salinization of the water table in coastal areas. As well as reducing the amount of available fresh water for direct consumption this would also have resulted in vegetation changes from normal terrestrial species to salt-tolerant ones (Titus 1987). In terms of a true archaeological example of the impact of sea-level driven geomorphological change on an ecosystem, Graham et al. (2003) have documented decreases in the abundance of rocky shore shellfish in southern Californian Holocene shell middens, and their replacement by sandy shore species and inland resources. These changes are interpreted as reflecting a sea level induced change from productive rocky shore kelp environments to less productive sandy beaches.

The data therefore suggests that at both the macro- and meso-spatial scale, rates of sea-level and most importantly coastal geomorphological change can operate on temporal-scales that coincide with the biogeographical and cultural timescales described for prehistoric hunter-gatherers. Direct archaeological evidence for such a hypothesis is generally lacking, although Larsson (2003), has previously postulated (on the basis of the positioning of rock art close to the water level) that rates of sea level change of more than 1m/century (i.e., 1 cm/yr) were perceivable by Mesolithic hunter-gatherers of northern Scandinavia and hence played an important part in their cosmology. To quote Larsson, "*The changes* [in the coastal landscape] *must have been noticeable during a normal life span especially in areas with a low elevation*" (Larsson 2003: 8).

Oceanographic factors and associated effects

The impact of the D/O oscillations on the coastal environment would not only be in terms of temperature and precipitation, because the postulated mechanism that drives these events involves dramatic and rapid changes to the oceanic circulation system. Although consensus has yet to be reached, one of the most prevalent theories argues that freshwater influxes from melting ice sheets were able to reduce, or shutdown, the oceanic 'conveyor belt' of heat transport (which is responsible for maintaining present-day interglacial conditions) thus plunging large areas into a near-glacial state. When melting slowed, the circulation system was switched back on, and climate rapidly warmed. Over time, this would have instigated further ice melting, thus maintaining the cyclical transition between climate states (see Stocker 2000; Broecker and Hemming 2001; Alley 2002; Rohling et al. 2003 for comprehensive reviews). The implications of this are that the oceans are also not stable entities, but are in fact capable of basin wide changes on decadal timescales (Stocker 2000), and hence further calls into question the assumed stability of the 'coastal zone.'

The interaction between sea level and climate change would also have impacted on oceanographic factors such as wave and tidal regimes. For instance, the early Holocene opening of the Straits of Dover led to the conversion of the Southern Bight of the North Sea from a quiet micro-tidal sea to one with a tidal range in excess of 2 m (Van der Molen and de Swart 2001). In the same area, increases in wave height, as a response to sea-level driven basin shallowing, have been predicted (from simple models) for the Holocene (Van der Molen and de Swart 2001).

On their own, oceanographic forces may be directly relevant to strategies of coastal colonization, specifically those that require the use of watercraft, such as the crossing from SE Asia to Australia. It is almost certain that prevailing winds and currents would exert a strong control on the directions that prehistoric watercraft could travel. However, winds and tides would also have influenced coastal migration strategies, via their ability to determine coastal geomorphology during these transitional periods. Barriers for example, are elongate accumulations of sediment that form parallel to the shoreline. For coastal societies these features are potentially very important as they protect the shoreline from storm waves and surges, while the lagoons created between the barrier and the shoreline are often highly productive ecological settings. Barriers however, are more likely to form on micro-tidal (<2 m tidal range) coasts, where wave action is the dominant oceanographic process. Conversely in macro-tidal areas, where waves exert a smaller influence, barriers are much less likely to form (Swift et al. 1991; Davis and FitzGerald 2004).

Reconstructions (Fig. 4) suggest that such a coastline transition may well have occurred along the Atlantic margin of Northwest Europe during the post-LGM transgression, as a

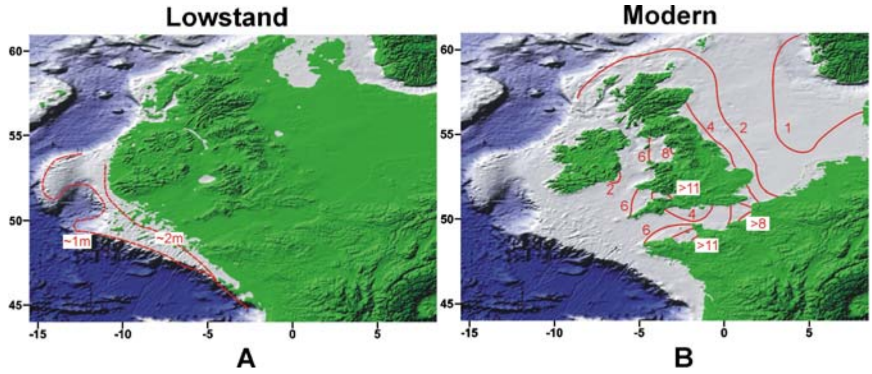

Fig. 4 Differences in large-scale coastline configuration and their impact on regional tidal patterns. A) The Northwest European continental shelf under lowstand conditions (i.e. a glacio-eustatic fall of 120 m). B) The modern coastal situation. The red lines are co-range tidal lines: predicted for the lowstand configuration and actual for the modern coastline. Note that the linear lowstand coastline, in close proximity to the shelf edge, would have been characterized by micro-tidal conditions. In contrast the development of large embayments (e.g. English Channel, Bristol Channel) in response to sea level rise results in enhanced tidal amplification to meso- and macro-tidal ranges

relatively linear lowstand coastline (Fig. 4A) was converted into the highly embayed form typical of the NW European margin today (Fig. 4B). The former shoreline configuration would have been dominated by tidal ranges of 2 m or less due to the relatively small distance to the shelf edge and hence reduced potential for tidal amplification; and an enhanced wave climate driven not only by basin shallowing (as described for the North Sea) but also the increased fetch and stronger wind regimes typical of the mid-latitude Atlantic at the LGM (Shin et al. 2003). As the transgression advanced the NW European shelf would develop increased tidal ranges (reaching an average spring tidal range of 12.3 m at the head of the Bristol Channel—the second highest in the world), reduced wave climates and the development of major estuaries and mud-flat systems.

Highstand phases

Even under present-day interglacial conditions (i.e. warm climates and relatively stable sea levels), a degree of variability/instability is inherent in coastal environments. Large-scale fluctuations in climate and oceanographic conditions are evidenced by the phenomena such as the El Niño Southern Oscillation (ENSO) and the North Atlantic Oscillation (NAO). The former is manifest by changes in SSTs off the eastern coast of South America at intervals of 2 to 10 years while the latter involves variations in the direction and strength of the westerly winds blowing across the North Atlantic (Stenseth et al. 2002). Importantly, both these occurrences have been linked to rapid changes in climate, such as varying precipitation patterns, and dramatic fluctuations in marine ecology. The ENSO for instance has been linked to mass die-offs of fish, plankton and their predators (marine mammals and seabirds), while the NAO is implicated in fluctuations of cod, herring and sardine stocks (Stenseth et al. 2002). There is no reason to assume that these changes did not take place in the past. For instance, evidence suggests that the ENSO was active in the Pleistocene as well as the Holocene (Keefer et al. 1998).

In addition, in many parts of the world, coastal engineers are engaged in continual management of coastlines in order to maintain their current geomorphological configuration. Beach nourishment, for instance, involves replenishing eroding beaches with sand brought in from other areas. This is a common practice in many parts of North America and Europe, and often represents an ongoing process, rather than a permanent solution to beach erosion (Woodroffe 2003).

Furthermore, we also have to consider that the present interglacial highstand situation may be atypical with respect to the Pleistocene. In fact, variations in the amount of insolation the Earth receives and hence its climate, are much smaller than at any time in the last 350,000 years. The Holocene may therefore be an exceptionally long and stable interglacial, whose nearest analogue is Marine Isotope Stage (MIS) 11 (c.405–340 ka) (Loutre and Berger 2003). Evidence of this can be seen in the fact that recent sea level records have shown eustatic oscillations of 10–15 m within interglacials MIS 5 and MIS 7, when it is commonly assumed that sea levels had reached a stable highstand position similar to today's (Thompson and Goldstein 2005).

Finally, the current coastal state reflects some 5–6000 years of relatively constant eustatic sea level coupled with a lack of continental ice sheets. Barring interglacial periods, Pleistocene highstands, such as during D/O and Heinrich events, would have been much shorter and subject to climatic influences resulting from perturbation by the ice sheets. In short, what this all implies is that present day coastlines, and hence our ideas about coasts, are the product of relatively unique environmental circumstances. Therefore we have to consider the fact that coastal environments, even under past highstand conditions, may have been quite different, certainly in terms of their stability and homogeneity.

Discussion

This paper therefore demonstrates that the archaeological assumptions regarding the coastal zone may be inappropriate to studies of coastal migration. Evidence for this comes from a variety of palaeo-environmental records which collectively suggest that rapid fluctuations (both in space and time) of sea and air temperatures, sea level, coastal geomorphology, oceanographic factors and coastal resources prevailed throughout much of the Pleistocene.

Therefore, if we are to view coastlines as a viable migration routes, we have to recognize their complexity and diversity, instead of focussing on homogeneity and stability. It must be stressed that this position does not rule out the possibility that coasts were used for migration; rather the role of the coast has to be seen as more than just a passive entity facilitating dispersal.

Consequently, three different scenarios can be envisaged:

1. The dynamism of the coast provoked people into rapid movement, as they sought new but familiar environments, as those they were in began to change around them.
2. The process of colonization may have been a more organic process of inland and coastal adaptation with behavioural flexibility the key. Groups may have been able to utilize both inland and coastal environments to varying degrees depending on the circumstances that they found themselves in.
3. If it does transpire that the key to coastal migration was in fact environmental stability, then it may be possible, through detailed analysis of palaeo-environmental records, to identify windows of stability amidst the dynamism in which pulses of migration were most likely to take place.

With respect to all three scenarios, a secure definition of the coastal zone and what constitutes a coastal adaptation is essential. This stems from the fact that some of these critical aspects of the coast can have effects that extend well inland of the shoreline depending on regional and local conditions. Hence, a secure archaeologically relevant definition of the coastal zone would provide a boundary that allows distinction between inland and coastal strategies of colonization. However, the influence of regional to local conditions means this can only be done once this approach has been shifted down to the next scale in the analytical hierarchy.

The next stage of this research should involve the application of the principles identified in this paper to specific coastlines, such as the west coast of the Americas, or the Indian Ocean shoreline. A relevant coastal zone can be defined and perceptually relevant changes in climate, sea level, geomorphology, oceanography and resources assessed. At this stage, archaeological and genetic evidence from the relevant period and region can also be integrated. Doing so may provide insights as to whether coastal migration was likely given the circumstances, and if so, what environmental processes existed that past humans would have had to contend with.

Conclusion

In recent years, archaeologists have begun to focus intensively on coastlines as an important component in the large-scale global dispersal of humans. In doing so, existing archaeological work has concentrated primarily on a bottom-up approach geared to locating and dating sites. However, this methodology is hindered by the submergence of much of the potentially relevant evidence by the Late Pleistocene sea level rise, while the theoretical principles underpinning coastal colonization appear to be based on the assumption that coastlines are characterised by environmental stability and homogeneity.

Therefore this paper has presented a complementary 'top-down' approach that examines coastlines at a global scale primarily through available palaeo-environmental data. This approach has demonstrated that archaeological assumptions of environmental stability may be inappropriate to the periods in question, as it is now apparent that coastlines may have been characterized by periods of intense spatial and temporal instability that would almost certainly have been perceivable by past humans.

At this stage of the development of this approach, the human responses to these fluctuations and subsequent strategies of colonization cannot be advanced beyond broad general scenarios. It is therefore intended that future stages of this work will decrease in scale, focus in on particular coastlines, thus providing a better understanding of the nature of the coastline in question, and hence a clearer idea of the processes through which past humans were able to utilize it as a means of migration.

Acknowledgements This work was supported by a Richard Newitt Bursary from the University of Southampton and a grant from the English Heritage Aggregates Levy Sustainability Fund (Project 3362). We wish to thank J. MacNabb and J. Steele for advice and stimulating discussion, and E. Rohling and M. Siddall for providing us with sea level data from the Red Sea. We are also grateful to H. Pälike and an anonymous reviewer for constructive comments on the submitted draft.

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