The Influence of Enhanced Post-Glacial Coastal Margin Productivity on the Emergence of Complex Societies

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Abstract

We analyze the dynamics of post-glacial coastal margin (CM) productivity and explore how it affected the emergence of six complex CM societies. Following deglaciation, global relative sea level stabilized after ~7000 BP and CM productivity significantly increased in many areas. Primary and secondary productivity (fish) likely increased by an order of magnitude or more. Aquatic animals were readily available in the CM providing sources of polyunsaturated omega-3 fatty acids, high quality protein, and nutrients, especially essential to human nutrition. In all six case studies, mature CMs appear to have been occupied by Neolithic agricultural and fishing villages within ~500 years of sea-level stabilization. Within a few hundred years population densities increased and roughly a millennium later social ranking and monumental architecture appeared. Sea-level stabilization and increased CM productivity in conjunction with agricultural intensification in lower alluvial floodplains were major contributors to the origins of many complex CM societies.

Keywords: origins of complex society | relative sea level | estuarine ecology | paleo-diet | polyunsaturated fatty acids | DHA | oceanography | archaeology | coastal science

Article:

Introduction

This study hypothesizes a link between sea-level stabilization beginning about 7000 BP (all dates are calibrated years BP) and the origins of complex coastal social organization of two or more administrative tiers. Anatomically modern humans require a great deal of long chain polyunsaturated fats or lipids (especially docosahexaenoic acid or DHA, and arachidonic acid) that are important components of the brain and sensory nervous system. These lipids, primarily derived from animal sources, are required for gestation, lactation, and adult maintenance (Broadhurst et al. 2002; Crawford et al. 2008; Scherer et al. 2007). Animal foods containing DHA-rich lipids are much more abundant in estuarine, lacustrine and lower river alluvial plain environments than other habitats (Broadhurst et al. 2002). DHA has been the chemical of choice for making brains for 500 million years, ever since brains have existed, in spite of there being similar molecules. Apparently DHA molecules are the best electrical signal conductor: they are the semiconductors of brains (Crawford et al. 2008:67). During growth, to some degree controlled by arachdonic acid, brains will only substitute similar molecules under extreme conditions of deprivation and generally with mental retardation as a result. During the Holocene

(11,700 BP to present), sustaining large populations would have been difficult without sufficient lipids and animal protein as existed in CM resources.

We previously presented information that relative sea-level stabilization supported increases in CM resources on flat inner continental shelves and lower alluvial valleys, which seem to be clearly correlated with bourgeoning late Neolithic populations and their eventual evolution into complex societies (Day et al. 2007; Day et al. 2004). In this article we expand our investigations of these linkages by examining local sea-level stabilization chronologies and the impact of resulting increases in CM resources on the diets of local communities. We chart the development of six societies with data available on local sea-level stabilization and prehistoric diets. Our objective is to provide a proof of concept that linkages between increases in CM resources and increases in Neolithic populations evolved into complex societies.

We recognize that other factors influence the development of complex cultures including shelf width and depth, topography, intensification of agriculture, climate, and pre-existing Neolithic populations. These factors affected the specific trajectories of the development of complex cultures in different regions but we suggest that the establishment and evolution of coastal ecosystems is an important component of the origins of complexity in the regions we have studied.

Change in Sea Level since the Last Glaciation

The Last Glacial Maximum occurred between 26,500 to 19,000 BP when ice sheets were at their greatest extent (Clark et al. 2009; Peltier and Fairbanks 2006). The onset of Northern Hemisphere deglaciation was induced by an increase in northern summer insolation (Clark et al. 2009). It caused a rapid rise in sea level by transferring approximately 50 million cubic kilometers of water from terrestrial ice sheets to rising global sea levels. In regions beyond the major glaciation centers (so called intermediate and far-field locations), sea level rose by as much as 120 m (Lambeck et al. 2002). This caused shores to move rapidly across continental shelves (Fleming et al. 1998). In contrast, sea levels fell in regions once covered by the major ice sheets (near-field locations) as a consequence of isostatic “rebound”, which may locally reach 500 to 1000 cm/century (Shennan et al. 2006).

Relative sea-level changes are part of a complex pattern of interactions among eustatic, isostatic (glacio and hydro), tectonic and local factors (Lambeck et al. 2002; Milne et al. 2005; Peltier 2004), all of which have different response timescales and the relative importance of which has changed temporally and spatially. Clarke et al. (1978) identified five types of sea-level curves (I-V) that reflect a range of relative sea level (RSL) histories recorded on coasts that have emerged, submerged, or are in transitional areas and record a combination of both uplift and subsidence (Figure 1). Although these curves provide the general impression of the rate and direction of RSL change, they do not reflect the now-understood true uncertainty associated with estimates of the altitude and age of former sea levels.

Figure 1. Sea-level zones and typical relative sea-level curves deduced for each zone by Clark et al. (1978) under the assumption that no eustatic change has occurred since 5000 BP. (adapted from Clark et al. 1978)

The six societies we describe in this paper are from intermediate and far-field locations. Therefore, they are characterized by rapid relative sea-level increase following deglaciation. The eustatic contribution to sea-level change during deglaciation averaged 100 cm/century. However, peak rates potentially exceeded 500 cm/century during “meltwater pulses” at 19,000 and 14,500

BP (Alley et al. 2005). Empirical data (Bard et al. 1996; Fairbanks 1989) and glacial isostatic modeling studies (Fleming et al. 1998; Lambeck et al. 2002; Milne et al. 2005; Peltier 2004) suggest a significant reduction in the eustatic contributions to sea-level change at ~7000 BP when the earth entered into a period of relative sea-level stability. After this, ocean elevation changed only by two or three meters.

At far-field locations (distant from glacial centers), relative sea-level observations are commonly characterized by a mid-Holocene (7000-5000 BP) sea-level maximum, or highstand (Milne et al. 2005). The slight fall of a meter or two in relative sea level from 4500 BP until the second half of the 19th century is a result of ongoing isostatic processes. These include local hydro-isostatic loading (termed continental levering) and a global fall in the ocean surface due to both glacio- and hydro-isostatic loading of the Earth's surface (termed equatorial ocean siphoning, Milne et al. 2005).

Increased Productivity of CMs in the Mid Holocene

Continental margins are commonly referred to as coastal margins or coastal margin ecosystems (CMs) and include continental shelves, near shore upwelling zones, estuaries, deltas, and lower river floodplains that are influenced by sea-level changes (Day et al. 2007:1). The latter is normally to the first shoals/falls/rapids of rivers and may extend hundreds of kilometers inland (~800 km for the Mississippi and Yellow rivers, see for examples, Brooks et al. 1986; Liu 2004).

The onset of Holocene conditions, stabilization of relative sea level, and the warming of the global oceans, acted synergistically two ways to increase productivity of CMs worldwide (Figure 2), probably from less than 300 g dry matter $m^{-2}yr^{-1}$ to more than 2000 g dry matter $m^{-2}yr^{-1}$. As sea level stabilized after ~7000 BP, the area available for CMs increased greatly because it placed CMs higher on inner continental shelves (i. e., Roberts 1997; Stanley and Chen 1996; Stanley and Hait 2000; Stanley and Warne 1993a, 1993b, 1997, 1998). The slope of continental shelves ranges from 1 in 1000 (steep) to 1 in 20,000 (flat, e.g., the Persian Gulf) compared to 1 in 200 for the steeper continental slope. Thus, a typical, productive estuarine depth range of 10 m is as little as 2 km wide near the shelf break compared to as much as 200 km on the inner shelf. At low stands of sea level, more of the CM would be over deeper slope water. Thus, CM productivity was greater at high stands of sea level both because productivity was higher on a unit area basis and the total area of CMs was much higher.

Figure 2. Width of a zone with a 10 meter depth range as sea-level rises across the continental shelf where more of the system is located over shallow shelf waters.

As relative sea level stabilized near its present elevation high on the continental shelves, there was a great expansion of estuaries, wetlands (Stanley and Hait 2000), enclosed bays, and reefs. Lower river flood plains (Figure 3) developed near-surface water tables and fertile river levees (Kennett et al. 2003). This is especially so near the mouths of large rivers where deltas formed (i. e., Roberts 1997).

Figure 3. Changes in lower river floodplain configurations following sea-level stabilization (adapted from Kennett and Kennett 2006).

Another function of the cessation of rapid sea-level rise is the stability of CMs. During deglaciation, on a 100 km wide continental shelf, the sea moved landward about a km per century while depth increased 100-200 cm/century during some phases of the Late Pleistocene. CMs are less productive at high rates of sea-level rise because large areas of very high productivity habitats (i.e., reefs, wetlands) cannot form because they are continually drowned. Thus, estuaries had low levels of productivity during most of the early Holocene period.

The same reasoning holds for lower river valleys. During the low stand of sea level, lower river channels were deeply entrenched and flood plains narrow compared to today (Kennett and Kennett 2006, see Figure 3). Frequent inundations in narrow flood plains would have prevented the establishment of large permanent settlements, especially major urban areas with monumental architecture. There would have been little subsurface water table to support agriculture or human populations on adjacent highlands. In addition, rapid infilling of entrenched lower river channels during sea-level rise also would have prevented the development of large urban centers.

Table 1. Primary productivity of coastal margin ecosystems (g dry matter $m^{-2}yr^{-1}$). (sources Mann 1982, Whittaker 1975)

Holocene conditions acted on CMs by increasing per unit productivity. It is known that the primary and secondary (e.g., fisheries) productivity per unit area of CMs, especially estuaries and lower floodplains, is among the highest on Earth (Table 1). This productivity is supported by a variety of prolific, shallow-water, primary-producer communities: wetlands including marshes and mangroves, sea grasses, phytoplankton, macroalgae, benthic algae, and floodplain forests. Dry matter productivity increases dramatically from open ocean water (125 g dry matter $m^{-2}yr^{-1}$), to shelves (300), upwelling areas (500), to estuaries (2000) and lower river floodplains (1000). In ocean waters, most phytoplankton production is consumed in the microbial food web, but in estuaries much more is channeled into large, fishable organisms higher in the food chain (Calbet and Landry 2004; Del Giorgio and Cole 1998; Ducklow and Ducklow 1993; Landry and Calbet 2004). Important to our discussion of early complex societies to follow, estuarine fisheries are high per unit area (50-500 kg $ha^{-1}yr^{-1}$), compared to shelf (10-200) and ocean (1-50) systems (Nixon 1992, see Figure 4c).

Among the Holocene conditions favorable to higher per unit productivity were, temperatures, light, nutrients, nitrogen, sediments and intertidal habitats.

Figure 4. Relationships among freshwater residence time, nitrogen retention, aquatic primary productivity, and fisheries for estuarine systems. After sea level stabilized, estuarine systems became larger and more enclosed by barrier islands. (A) This led to longer residence times and more nitrogen retention. (B) This coupled with higher nitrogen input from increased river flow led to higher aquatic primary productivity. (C) In marine systems, primary production is related to fisheries yield with estuaries being greater than ten times more productive than open marine systems. See text for references.

Temperatures: During the post-glacial period, global average temperature increased by 8ºC (Petit et al. 1999) and biological activity usually increases non-linearly with temperature. Latitude provides an analogy with productivity of similar habitats being generally higher in the tropics and subtropics than toward the poles (Mendelssohn and Morris 2000).

Light: Estuarine wetland area is related to the amount of fisheries reflecting the high secondary productivity of fishable organisms (Turner 1977). In far field and intermediate regions, rising sea level from the steeper outer edge of continental shelves, to flatter inner shelves led to light conditions that were progressively more favorable for aquatic producers. The inner shelf conditions allowed wider, shallower communities of primary producers. The response of submerged primary producers to light follows Michaelis-Menton kinetics (Day et al. 1989). Light levels decrease exponentially with depth, so total water column above the critical depth is important for net photosynthesis. Critical depth is the depth where photosynthesis equals respiration. Above critical depth there is net production of organic matter. Estuaries with broad areas above critical depth, as occurred in the Holocene, are more productive.

Nutrients: Terrestrially derived nutrients are also important to CMs. Nutrients were elevated by increased river discharge rates in the Holocene, especially in the early and mid Holocene (Gasse 2000). The input of nutrients in river discharge is related to coastal primary production (Nixon 1992) and fisheries (Nixon 1982, see Figure 4C). The kinetic response of CME primary producers to nutrients also follows Michaelis-Menton kinetics (Day et al. 1989).

During the last glacial maximum, river flow was lower and discharge was generally into oceanic waters on outer shelves and continental slopes. Nutrients in outer shelf waters would have been diluted by open ocean water (see Figure 2). Conditions were similar to current western continental margins of much of the Americas with narrow continental shelves and river discharge mostly to open oceans. In upwelling areas, as off Peru, however, near-shore phytoplankton productivity was very high leading to dense populations of plankton feeding fish. These played an important role in the diet of the societies we discuss for the Peru region. Discharge to shallow, broad, inshore areas such as the Mississippi and Grijalva river deltas on the Gulf of Mexico was uncommon. As sea level stabilized on inner shelves and CMs became enclosed and river water residence time increased substantially, CM habitats (barrier islands, deltas, estuaries, mollusk reefs, lower floodplains) could develop to their fullest.

Nitrogen: Nitrogen is an especially important nutrient. Nitrogen generally limits CM productivity (Day et al. 1989). The log of freshwater residence time is related to nitrogen export to the open ocean (Nixon et al. 1996, see Figure 4A), so the increase in residence time in broad, enclosed CMs resulted in less nitrogen exported to the ocean. Productivity increased dramatically.

Sediments: River discharge also carries high levels of sediments important in the formation of coastal wetlands. As long as sea level was rising, wetlands that became established faced drowning. In the Mississippi delta, the earliest deltaic lobe is only one of seven major delta lobes that have no surface expression because it was inundated as it was formed (Roberts 1997). Fresh sediment supply is necessary to co-elevate wetlands with upward changes in sea level.

Intertidal habitats: Intertidal reef communities such as oysters and clams have very high biomass and serve as a habitat for many species of fish (Turner 1977). They contribute greatly to estuarine productivity by providing food and habitat for estuarine consumers and in conserving and recycling nutrients.

In summary, we believe that initially, rapid sea-level rise and coastal advance resulted in small, ephemeral, intertidal communities. As relative sea level stabilized in the shallows of the continental shelves, the area of intertidal habitats increased dramatically (Kennett et al. 2003; Stanley and Hait 2000) while their productivity was augmented by better light conditions, more river input, higher temperatures, and greater nutrient availability. At the low stand of relative sea level, rivers flowed across the coastal plain in entrenched valleys and discharged to the outer shelf and slope, which had relatively low productivity. An exception was upwelling coasts where high phytoplankton productivity was maintained by nutrients in the deeper upwelled water. The rise and stabilization of sea level led to flooding of lower river valleys, infilling incised river channels, and the formation of extensive floodplains. An important consideration for this study is the decades to centennial times scales required to establish widespread, mature coastal habitats such as shellfish reefs and intertidal wetlands that were also accessible to humans (i.e., Roberts 1997).

CM Productivity and Origins of Complex Societies

Significant to human coastal margin residents is that maritime and terrestrial habitats are often productive at different times of the year, especially in tropical and subtropical latitudes (Perlman 1980; Rojas-Galaviz et al. 1992), and easily accessible, thus ensuring an ample supply of high quality animal polyunsaturated fats and protein year around. In arid and semi-arid environments, such as Mesopotamia and Peru, the contrast in productivity between aquatic and wetland CMs and adjacent terrestrial ecosystems can be extreme. These CMs encompass the areas where ranked societies appeared among early farming communities (Figure 5).

Figure 5. World distribution of early complex societies. The distribution of mangroves and salt marshes is indicated by dark and light shaded coastal areas. Areas of high coastal margin productivity at lower latitudes are the locations of early social complexity. Samples used in this study are in large, bold letters. (adapted from Day et al. 2007)

Our hypothesis is that most initial complex social organizations developed following sea-level stabilization because they were subsidized by the newly evolved, high productivity of CMs. The relationship of complex social organizations and the dramatic increase in coastal margin productivity could be questioned if previous evidence of complex societies were hidden by sea-level rise before 7000 BP (for example Washington 2007). We believe, however, that this is improbable because the rapidity of change and instability of sea level before that date would have prevented the establishment of broad areas of rich coastal margin resources and thus large permanent human settlements with multi-tiered administrative functions.

The issue of human adaptations before and after sea-level rise has been researched and discussed for some time. Especially helpful were chemical analyses of human bone in discovering changing dietary habits (Benfer 1988; Quilter and Stocker 1983; Schulting and Richards 2001). Requirements and availability of carbohydrates and protein have been considered in terms of terrestrial animals, fish and shellfish (Erlandson 1988). Stothert et al. (2003) on the Santa Elena Peninsula of Pacific coast South America found that before 7000 BP marine resources in the area were ephemeral causing the inhabitants to adjust to shifting, small estuaries and deltas. They, therefore, relied dominantly on terrestrial animals. After sea-level stabilization, however, fish replaced small mammals. A similar case is made for the Caribbean coast of South America (Oyuela-Caycedo 1996). We suggest that similarly elsewhere, under-sea archaeological sites will be limited to the Paleolithic, and Mesolithic. In special cases of regions affected by isostatic land surface adjustments, Neolithic communities may be drowned (medium field) or elevated (near field). Examples are those found under the North, Baltic, Mediterranean and Black seas and the Atlantic coast of North America from a time before sea level rose to current elevations (Flemming 2004; Galili et al. 1993; Kerr 1998; Russo 1996; Wilson 2001). Only in the case of the Persian Gulf do there appear to be questions about possible complex societies under sea (Rose 2010).

Studying Increasing Neolithic Populations following Sea-level Stabilization

In our earlier article (Day et al. 2007; Day et al. 2004) we analyzed a dozen locations worldwide (see Figure 5) to determine if increased populations, and the more complex social organizations that usually implies, followed global relative sea-level stabilization in a systematic fashion and proximate to aquatic resources. Our findings supported this idea though involving hundreds of years for the various supporting systems to develop sufficiently to sponsor full-blown state societies. In addition to the time for CMs to mature, human populations also required time to settle near estuaries and evolve new social forms that facilitated massive labor mobilization involving millions of person hours. Naturally, new technologies had to be developed and tested. This all seemed to take about another millennium or so.

Although the emergence of complex societies continues to the present day (Trigger 2003), the six societies investigated here are representative of the initial, most original and influential transitions. They developed monuments an average of ~2700 years after 7000 BP (Table 2). Taking the broader perspective of the 13,000-year Holocene, they arose in this relatively narrow time window of 21% of the available time. Spatially, Stanley and Warne (1997) identified 34 appropriate delta environments worldwide that might be expected to nourish increasing populations and complex societies after sea-level stabilization. The sample of six societies we discuss here covers 18% of these potential locations.

Table 2. Six complex societies' time from global sea-level stabilization to first construction of monuments.

As we turn our attention to looking at the relationship between sea level and diet, we will consider a range of methodologies. The majority of post glacial sea-level reconstructions are provided from wetland sediments because the distribution and characteristics of salt-marsh flora are intrinsically linked to the frequency and duration of tidal inundation and their organic remains can be radiometrically dated (van de Plassche, 1986). Dietary information is recovered by archaeological excavation, screening, and flotation of midden or discard deposits of ancient people. The era of emerging complex societies is most easily recognized as that of multi-tiered administrative settlement systems that constructed monuments. During the last 50 years many studies of settlement pattern hierarchies have enabled a much clearer understanding of the origins and forms of complex social systems (examples include Adams and Jones 1981 in the Maya Lowlands, Cyphers and Zurita-Noguera 2006 Olmec; Johnson 1980 in Mesopotamia; Liu 2004 in China; Renfrew 1973 in Britain; von Nagy 2003 in the Olmec heartland; Willey 1953 on Pacific coast of Peru). A clear and accessible exposition of the methods used by modern archaeologists to interpret the complexity of societies by analyzing settlement pattern hierarchies can be found in (Liu 2004:159-161).

In the broad scope of archaeological discourse, the idea that food issues are important to the evolution of complex society is a well established genre. In a 1930s book Childe (1936) believed that post-Pleistocene drying caused people to contract into densely populated oases resulting in a food producing “Neolithic Revolution”. Cohen (1977) summarized these food issues in a widely read book *The Food Crisis in Prehistory*. In a similar but opposite approach, our hypothesis might be called the “food opportunity in prehistory”, although like Childe and Cohen, we also find eventual food shortage issues being compelling forces in the expansion of coastal fishing villages into lower river urbanized states.

Some archaeologists recognized following the 1950s that CME productivity could have contributed to the development of complex societies worldwide (Binford 1968; Osborn 1977; Roosevelt et al. 1991:1624; Yesner 1980). McNeish (cited in Adams 2005) writing at an early date (1966) of lowland Mesoamerica, including our Grijalva case, placed the development of sedentary villages in coastal lowlands between 7,000 and 5,000 BP in alignment with our suggested relative sea-level stabilization mechanism and with later findings as discussed in the Grijalva region below. However, many regional specialists have understood for some time that increases in regional, late Neolithic populations was often related to coastal zone resources (Clark et al. 2010; Moseley 1975; Perlman 1980; Voorhies 2004; Widmer 2004; and others), as have specialists in other disciplines (Kennett and Kennett 2006; Stanley and Warne 1997). Erlandson and Fitzpatrick (2006) overview studies of CMs and human utilization. After about 1980 serious debates over CM productivity and the role they played in human social evolution began (Erlandson 2001).

In this article we focus on the next step in understanding issues of the influence of coastal zone utilization on the origins and sustaining of complex societies. As Erlandson and Fitzpatrick (2006:10) point out, “Instead of global generalizations about the productivity of dynamic island and coastal environments, we need specific information on the nature of local or regional ecosystems (terrestrial and marine) in coastal areas around the globe—and how they changed through time”. In this article we are interested in both whether societies used marine resources and to what extent those resources subsidized the evolution of middle Holocene complex societies and carried through to sustaining early civilizations. Background to each of our six regions is provided in the following regional discussions. Our objective here, then, is to examine our hypothesis in the context of linked CM ecological systems (marine, estuarine, sedimentary, human) to population increases late in the Neolithic period and social complexity.

Sea Level, Diet and Early Complex Societies

We have shown above that the productivity of different CM primary producers is dramatically different (seevTable 1, Figure 4) and that the most productive habitats could not develop until the rate of sea-level rise slowed and stabilized on low slope inner coasts (Nixon 1982; Nixon 1992; Nixon et al. 1996). Thus there is a general relationship between the rate of sea-level rise and CM productivity. This relationship is important to our discussion of Post-Pleistocene coastal margin evolution with the development of complex societies. We used descriptions of sea-level rise in each region and related this to the advent of complex societies to local rates of change rather than to a worldwide date of 7000 BP as was done in our original article.

The order of discussion of the societies is based on the intricacy of their culture histories, or narratives. This begins with the relatively straight-forward South American case of the Supe River valley and proceeds through six steps to the very complex story of China. Taken together, the six case studies offer a range of decision paths from Neolithic villages to urbanized states.

Supe River, Peru

The west coast of South America south of the tropics (Figure 6) has a long history of marine subsistence. Geologically located in a narrow band of desert between the Andes and the Pacific, it ranks among the earliest of complex societies. Consumption of aquatic foods begins extremely early as the area benefits from an off-shore upwelling zone, estuaries, and lower river valleys. An interesting question relative to our theory is, why didn’t complex societies that built monumental architecture co-occur with the precocious timing of aquatic dependency in the area? They followed only after sea-level stabilization.

Figure 6. Location map of the Supe River valley and the locations of the Aspero and Caral archaeological sites. (adapted from Solis et al. 2001)

The sea-level record in Peru is sparse and complicated by tectonics. Limited sea-level data suggest that sea level rose rapidly during the early Holocene to a high stand of +1 m above present at between 9000 and 7000 BP (Wells 1988); we use a median date of 8000 BP for sea-level stabilization in Table 3. Thereafter sea level began to gradually fall to that of the present indicating a 7000-year plus history of high productivity in estuaries and deltas. Likewise, near the Casma River, Ecuador, 900 km northwest, Stothert et al. (2003) estimate that sea-level was 30m below present in 10,000 BP, rising rapidly till 7000 BP. This latter figure gives some sense of the rate of sea-level rise during the early critical years of Holocene societies (see Table 3).

Table 3. Episodes of lower and higher productivity in six regions and the onset of growing populations (Neolithic Inflection) and monumental architecture (Monuments). Values in the table are sea-level rates of change in cm/century. We assume that sea-level rise rates of 20 cm/century or less were conducive to widespread formation of coastal margin habitats (i.e., Cahoon et al. 1995) while sea-level changes greater than 20 cm/century limited the existence of these habitats.

Verifiable consumption of marine resources began relatively early after 13,000 BP (Archaic Period) (Keefer et al. 1998) reflecting the stable, long term reliability on off-shore upwelling. Domestication of plants followed by 11,000 to 10,000 BP (Dillehay et al. 2007; Stothert et al. 2003) both on the Peruvian and Ecuadorian coasts. Even so, there were notable upturns in intensity of population, sedentism, and ceremonialism around 8000 BP corresponding to local sea-level stabilization. The coastal community's pre-adaptations to maritime resources since the late Pleistocene probably accounts for its early development of complex society since there was an immediate increase in population adjusting to the new range and magnitude of resources at the onset of high coastal productivity.

Indications of social complexity begins at the mouth of the Supe River in the sea-side site of Aspero with some small mound building after 5700 BP (Feldman 1983; Haas and Creamer 2006; Moseley 1975). Apparently cotton was independently domesticated to make fish nets. Solis et al. (2001) report this coastal adaptation evolved toward large-scale monuments in the interior by 4700 BP. As we shall see, first stage complexity near coasts, probably "chiefdoms" (two or three tiered administrations, Liu 2004:160), followed by greater interior social complexity more at the scale of "states" (four tiered), is characteristic of the urban transition worldwide, a pattern repeated in other regions. This can probably be explained because CM resources cannot be expanded without extensive modern aquaculture (Wilkinson, personal communication to Gunn, 2011). On the other hand, lower river valley productivity could be extended by intensifying Neolithic plant and animal species thanks to new, near-surface water tables made possible by sea-level stabilization (see Figure 3 and related text). An important implication of this study is that agricultural intensification did not arise from Neolithic villages but rather from complex coastal system communities extending their reach inland. To maintain population densities that supported complexity, they had to make the resources of the lower river valleys correspond to coastal productivity by intensifying Neolithic plant species productivity by irrigation, and by fish farming. This concept might be somewhat in the mode of Cohen’s (1977) thinking about food crises, but solved by agency.

As growing populations expanded inland, they continued to rely on the ocean and estuaries for lipids and protein as was feasible. At Caral, Solis et al. (2001:725) report finding, "…squash, beans, lucuma, guava, pacay, camote, and cotton. Animal remains are almost exclusively marine, including quantities of clams and mussels and an abundance of anchovies and sardines. …. a mix of plants grown in irrigated fields within the Supe Valley and marine resources from the Pacific Ocean, 23km to the west."

The presence of clams and mussels indicates that shallow-water, food resources were added to the earlier consumption of marine fishes. Sardines would have come from the upwelling zone while clams and mussels would have been harvested from the intertidal and shallow subtidal zones. In other words, the society was intensifying its use of both marine and terrestrial resources to support increased populations and social complexity.

Given that Caral was located in a desert, and that irrigation agriculture followed marine resources, we suppose that aquatic species provided the subsistence capital for this society to develop intensive agriculture and social complexity. This is a pattern we will see repeated in some subsequently described regions. The Humboldt Current upwelling zone and coastal South America continues to the present to supply large volumes of protein and fish oil to local and world markets.

Grijalva River, Mexico

The Olmec whose heartland includes the extensive delta of the Grijlava River, were the earliest monumental society in Mesoamerica (Adams 2005). Increasing carbon concentrations in pollen diagrams suggest that land clearance began with sea-level stabilization after 7000 BP and coastal communities subsisting on marine resources soon followed. The onset of highly complex social organization, however, was relatively delayed to around 3,900 BP raising an interesting question of timing.

Figure 7. Location map of the Grijalva River Delta. (adapted from Pope et al. 2001)

Blum et al. (2001) suggest that early Holocene sea level along the Texas Gulf of Mexico coast was at –9 m at ~7,800 BP, and then rose rapidly to +2 m or more by ~6800 BP. Simms et al. (2009) contested the existence of a mid Holocene high stand. They suggested that sea-level within the Gulf of Mexico did not reach above +0.4 m and did not reach below –1.2 m until sometime after 5600 BP. Nevertheless, these data illustrate that sea level was at, or very close to, present elevations throughout the mid to late Holocene along the Gulf of Mexico shoreline. Documented changes in sea level of the Caribbean region during the Holocene (Milne et al. 2005; Toscano and Macintyre 2003) also show that the rate of rise in sea level was greatest prior to ~7000 BP and then diminished after this time (Wooller et al. 2007). These and additional data from the archaeological work discussed next indicate a time of sea-level stabilization slightly before 7000 BP (see Table 3).

At San Andrés, Tabasco, Mexico in the southern Gulf of Mexico, sea level reached current elevations at about 7100 BP (Pope et al. 2001; von Nagy 2003). On barrier islands and a relict channel of the Grijalva River, the first inhabitants consumed brackish gastropods, marsh clams, oysters, freshwater, estuarine, marine fishes, and manatee (Pope et al. 2001). The inhabitants developed the earliest recorded wild maize outside its native habitat in the Mexican highlands at 7100 BP, after which they domesticated maize by 6000 BP, manioc from South

America was present at 5800 BP, and by 4000 BP sunflower seeds and cotton appeared. This diet of aquatic and terrestrial food was continued through maximum land clearance between 7000-6000 BP, settled communities after 5000-4000 BP, and monument cities after 3900 BP (Adams 2005:50ff; Cyphers and Zurita-Noguera 2006; Lawler 2007:23) although substantial populations were evidently present soon after sea-level stabilization at 7000 BP and verifiable villages only by 4600 BP.

Recent research reveals a very dispersed footprint of Olmec urbanization, which is typical of tropical environments. These dispersed, tropical cities have historically caused problems (under estimations) in interpreting social complexity from an ethnocentric western perspective rooted in medieval European culture (Sassaman and Hekenberger 2004; Scarborough 2008). However, given the huge effort needed to build the Olmec's first monumental city of San Lorenzo following 3900 BP, there can be no doubt that it was a populous, well organized and complex society with multiple administrative levels.

To the present day, the Olmec region supplies the greatest proportion of aquatic resources of any in Mexico and is noted for its seafood cuisine. It is worth observing that in both the Supe and Grijalva cases, domestication of plants entrains on utilization of aquatic resources.

Mississippi River, USA

The 800km of the lower Mississippi River valley, or Mississippi embayment, rival that of China's great central plain in length (see below) although not in width. As in the China plain, the valley remains influenced by sea level up to the Poverty Point site 475 km inland (Figure 8). Monument construction within the valley is delayed relative to sea-level stabilization (see Table 3). However, at around 6900 BP other locations along the Gulf Coast have what may be the earliest mounds in the western hemisphere (Russo 1996:274; 283); the Horr's Island Mound site is on an island and associated with fish subsistence. Advance social complexity in the Mississippi valley is associated with the Poverty Point culture and its predecessors. It achieved truly monumental construction works (perhaps 7 million person hrs, Gibson 2006), but the presence of the tradition was intermittent with a period of archaeological invisibility around 5000 to 3500 BP (Gibson 2006), a ~–1m sea-level episode (Tanner 1993). It may be that during such times when the lower valley would have been drained of standing water, the less-elevated Mississippi delta could have served as a refugium for the ideas of complex societies; the earliest Poverty Point date comes from that area.

Figure 8. Map of the Lower Mississippi River valley showing the area that remains near sea level. (adapted from Gibson 2001)

Following the last glacial maximum, sea level rose rapidly until the early Holocene (7000 to 8000 BP) when the rate of rise decreased dramatically (Coleman et al. 1998). Coleman and Smith (1964) and Redfield (1967) illustrate a relative sea-level rise of 7 cm/century until ~4,500 BP with a marked reduction thereafter. More recently, an extensive sampling program in the Mississippi delta by Törnqvist et al. (2004) focused on the collection of basal peats (Figure 9). They suggest that sea-level rise rose rapidly from 8000 to 6000 BP and followed a relatively smooth trend to the present. In Table 3, we use this latter figure to mark higher productivity after 6000 BP.

Figure 9. Törnqvist et al. (2004) sea-level rise curve for the Mississippi delta. The error boxes show radiocarbon errors. The curve was corrected for a 1.1 mm/yr subsidence rate. (adapted from Törnqvist et al. 2004)

The first appearance of the Poverty Point culture was at around 5100 BP at the Linsley Site (Gibson 1996:293; Russo 1996:181-184). It lies on a levee within 15 km of the Gulf with the Poverty Point culture level at about 6m below current sea level because of subsidence. Subsistence was brackish shellfish with signature baked clay objects of the Poverty Point culture. Slightly later and 485km up the Mississippi valley, Poverty Point mound sites begin to appear (Saunders 2004). At 5000 BP, bone assemblages from these sites consist of 50-90 percent fresh water fish from the immediate area (Sassaman and Hekenberger 2004). Poverty point culture seems to never have been concerned with agriculture although the southeastern United States had a locally developed suite of domesticated plants. Carbohydrates were collected from aquatic plants such as cattail (Clark et al. 2010).

South Louisiana’s and New Orleans’ sea food-based cuisine continues to thrive in spite of anthropogenic destruction of the delta’s resources (Day et al. 2007).

Loire River area, France

The regional culture of Northwest Europe (Brittany, Normandy, Belgium, The Netherlands, England, Ireland) constitutes a landscape whose nature is still being debated for the period under consideration. As a geographic landscape it is difficult to define as a watershed because of intervening bodies of ocean including the English Channel and the Celtic Sea. Before sea-level rise, however, these seaways were river ways giving some ancient unity to the area. We will address this region by reference to the Loire River in western France because that is where the earliest megalithic monuments are and one of the great salt producing areas of Europe, always an important consideration in prehistory. However, the Loire area is understood to include the drainages of the Avon, Seine, Boyne and others that contain large monuments whose lower river valleys, were inundated by early Holocene sea-level rise.

Figure 10. Distribution of megaliths in the Loire area. As the terrestrial Neolithic swept westward along the interior loesslands, communities began to interact with indigenous coastal Mesolithic groups along lower river valleys. Some of these Mesolithic groups were already influenced by Mediterranean Neolithic cultural diffusion. These indigenous societies, having no tradition of nucleated communities around which to build labor forces, built communities around ritual centers now seen as megaliths. (adapted from Patton 1993, and Sherratt 1990).

Once thought to be a pale reflection of the Near East and North Africa, monument construction is now known to compete favorably with its eastern neighbors and the rest of the world in times and scales of monument building (Renfrew 1973). There is a long-standing debate over whether complex societies in the region developed out of maritime Mesolithic or Neolithic culture. There is a much argued understanding that the Mesolithic societies of western Europe were something out of the ordinary for hunter-fishers, perhaps more like those of the North American northwest coast area (Warren 2005).

In Northwest Europe, there is an extensive archive of sea-level data that reveals a complex, regionally and temporally varying sea level since the Last Glacial Maximum. Relative sea-level observations and geophysical isostatic models clearly define the area of postglacial rebound in Fennoscandia. This is surrounded by a subsiding zone situated in the North Sea between Norway and Great Britain that has the greatest postglacial subsidence (the so-called glacial forebulge or peripheral bulge). It extends through the northwestern Netherlands and northern Germany (see Kemp et al. 2011 for detail geographic description).

During the Last Glacial Maximum the southern North Sea was 110–130 m below present sea level, so most parts of the North Sea basin were dry land (e.g., Streif 2004). Marine mollusks found at a depth of 72 m below present-day sea level yielded an assay of ~12,000 BP. A phase of the transgression lasted until 8000 BP when relative sea level rose from 72 to 25 m below present (e.g., Streif 2004). The average rate of relative sea-level rise was 150 cm/century (Denys and Baeteman 1995).

Holocene sea-level data for the Belgian coastal plain suggested an initial relative sea-level rise of ~70 cm/century (low productivity) before ~7500 BP. This resulted in a very rapid shift of the facies belts across the continental shelf toward a position close to the present-day boundary of the coastal plain. At ~7500 – 7000 BP, the relative sea-level curve showed a distinct decrease in rate-of-rise to an average of 25 cm/century and consequently, the rapid landward shift of the various sedimentary environments ceased. The rate of relative sea-level rise continued to decrease, and after ~5500 – 5000 BP, it fell to an average of 7 cm/century, indicating higher productivity (see Table 3).

Consumption of aquatic resources is evident both in shell mounds and in human bone assays by around 7500 BP (Mesolithic Period, moderate fish resources) all along the Atlantic coast. However, because of the isostatic processes described above, the region behaved in a seesaw fashion, in Denmark and other regions of Northern Europe (e.g. Scotland and Sweden) rising slightly faster than eustatic sea level (e.g., Berglund et al. 2005; Yu et al. 2007) and in

Brittany and elsewhere within the low countries (e.g., Belgium, Netherlands) sinking as much as 20 m since Mesolithic times (e.g., Denys and Baeteman 1995; Allard et al. 2008; Hijma and Cohen 2010)). As a consequence, accessible archaeological deposits are exposed above sea level in Denmark while they are only visible on islands off Brittany. In Denmark and Scandinavia, stable marine conditions sustained long-lived cultures from the Mesolithic to modern times. In areas of subsidence in the Baltic and North Sea, Mesolithic archaeological remains have been found (Flemming 2004). Further south, the effects are evidently of a different outcome and require our attention to understand them.

The advent of Neolithic ideas spurred important cultural changes in western Europe after about 7500 BP (Sherratt 1990). It came along two trajectories (see Figure 10). The first Neolithic influences arrived after 7500 BP via the Mediterranean as more of a diffusion of ideas about pottery, stone axes, and domestic animals, spread rapidly up the Atlantic coast among the indigenous Mesolithic populations (Scarre 2002; Sherratt 1990). A second train of influences followed through the Hungarian Basin and the loess plains from Poland to the Paris Basin after about 7000 BP. This terrestrial Neolithic brought with it concepts of labor organization based in Neolithic villages that eventually facilitated and/or stimulated megalithic construction, though not in the loess regions (Sherratt 1990). The coastal Mesolithic settlement pattern was not village-based but rather founded in scattered hamlets of single or a few houses. Probably to compete with the new, nearby loessland Neolithic societies, and with other rising communities of their own, the Mesolithic groups developed ceremonial centers to organize large labor groups, a feature of which are large megalithic standing stones and passage graves. Passage graves have an internal structure of passage ways and are used for repeated burials.

The mixing of marine and terrestrial Neolithic concepts with Mesolithic cultures in varying proportions produced a distinctive mosaic of cultural variations important to understanding the distribution of monuments of various types, including megalithics, earthen mounds and passage graves. The Neolithic traditions of the Paris Basin threaded coastward toward the lower Loire and Seine valleys. Along the Seine the mix produced a culture more resembling the loessland Neolithic but the Loire and southern Brittany traditions lead to an explosive megalithic culture more related to the Mesolithic and marine Neolithic.

Because of relative sea-level rise since the Mesolithic, coastal adaptations in that period are preserved on islands off south Brittany and on the Channel Islands off the Seine River delta. Interpretations of human bone composition analysis vary among authors (e.g., Bonsall et al. 2007; Richards et al. 2003; Scarre 2002; Schulting 2005). Following Schlting and Richards (2001) and Scarre's (2002) arguments, evidence from Hoédic Island off the south Brittany coast shows that diet was predominantly of marine sources and that women raised in the interior Neolithic sites were joining coastal groups, presumably as marital partners. Grain was also flowing from the interior to the coast. In ethnographic contexts, the movement of women to the coastal society indicates that it provided evident attractions as opposed to life in the interior. The reason for this could well be that the rising availability of CM resources as happened elsewhere in the world (Stanley and Warne 1997). The added resources provided rising populations that formed competitive groups utilizing newly learned terrestrial Neolithic labor organization principles.

The Hoédic Island site also reveals a fascination with standing stones in the Mesolithic. The site dated at 7600 BP contained small standing stones in association with a small mound (Scarre 2002:25). These small monuments could well be the predecessors of more impressive

Carnac monuments 1500 years later. At that time around 5900 BP monuments of huge proportions were erected along the south Brittany coast. The Grand Menhir Brisé (348 tons, Patton 1993:62) is still visible, apparently because it was too large to be re-used by later rebuilders (Patton 1993:46). It is one of the largest objects moved by humans before the industrial age and probably required about 800,000 person hours to acquire and erect judging by figures Patton (1993:62-63) provides. Large earthen mounds were also constructed. The out-of-proportion efforts may imply that competitions between communities to erect megaliths had become ends in themselves (Sherratt 1990).

As might be expected, the more maritime culture of Brittany appears to have influenced western Britain and Ireland with similar monument building principles including megaliths and passage graves. Across the Celtic Sea at Newgrange a large passage grave was constructed around 5200 BP (Pryor 2003:213). Renfrew (1973) identifies the arrival of hierarchy (complex chiefdoms) with the building of henges that require over a million hours of labor to construct although this inference remains controversial (Pryor 2003).

An issue that bears watching is the question of dietary changes during the Neolithic. Measurements of nitrogen and carbon in human bone collagen have been taken as indicators of proportions of protein and carbohydrate in the diet. The results in northwest Europe seem to be showing that Neolithic inhabitants changed rapidly to a carbohydrate diet (Richards et al. 2003; Schulting 2005). The picture has been obscured, however, by a number of alternative hypotheses reviewed by Bonsall et al. (2007). For one, archaeologically recovered equipment indicates continued fishing activity in the Neolithic. Another is that changes in diet trend with latitude and longitude suggesting environmental influences. Length of the growing season, roughness of the seas, and changes in salinity of sea water have been suggested as possible causes. It is not a problem for the CM-and-complexity concept that a more plant-oriented diet appeared following sea-level stabilization as that would be expected once complex social forms were in place, in this case advanced labor organizations, and the transition to inland agricultural intensification. We would expect fish consumption to remain high during the Neolithic population inflection and in the coastal regions, which appears to have been the case on the Baltic coast of Sweden. It may be that a change was made to shellfish, which appear to not register in the carbon-nitrogen ratio. On the east coast of the USA, shellfish in addition to being a common staple are thought to have been a protein backup for agriculturalists because they required no special skills to harvest and therefore easily activated during times of scarcity. A possible test of our hypothesis that increased marine resources were important to subsidizing complexity is whether the outburst of large megalithic activity on the south coast of Brittany, along with population increases that implies, was fueled by marine diet.

Euphrates River, Iran

The Euphrates (and Tigris) river valley, otherwise known as Mesopotamia (Figure 11), has long been regarded as the cradle of complex societies and has been studied intensively, including detailed studies of the settlement pattern hierarchy (Johnson 1980). The complex, urbanized society in the valley appears to have arisen out of the headwaters of the long, shallow Persian Gulf. Infilling in the Holocene has left once-shoreline Neolithic fishing communities kilometers from the sea. The sea-level stabilization picture is left somewhat murky by a precocious rise of population in Neolithic communities in the early Holocene at sites like Jericho and Çatalhöyük. They are, however, located near aquatic resources, Jericho on a river exploited since the Upper Paleolithic for fish (Erlandson and Fitzpatrick, 2006:11) and Çatalhöyük on a wetland. They represent critical trade nexi linked to the more populous coastal populations of southern Mesopotamia through what Stein (Stein 2002, see also Cowgill 2004) calls “trade diasporas”, distant Sumerian communities attached to local upper Mesopotamian communities for purposes of facilitating trade. Southern Mesopotamia remains the original seat of urbanization with aquatic food resources making a major contribution to the development of earliest complex societies. It is also clear that the descendant communities of coastal villages in Sumer played a leading role in forming an early, complex, sea-going society.

Figure 11. Location map of the Euphrates River with important sites. The solid line is the shore of the Persian Gulf at 6000 BP. (adapted from Kennett and Kennett 2006)

Little is known about the post-glacial evolution of sea level in the Persian Gulf and there are some disagreements regarding the quality of the observations (Heyvaert and Baeteman 2007). According to the relative sea-level record (Dalongeville et al. 1993) it is assumed that sea level rose progressively in the Gulf basin from 14,000 BP onwards. Relative sea-level rise was rapid between 9000 and 6000 BP and reached a maximum level of at least 1 or 2 m above present-day sea level at ~4300 BP, followed by a gradual sea-level fall to the present-day level, upon which some oscillations are superimposed.

A more recent study by Heyvaert and Baeteman (2007) in southwest Iran showed that the coastline rapidly transgressed across the shelf drowning a major valley that resulted in the development of extended tidal flats during the early Holocene. The deceleration of sea-level rise after approximately 5500 BP, together with probably more arid conditions, allowed coastal supra-tidal salt flats to extend widely and to aggrade while the position of the coastline remained relatively stable. Continued deceleration of sea-level rise initiated the progradation of the coastline from ~2500 BP.

The solid sea-level curve in Figure 12 illustrates Heyvaert and Baeteman's newer concept of sea-level change at the head of the Persian Gulf. Moderate productivity is implied from 7000 to 5500 BP and high productivity since.

Figure 12. Sea levels and sea-level rates of change in the Euphrates River. (adapted from Kennett and Kennett 2006)

Because Mesopotamia is precocious in a number of ways, it might be considered an exception to the rule of sea-level stabilization and population inflection. However, it is notable that temple towns began to flourish at the time of higher fish productivity. The coastal villages of Eridu and Ur among others were established at about 6500 BP with the advent of higher productivity. A population increase is generally recognized during the Ubaid period (8,000-5,500 BP, Kennett and Kennett 2006:68) resulting in towns (500-2500 persons), probably low level, two-tiered chiefdoms. Thus, the Neolithic population inflection applies even if there were already sizable populations resident in the valley. Also, sea-side Eridu is recognized in both the archaeological (Kennett and Kennett 2006) and biblical literature as the place where monuments and complexity originated.

Kennett and Kennett tie much of the early population increase in the lower Mesopotamia to CM resources and ability to travel by boat as well as floodplain alluviation and stabilization of the water table under the flood plain made possible by elevated sea level. They also report that Sumerian society during its time was regarded as a marine-oriented society. Anticipated archaeological exploration of these areas was recently opened by Saddam Hussein’s draining of the Euphrates marshes (Lawler 2011), projects that should return sound dietary data on the use of fish and social complexity in early coastal villages. Literary documentation in Mesopotamia notes the transport of 13,000 fish inland over 200 km (from Lagash, another village on the Persian Gulf, to Nippur, Trigger 2003) documenting the continued reliance on the sea as inland agricultures were intensified by irrigation to support large human populations.

Yellow-Yangze Rivers, China

China offers the most complicated story of the origins of complex society. Involvement is increased by the near-intersection of two major rivers crossing a 700 km long plain, that was itself once part of the sea and during the study period near sea level (Figure 13). One of the rivers, the Yangtze, is tropical in location with most water coming from monsoon rains. The Yellow drains a more arid basin. Through time the tropicality of the Yangtze and the aridity of the Yellow have varied with shifts in global climate, with a major transition from tropical to arid at about 6000 BP, the Middle-Late Holocene transition. On top of it all, much of China is located in one of the most geologically active areas in the world, and as a consequence there have been rapid, major shifts in river channels and deltas by over 100 km in the era of complex societies. Sorting out sea-level stabilization and the origins of complex societies in this area is above all others, challenging.

Figure 13. Map of the Great Central Plain of China showing Henan and Shandong provinces. The 700 km length of the coastal plain (dashed lines, bipointed arrow) is along the Yellow River. (adapted from Liu 2004:3, 171)

Zong (2004) summarized sea-level data for Yellow and Yangtze rivers. The reconstructed curve implies that sea level rose rapidly during the Early Holocene up to ~8000 BP. It reached –5 m around 8000 BP, since when it has risen at a markedly reduced rate of 10 cm/century implying higher fish productivity. Over the last 3000 years, sea level has been very close to the present-day level (Saito 1998; Zong 2004).

According to litho-stratigraphic data, before ~8900 BP the area now occupied by the Yangtze delta plain and the Taihu Lake was largely exposed to the sea. By 7800 BP, marine inundation reached its maximum extent inland with the apex of the Yangtze estuary 180 km inland from the apex of the present-day delta (Zhu et al. 1996). The delta plain started to emerge around 3000 BP (Chen and Zong 1998; Hori et al. 2001). A number of shell-enriched sand ridges lie along the northern and southern edges of the current delta at altitudes of –1 m to +2 m (Liu 1987; Zhao 1987). The age of these ridges ranges from 7500 to 2500 BP suggest relatively stable sea levels over that period (Zong 2004).

These studies are summarized in Figure 14. Before 6000 BP the rate of change seems to be in the range of 70 cm/century (low fish productivity). The wave function after 6000 BP falls in amplitude from about 200 cm in 5 centuries (technically 40 cm/century, lower productivity, but it was a hotter, more tropical environment with large lakes) to half that after 4500 BP, 10 cm/century to virtually nothing after 3500 BP (higher productivity).

Figure 14. Generalized sea-level curve for coastal areas of China. Superimposed are productivity classes and the Henan cultural sequence. (adapted from Zhao Xitao 1993:39; cited in Liu 2004)

Traditionally the prehistory of the great China central plain turns on a date of about 5000 BP, the beginning of the Longshan period, approximately the onset of higher fish productivity. This would have followed on the heals of the above-cited retreat of marine inundation, which reaches full effect by 5000 BP (see Figure 14), also the beginning of the Longshan Period. There are, however, complicating issues that will be addressed in the following discussion.

Because of the location of the great China central plain is near sea level and near the tropical-subtropical climate boundary, its prehistory is so complex it requires a book the scope of Lui's (2004) to grasp the rudiments. Nevertheless, it too can be resolved by the sea-level stabilization model if both of these vectors of change are considered together. Sea level falls and the coast moves toward the sea side of the plain between 7000 and 5000 BP, which means the scene of complexity development shifts from Henan province at the back of the plain to Shandong province at the sea side of the plain, all of this at the Middle-Late Holocene climate boundary (see Figure 3). Where data are accessible, shell mounds and faunal remains indicate intense utilization of coastal and marine resources by greatly increased populations beginning around 6500 BP (Jiao 2007; Liu 2004:203). It was at the back of the plain that three-tiered (chiefdom) settlement hierarchies first appeared before the Longshan period (Liu 2004:164), an important consideration to work into the model.

Conflating the two provinces in our narrative somewhat reduces the complication. This involves using the Henan cultural terminology to discuss both regions, something Chinese archaeologists do in some respects by defining a "Longshan Period" that spans both provinces (Liu 2004).

During the Longshan period after 5000 BP the number of occupation sites increased fourfold along with walled enclosures (Liu 2004:194) giving it the appearance of the earliest complex society. However, climate complicates the story as the preceding Yangshao period (7000-5000 BP) appears to have the real roots of complex social organization from the point of view of settlement hierarchies. The complication is unraveled by including climate. Climate was tropical in the Middle Holocene and the Yangshao period, so a more dispersed tropical urban foot print of settlements is to be expected in the Yangshao period (see Scarborough 2008). The tendency has been to classify the Yangshao period as “Neolithic” because of its dispersed tropical urban footprint. However, a three-level administrative hierarchy (complex chiefdom) indicates the beginning of social complexity as do grave goods beginning in Shandong province near the sea (Liu 2004:203; Pearson 1981). The overall effect of the Middle-Late Holocene transition would have been to transform tropical Yangshao society from a culture like the Maya or Angkor Wat, currently termed “low-density, agrarian-based urbanism” (Fletcher 2009), to a society more like dry Mesopotamia with its highly aggregated urban concentrations, Longshan society.

Geology adds another twist. The Yangshao/Longshan culture is disturbed by other important sea-level and channel changes in the Yellow River, most notably another sea level rise after 4800 BP that forces coastal populations again toward the back of the coastal plain. It is there that Chinese civilization breaks into history as the Shang/Zhou dynasties and their immediate predecessors.

Conclusions

In summary, we suggest that as the Earth warmed during the early Holocene period (11,700-7,000 BP) and sea level rose rapidly, shorelines moved across continental shelves at rates too rapidly for the evolution of stable, broad CMs. During this period, lower river streams flowed to the sea in incised channels precluding the development of wide alluvial plains. River discharge was to the outer shelf. When sea level rose and stabilized, water temperatures warmed, river discharge, fresh water residence time, and nutrient levels increased, and light conditions became more favorable to higher secondary marine productivity yielding larger quantities of consumable fish, shellfish and other organisms. Incised river valleys filled and broad alluvial plains formed with high water tables. With sea-level stabilization on flat continental margins, there was a dramatic increase in CME area and productivity. The high secondary productivity animals rich in fatty acids and proteins of estuaries and lower river valley floodplains was readily available to human populations. These populations were organized into multi-tiered administrative structures after a millennium or two. Fertile, broad river levees and floodplains provided space for intensified agriculture under the sponsorship of the newly minted, hierarchical societies. In combination, increasing CM productivity and agricultural intensification facilitated widespread complex social organizations.

The development of complex societies followed the enrichment of CM food resources worldwide. In our sample of six societies, the Neolithic population inflection appeared in coastal zones and deltas in an average of 67 (s=954) yrs after local sea-level stabilization. In about a millennium, societies with social rankings were organized as evidenced by increased diversity and richness of grave goods. This was followed at regionally variable time intervals by construction of monuments marking the end of the Neolithic-Urban transition.

In the late Holocene, coastal villages with stratified societies were overshadowed by more powerful interior descendants. The greatly enhanced CM productivity helped underwrite the transition to complex social organization and agricultural intensification. These later polities experienced economic and social stresses that required more grandiose politico-religious infrastructures and, reflecting that, greater monumental edifices.

Using local sea-level stabilizations, the mean time to monument construction in the six regions was 2283 (s=1270) years, a difference of 417 years (reduction in error) from the 2700 (s=1110) years calculated in Table 2 from the global relative sea-level stabilization (Table 4). Although obvious differences can be seen between global and local findings, especially in China, the results suggest that in areas where local sea-level studies are not available, within a few 100 years and a few meters, the global value serves as a relatively reliable estimate of the local.

Table 4. Six complex societies time-to-monuments following local eustatic/isostatic sea-level stabilizations.

Notes: (2) All dates calibrated by CalPal A version 2004 July 15.

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Figures

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Figure 2. Width of a zone with a 10 meter depth range as sea level rises across the continental shelf where more of the system is located over shallow shelf waters.

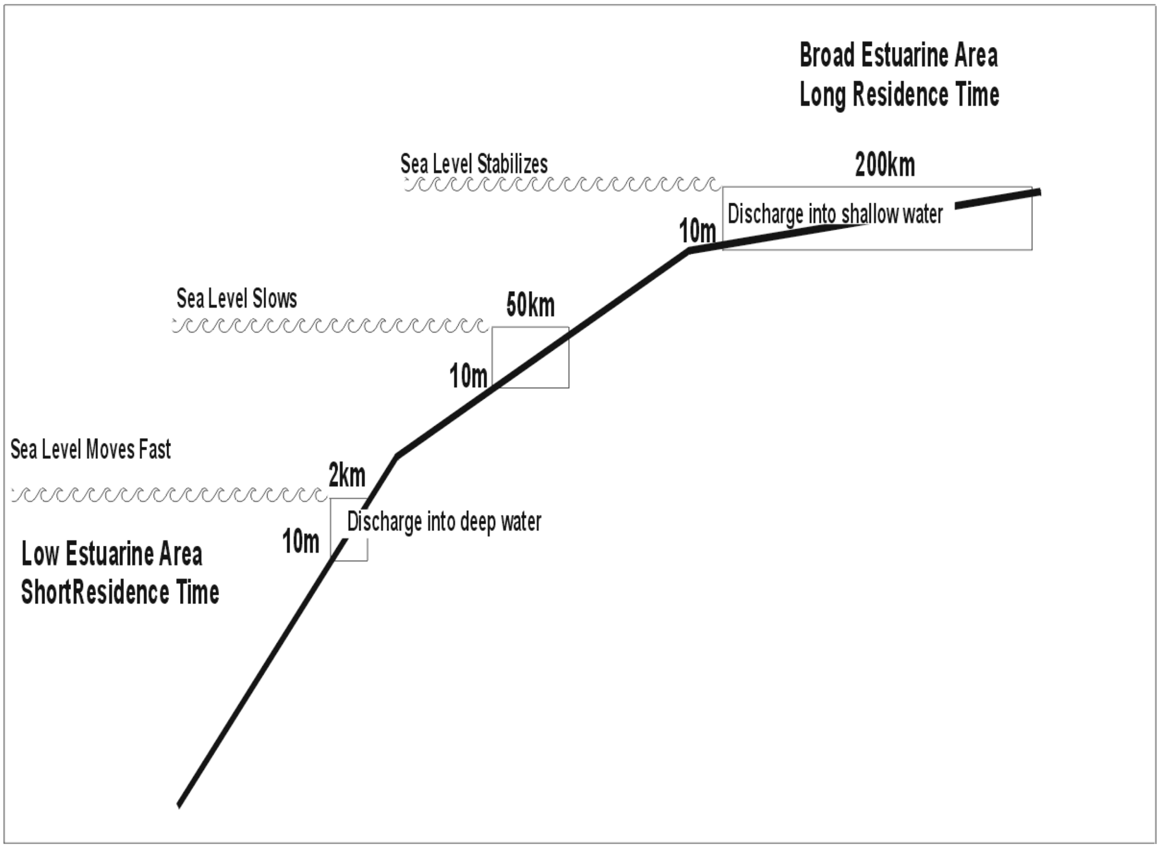

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Figure 4. Relationships among freshwater residence time, nitrogen retention, aquatic primary productivity, and fisheries for estuarine systems. After sea level stabilized, estuarine systems became larger and more enclosed by barrier islands. (A) This led to longer residence times and more nitrogen retention. (B) This coupled with higher nitrogen input from increased river flow led to higher aquatic primary productivity. (C) In marine systems, primary production is related to fisheries yield with estuaries being greater than ten times more productive than open marine systems. See text for references.

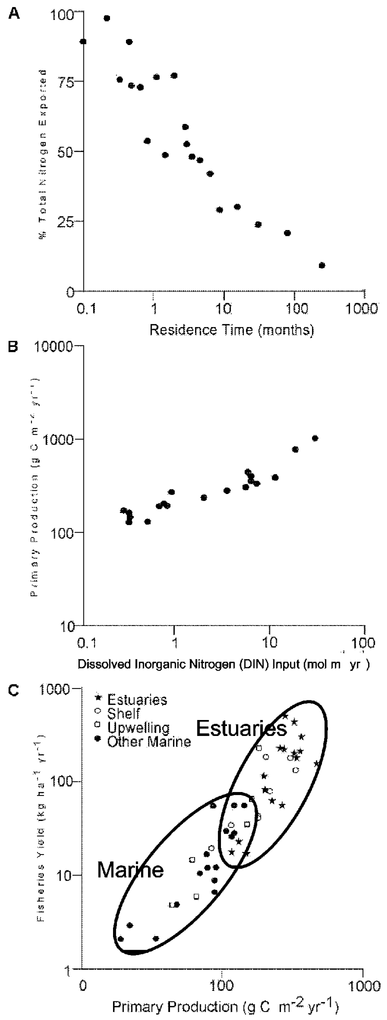

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Table 2. Six complex socieites’ time from global sea level stabilization to first construction of monuments.

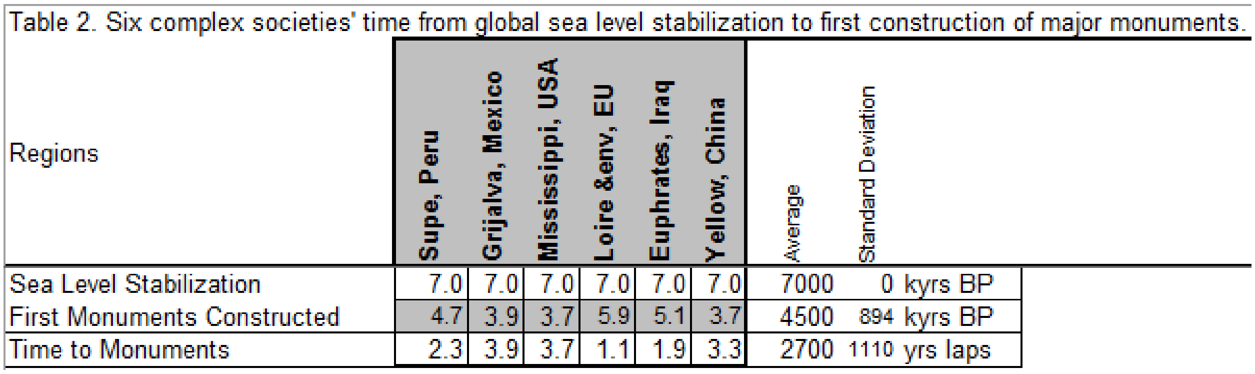

Table 2. Six complex societies' time from global sea level stabilization to first construction of major monuments.

Regions	Supe, Peru	Grijalva, Mexico	Mississippi, USA	Loire &env, EU	Euphrates, Iraq	Yellow, China	Average	Standard Deviation	
Sea Level Stabilization	7.0	7.0	7.0	7.0	7.0	7.0	7000	0	kyrs BP
First Monuments Constructed	4.7	3.9	3.7	5.9	5.1	3.7	4500	894	kyrs BP
Time to Monuments	2.3	3.9	3.7	1.1	1.9	3.3	2700	1110	yrs laps

Table 3. Regional sea level rates of change in cm per century.

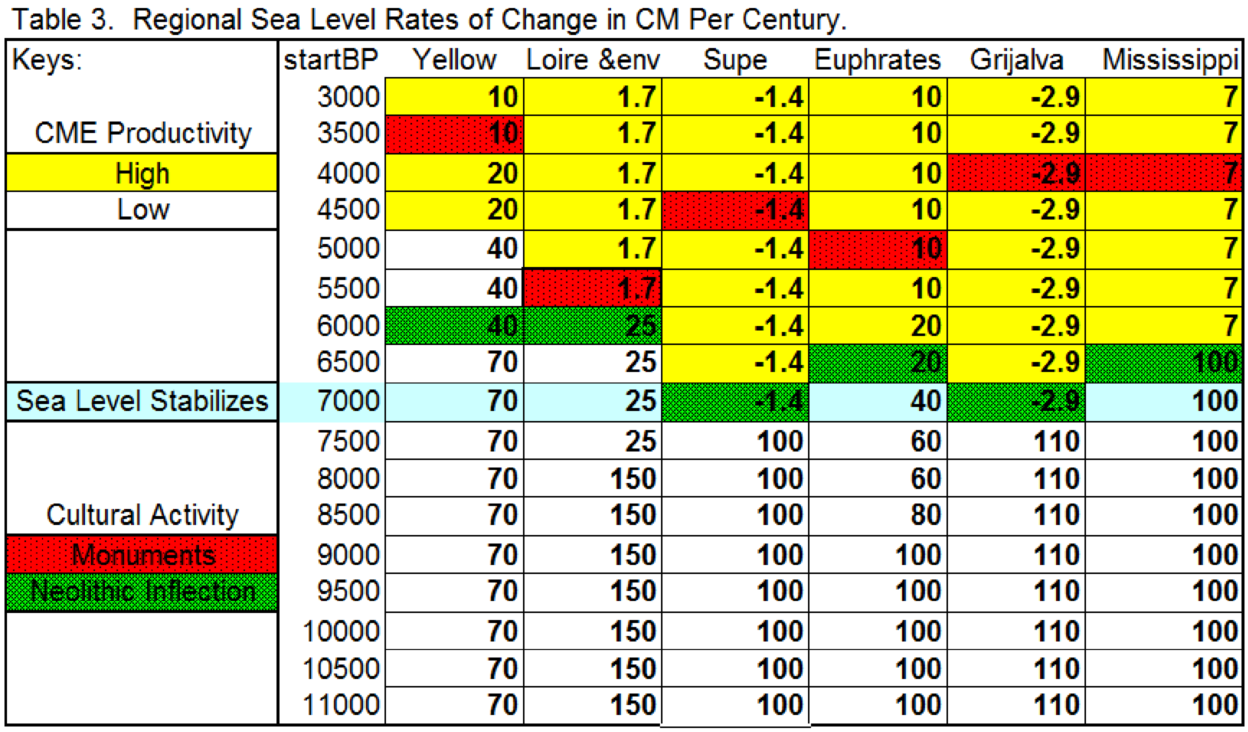

Table 3. Regional Sea Level Rates of Change in CM Per Century.

Keys:	startBP	Yellow	Loire &env	Supe	Euphrates	Grijalva	Mississippi
	3000	10	1.7	-1.4	10	-2.9	7
CME Productivity	3500	10	1.7	-1.4	10	-2.9	7
High	4000	20	1.7	-1.4	10	-2.9	7
Low	4500	20	1.7	-1.4	10	-2.9	7
	5000	40	1.7	-1.4	10	-2.9	7
	5500	40	1.7	-1.4	10	-2.9	7
	6000	40	25	-1.4	20	-2.9	7
	6500	70	25	-1.4	20	-2.9	100
Sea Level Stabilizes	7000	70	25	-1.4	40	-2.9	100
	7500	70	25	100	60	110	100
	8000	70	150	100	60	110	100
Cultural Activity	8500	70	150	100	80	110	100
Monuments	9000	70	150	100	100	110	100
Neolithic Inflection	9500	70	150	100	100	110	100
	10000	70	150	100	100	110	100
	10500	70	150	100	100	110	100
	11000	70	150	100	100	110	100

Table 4. Six complex societies time-to-monuments following local eustatic/isostatic sea level stabilizations.

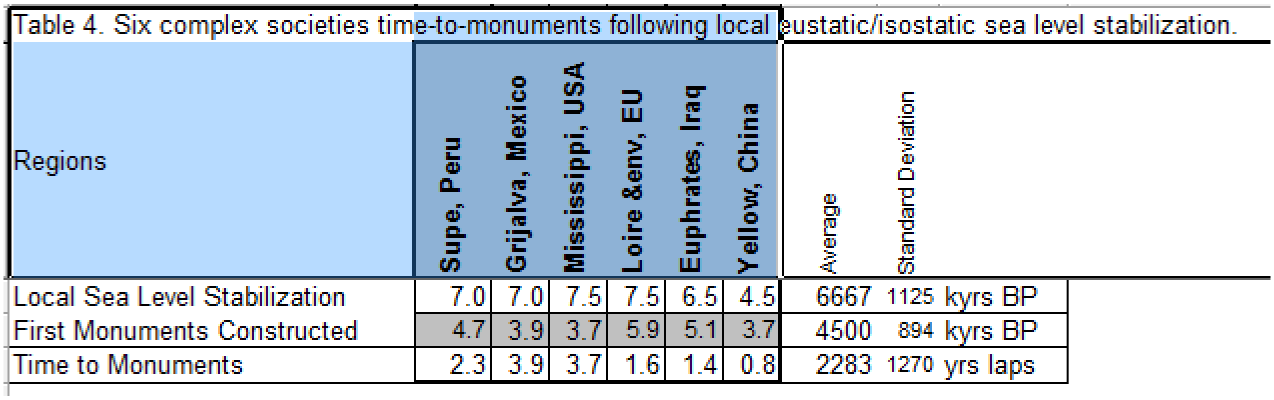

Table 4. Six complex societies time-to-monuments following local eustatic/isostatic sea level stabilization.

Regions	Supe, Peru	Grijalva, Mexico	Mississippi, USA	Loire &env, EU	Euphrates, Iraq	Yellow, China	Average	Standard Deviation	
Local Sea Level Stabilization	7.0	7.0	7.5	7.5	6.5	4.5	6667	1125	kyrs BP
First Monuments Constructed	4.7	3.9	3.7	5.9	5.1	3.7	4500	894	kyrs BP
Time to Monuments	2.3	3.9	3.7	1.6	1.4	0.8	2283	1270	yrs laps