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Archaeology, Marine Ecology, and Human Impacts on Marine Environments

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COVERING MORE THAN 70 percent of our blue planet, the oceans dominate the earth in a variety of ways. With an average depth of almost 4 km, they provide over 99 percent of the habitable space for life on earth (Woodard 2000:31). As human populations have grown exponentially over the past century, and with 60 percent of the world's population living within 100 km of the coast, many have looked to the oceans as a source of hope and protein to feed the masses. Once thought to be nearly inexhaustible, many global fisheries have collapsed or are severely depleted (Jackson et al. 2001; Pauly et al. 2002; Roberts 2002; Worm et al. 2006). Pollution, habitat loss, global warming, and the introduction of exotic species also take an increasing toll on coastal and pelagic ecosystems (see Carlton et al. 1999; Earle 1995; Ellis 2003; Vitousek et al. 1997:495; Woodard 2000). We are only beginning to understand the larger ecological consequences of such impacts, including the wholesale collapse of many coral reef, kelp forest, estuarine, arctic, benthic, and other ecosystems—foundations of marine productivity that have nurtured human societies for thousands of years. These impacts are now global in scale, but humans have had the heaviest impact on nearshore and coastal areas (0–50 m in depth), substantial impacts on deeper continental shelf habitats (50–200 m), and comparatively less impact on the deeper oceans (Steele 1998).

In the last few years, two national commissions have issued reports concluding that the world's oceans and fisheries are in a state of crisis (Pew Oceans Commission 2003; U.S. Commission on Ocean Policy 2004). The management of fisheries and our understanding of the broader ocean crisis have been hampered by the shallow historical focus of policy makers and resource managers, who have based many decisions on ecological observations that span 10, 20, or 30 years, or on historic catch records that rarely span more than a few additional decades. Just over a decade ago, Daniel Pauly (1995) referred to this problem as the "shifting baselines syndrome," where fisheries managers use recent historical baselines to manage fisheries that are depleted or collapsed. Such recent historical baselines are often fundamentally flawed because they fail to account for the abundance of key species prior to heavy fishing or hunting by indigenous peoples or early commercial harvests (Dayton et al. 1998; Jackson et al. 2001). Roman and Palumbi (2003) analyzed the DNA of living whales, for instance, and suggested that the original population sizes for some whale species was 10 or more times larger than estimated by the historical records currently used as baselines for restoring and conserving whale populations. A growing number of marine scientists are now calling for fundamental changes in the management of marine fisheries and ecosystems, including much deeper historical analyses that incorporate archaeological and other data sets into the development of better fisheries management plans, ecosystem restoration efforts, and a sustainable oceans policy.

An important step forward in this effort was a 2001 article in *Science* called "Historical Overfishing and the Recent Collapse of Marine Ecosystems," named by *Discover* magazine as the top science story of the year. In it, Jackson
[AU1] et al. (2001) argued that human impacts on marine fisheries began relatively early, but they also recognized that human fishing has evolved through three general (and often overlapping) historical and geographic stages: (1) aboriginal fisheries confined to "subsistence exploitation of nearshore coastal ecosystems" with "relatively simple watercraft and extractive technologies"; (2) colonial exploitation of coastal and continental shelf ecosystems controlled by "mercantile powers incorporating distant resources into a developing market economy"; and (3) a global stage marked by "more intense and geographically pervasive exploitation of coastal, shelf, and oceanic fisheries integrated into global patterns of resource consumption." Within this framework, human impacts on marine fisheries and ecosystems have accelerated through time and expanded geographically as human populations grew, extraction and distribution technologies improved, and increasingly global markets emerged. Here, we argue that management strategies for fisheries and other ocean resources need to consider not just shifting baselines and the historical ecology of marine ecosystems, but the "shifting timelines" that emerge from the knowledge that the history of boats, maritime migrations, and marine fishing and hunting developed considerably earlier than previously believed in many parts of the world (Erlandson and Fitzpatrick 2006).

Like most archaeologists, we have long thought of ourselves as pretty interdisciplinary guys, with a relatively good grasp on the geology, biology, and ecology of Pacific Coast ecosystems. A few years ago, one of us (JME) was asked to join a working group (Long-Term Ecological Records of Marine Ecosystems) at the National Center for Ecological Analysis and Synthesis (NCEAS). Chaired by Jeremy Jackson, this group of 25 marine scientists met periodically for several years to discuss, debate, and reconstruct regional and global patterns in the historical development of human impacts on marine ecosystems. Several members of that group—Bruce Bourque, Debbie Corbett, Jim Estes, Mike Graham, and Bob Steneck—are participating in one way or another in this volume. After joining the NCEAS group, Erlandson learned that his knowledge of biological and ecological issues was as broad as a river but shallow as a thin sheet of water. It also became clear that most ecologists think of "long-term" ecological records as spanning two or three decades of regular scientific observation, sometimes supplemented with a few decades more of historical catch data. When the archaeologists in the group described coastal archaeological records spanning millennia in California, the Aleutians, and the Gulf of Maine, the marine ecologists were amazed at their potential. When the marine ecologists described the structure and dynamics of kelp forest ecosystems in each area, it was the archaeologists' turn to be astonished. What followed was a remarkable series of meetings with these and other colleagues examining the historical ecology of coastal ecosystems and the changing nature of human impacts to such systems through time.

Growing out of these interdisciplinary sessions, and several years of related research they inspired, we also gained clearer insight into just how much coastal archaeology has to offer current research, debates, and policy related to marine conservation and restoration, fisheries management, and other crucial ocean issues. As Lyman and Cannon (2004) argued, the application of archaeological data to current problems in conservation biology raises a number of thorny issues, but it also represents a tremendous opportunity for archaeologists to better meet the crucial test of relevance for modern society. Already widely perceived in the real world as an interesting but esoteric field, archaeologists cannot afford to miss opportunities to prove our relevance to current and pressing issues, not if we hope to receive continued funding for our work and support for the protection of archaeological sites.

THE ARCHAEOLOGY OF HUMAN IMPACTS

> The archaeological record encodes hundreds of situations in which societies were able to develop long-term sustainable relationships with their environments, and thousands of situations in which the relationships were short-lived and mutually destructive. The archaeological record is "strewn with the wrecks" of communities that obviously had not learned to cope with their environment in a sustainable manner or had found a sustainable path, but veered from it only to face self-destruction.
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> (Redman 1999:4–5)

In recent decades, there has been tremendous interest in the archaeological study of human impacts on ancient ecosystems, including the role early hunter-gatherers and agriculturalists played in the extinction of animal species, major habitat alterations, and the collapse of complex cultures (e.g., Grayson 2001; [AU2] [AU3] Grayson and Meltzer 2001; Martin 1967; Martin and Klein 1984; Redman 1999; Redman et al. 2004). Far from "living in harmony" with their environments—if any scientists ever actually believed this notion—the arrival of anatomically modern humans *(Homo sapiens sapiens)* in newly colonized lands often appears to be associated with significant habitat changes and accelerated rates of extinction. As Grayson (1991, 2001; Grayson and Meltzer 2003) and others have shown, it can be difficult to prove that human hunting was the *primary* cause of many animal extinctions. Nonetheless, cases for a significant human contribution to extinction events or other environmental impacts have been made for late Pleistocene Australia (Flannery 1994; Miller et al. 1999; Roberts et al. 2001), the Americas during the terminal Pleistocene (Alroy 2001; Martin 2002), some Caribbean Islands in the Early Holocene (Morgan and Woods 1986; Steadman et al. 2005), many Pacific Islands and Madagascar during the Late Holocene (Anderson 1984, 1989; Kirch and Hunt 1997; Simmons 1999; Steadman 1995, 2006), and other areas around the world. It is not always clear if such changes resulted from human hunting, forest clearance or intentional burning of landscapes, the introduction of exotic animals (dogs, pigs, rats, etc.) and the diseases they carried, or a combination of factors. What is clear, however, is that the initial arrival of behaviorally modern and technologically sophisticated *H. s. sapiens* in any given region appears to have posed significant problems for many endemic species, especially where such species had not been subjected to hominid predation before.

Although both continental and island landscapes have played important roles in studying the impacts of early humans, discussions of human-induced extinctions are limited almost exclusively to vertebrate species that live, nest, feed, or breed on land. In cataloging a global bestiary of large animals potentially driven to extinction by our ancestors, Martin (2002) listed scores of terrestrial genera, but no marine or aquatic species. As Martin (2002:1) noted: "Whatever caused large animal extinctions on land, had no impact on large mammals in the oceans." The differential patterns of prehistoric large animal extinctions in terrestrial versus aquatic ecosystems raise two very interesting questions that require further exploration: (1) why did the expansion of anatomically modern humans differentially affect terrestrial versus marine species?; and (2) does the lack of documented extinctions in marine ecosystems mean that human impacts on those ecosystems were absent or severely limited until very recently?

SHIFTING TIMELINES

In the past, the first question was easily answered with traditional anthropological theory, which held that hominids did not intensively exploit marine or aquatic resources until relatively late in human history—between about 15,000 and 5,000 years ago (e.g., Osborn 1977; Washburn and Lancaster 1968; Yesner 1987). Boats and other relatively sophisticated maritime technologies were also viewed as relatively recent developments, suggesting that most island archipelagoes were not colonized until relatively recently. The supposedly late shift toward intensive aquatic adaptations, in which marine resources were largely ignored for 99 percent of human history, was often explained as a shift toward "marginal" aquatic resources after the "optimal" large land mammals were hunted to extinction or severely depleted. If humans developed intensive marine fisheries relatively late in prehistory, then perhaps the dearth of aquatic extinctions is simply due to the differential antiquity of terrestrial hunting versus aquatic hunting and fishing.

The problem with this scenario, of course, is that we live in an interglacial period of high sea levels unmatched in the last 120,000 years. As global sea levels rose over 100 m between 20,000 and 5,000 years ago, the coastlines of the world changed dramatically. Most coastlines moved laterally tens or even hundreds of kilometers, meaning that most sites located along modern coastlines were far from marine habitats during the late Pleistocene (see Parkington 1981). Coastal erosion also destroyed, dispersed, or severely damaged most coastal sites submerged during this marine transgression (Erlandson 2001; Erlandson and Fitzpatrick 2006). Unfortunately, these dramatic changes in coastal geography coincide with the later development and spread of anatomically modern humans *(H. s, sapiens)*, insuring that records of early coastal adaptations or migrations are severely limited.

Despite such problems, recent research in a series of African sites of Last Interglacial age, other sites in coastal zones where steep bathymetry limited lateral shoreline movements, islands that humans could have colonized only by boat, and freshwater aquatic localities has dramatically altered our view of the antiquity of aquatic adaptations, maritime migrations, and human fishing and hunting in marine ecosystems. Dozens of coastal Middle Stone Age sites in southern Africa appear to contain evidence for the use of shellfish, marine mammals, seabirds, and even fish by anatomically modern humans between about 125,000 and 40,000 years ago (e.g., Brink and Deacon 1982; Henshilwood and Sealy 1997; Klein et al. 2004; Marean et al. 2004; Singer and Wymer 1982). Barbed bone harpoons from Katanda in Zaire suggest that sophisticated freshwater fishing technologies may have existed by 80,000 to 90,000 years ago (Yellen et al. 1995). The Pleistocene peopling of Australia and western Melanesia by maritime migrations through island Southeast Asia between roughly 60,000 and 35,000 years ago (see Allen et al. 1989; Clark 1991; Wickler and Spriggs 1988) suggests that our ancestors may have dispersed out of Africa by land and by sea, some of them following the coastlines of southern Asia (Erlandson 2001, 2002; Stringer 2000). The colonization of the Ryuku Islands and evidence for the use of boats in Japan 35,000 to 25,000 years ago suggests that early maritime peoples had adapted to the relatively cool waters of the Northwest Pacific during the Last Glacial. The settlement of California's Channel Islands by maritime peoples as much as 13,000 to 12,000 years ago (Erlandson et al. 1996; Johnson et al. 2002; Rick et al. 2001, 2005), as well as coastal shell middens on the Andean coast more than 11,000 years old (Keefer et al. 1998; Richardson 1998; Sandweiss et al. 1998), also demonstrates an earlier and more sophisticated use of maritime or aquatic technologies than previously believed and may support early coastal colonization models. These data, along with the terminal Pleistocene expansion of maritime peoples into recently deglaciated coastal regions of Scandinavia,

FIGURE 1.1. Middle Holocene red abalone midden (SNI-161) eroding out of sand dune on northwestern San Nicolas Island (photo by René Vellanoweth).

the Early Holocene settlement of some Caribbean Islands, and the later but equally amazing maritime migrations of Austronesian and Polynesian peoples allow us to view the development of diversified coastal and aquatic economies around the world as the outgrowth of the origins and expansion of intellectually and technologically sophisticated anatomically modern humans in Africa some 150,000 years ago.

The early emergence of maritime peoples in many parts of the world also suggests that it is time to reexamine the archaeological evidence for human impacts in coastal environments. If humans have been gathering, hunting, and fishing in some marine ecosystems much longer than previously believed, then a relatively recent development of coastal economies cannot explain the lack of human-induced extinctions in those marine environments. With greater amounts of time for coastal peoples to expand their populations, increasing evidence for the early development of aquatic and maritime technologies, and a deeper history of colonizing many of the less remote island arcs around the world, we should expect to find earlier and more extensive evidence for prehistoric human impacts to coastal and marine ecosystems than previously believed possible.

LESSONS FROM THE PAST: OVEREXPLOITATION, CONSERVATION, AND SUSTAINABLE ECONOMIES

This brings us back to the question of whether the dearth of prehistoric extinctions in marine ecosystems implies a lack of significant human impacts. By now, the answer to this question should be obvious. We clearly believe that the limited evidence for human involvement in prehistoric aquatic extinctions should not be considered a lack of substantial impacts on ancient marine, estuarine, and freshwater species or ecosystems. In fact, a variety of evidence has been marshaled for a significant impact of early human predation on the size, distribution, or population structure of aquatic species, including shellfish, fish, and some sea mammals (see, among many others, Erlandson et al. 2005; Hildebrandt and Jones 1992; Klein et al. 2004; Reitz 2004; Simenstad et al. 1978; Steneck et al. 2004). The nature and extent of such impacts remain to be documented in various areas around the world, however; and the growing collaboration between coastal archaeologists, marine ecologists, and other scientists is developing new methods for recognizing and measuring the nature of those impacts (Figure 1.1).

Ancient humans did not live in complete harmony with their natural environments—at least not for long. By definition, at least for our purposes, all humans affect their environment, and large human populations generally have larger ecological impacts. Identifying archaeological evidence for such impacts, however, is not necessarily the same as demonstrating that some human societies never developed conservation measures or sustainable economies. If ancient peoples never learned from their mistakes and developed effective conservation strategies, there may be little to be learned from studying the past. While it may be true, as Kay (2002:259–260) has argued, that it is condescending and morally indefensible to claim that indigenous peoples were not capable of significant environmental impacts, it would be equally condescending to suggest that such people were incapable of recognizing the ecological impacts they had or developing practices that encouraged conservation or sustainable yields. As archaeologists and anthropologists, we find it difficult to believe that ecological awareness and conservation strategies are solely the province of literate or modern human societies.

Although some of our participants may touch on such issues, we are not particularly interested in debating theoretical stances about whether ancient peoples engaged in conservation, sustainable practices, or ecologically sound management principles. We have followed this debate closely, particularly as it has played out in relation to Native North Americans (see, e.g., Alvard 1998; Grayson 2001; Guthrie 1971; Hunn et al. 2003; Kay and Simmons 2002; Krech 1999). Such issues can be quite difficult to address using fragmentary archaeological data, and some of the rhetoric has been unnecessarily polarized and politicized. Native Americans, for instance, are variously portrayed as having either widespread cultural systems for conserving natural resources, or virtually no effective conservation strategies, with little middle ground. Such characterizations ignore the wide range of behaviors that might be expressed by a succession of individuals or groups within a single region over long stretches of archaeological time.

Over more than 10,000 years of Native American occupation along the California Coast, for instance, there is every reason to expect to find evidence for a wide range of harvest strategies, from overexploitation when resources are abundant, to more conservative practices when key resources became depleted. This is clearly the case with historical fishing strategies—where regulation is generally limited or absent until a fishery is significantly depleted. Nor is it correct to conclude that indigenous harvesting of small abalones or female seals or pups—forbidden by most historical regulations—is necessarily the antithesis of conservation or sustainable practices (see Porcasi et al. 2000; Raab 1992). Historical regulations were developed in response to specific harvest levels or practices that may not have applied to or been appropriate for prehistoric peoples. Relatively small hunter-gatherer populations might regularly harvest a limited number of female, juvenile, and infant seals from a large rookery, for instance, without a measurable decline in the local seal population. Under such demographic contexts, the hunting of female seals or their pups may have no bearing on the long-term sustainability of such practices. As populations grow, however, the impact on these resources will inevitably be more severe, perhaps causing the relocation of rookeries and possibly greater impacts on sea mammal population structure.

We are not arguing that prehistoric peoples did not cause resource depression or alter the structure of local ecosystems; in coastal zones around the world the archaeological evidence is overwhelming that they often did (see Anderson 1983; Broughton 1999; Butler 2000, 2001; Grayson 2001; Mannino and Thomas 2002; Nagaoka 2002). Yet the widespread evidence for localized resource depression does not necessarily signal a complete lack of conservation practices or sustainable economies among small-scale societies. As with swidden agriculture under low population densities, shifting residence patterns can cause the serial depletion of marine resources within local foraging territories without a long-term alteration of the larger ecosystem. In such cases, local resource depletion combined with a pattern of "shifting sedentism" might be part of a sustainable settlement and economic strategy that could span hundreds or even thousands of years.

As human populations fill their physical and social landscapes, of course, residential mobility can be constrained by neighboring groups. With the filling of spatial niches and the coalescence of foraging territories ("territorial circumscription") caused by human demographic expansion, impacts in local foraging territories may also coalesce into a regional depression of resources and increasingly anthropogenic landscapes and seascapes. It is here that archaeological investigations for the earliest evidence of significant regional human impacts to marine ecosystems are likely to be most fruitful. At the same time, such serious ecological impacts may sometimes have led to the development of social mechanisms that more effectively managed human harvest practices to encourage sustainable yields. Thus, it is conceivable the widespread resource depression, which some have argued was typical of much of Native North America prior to European contact (see Kay and Simmons 2002), gave rise to the conservation-oriented ecological management principles that many Native American tribes espoused after European contact—beliefs reinforced by the commercial decimation of many animal populations by rapacious colonial exploitation practices under European and Euroamerican regimes (see Ellis 2003; Mowatt 1984).

In our view, recent evolutionary theory often portrays individual humans as overly preoccupied with personal gain and reproductive success, ignoring the fact that human survival and success has most often been accomplished in group settings where people may maximize their success by adhering to communal decisions that benefit the larger group (see Ehrlich 2000:310). In human groups, elaborate cultural mechanisms (e.g., shame, ostracism, banishment, and death) are developed to control or punish those who unacceptably enrich themselves at the expense of the common good. Such strictures, imperfect as they were and are, operated both within and between social groups. The riverine peoples of the Pacific Northwest who blocked streams with weirs each year to harvest prodigious amounts of salmon knew, for instance, that blocking all the salmon from ascending the stream would have disastrous consequences for future fish runs, for their upstream neighbors, and ultimately for their own peace and prosperity. In such cases, the interests of individual tribal members and their larger social group were virtually inseparable from ecologically sustainable practices. This is not to suggest that there were not many difficult lessons learned in the long evolution of subsistence strategies and social relationships among such tribes.

Ultimately, suggesting that conservation did not take place in nonliterate societies implies that we have little to learn from the environmental relationships of smaller-scale cultures. Archaeological and historical records indicate that many human groups were incapable of surmounting the problems caused by their environmental impacts, while others were able to adjust their strategies (see Diamond 2005; Redman 1999). In the past, humans were confronted with countless environmental challenges—some of them of their own making—and responded in a variety of ways, both effectively and ineffectively. Learning what worked for those ancient peoples and what did not holds valuable lessons for us today as we strive to more effectively manage the environmental impacts of our species on both land and sea. Human impacts may be inevitable, but long-term environmental catastrophe and ecosystem collapse are not (see Kirch 1997; Redman 1999).

MEASURING HUMAN IMPACTS TO MARINE ECOSYSTEMS

In the absence of numerous extinctions of marine species linked to prehistoric human colonization, how do we recognize human impacts to ancient marine ecosystems? Other than the standard predictors and proxies of population growth or intensification, how can we use data from coastal archaeological sites to identify significant human impacts in marine environments? How do we compare archaeological data to historical and ecological data that are often collected in very different spatial and temporal scales? The answers to such questions are complex and, in some cases, not fully worked out. There are some general methods archaeologists and marine scientists have used, however, that provide insights into the nature of human interactions with marine ecosystems over long periods of time. At this point, any methodology for measuring human impacts across prehistoric, historic, and recent times must be considered a work in progress, since historical ecology is a very young discipline and interaction between archaeologists and marine scientists is still relatively limited.

Obviously, one of the first and most important issues is to differentiate natural (nonhuman) variations in marine ecosystems from those caused by humans (Redman 1999; Reitz and Wing 1999:252). On the ecological side of things, there are few if any marine ecosystems around the world where we have a comprehensive understanding of the historical ecology with any real time depth. Since careful, "long-term" ecological monitoring records rarely span more than a few decades, we do not yet know the full extent of cyclical fluctuations in most ecosystems that operate on decadal scales or longer. It is only relatively recently, for example, that the notion of decadal regime shifts or the dramatic and far-reaching climatic and oceanic patterns involved in El Niño/La Niña cycles have been fully recognized, and their historical parameters are still being defined. It is also increasingly clear that the historical range and behaviors of many marine species have changed significantly as their populations were devastated by early historical exploitation and, in some cases, have rapidly expanded under protective regulations or legislation. Knowledge of the geographic range and behavior of marine mammals along the Pacific Coast of North America—which ecologists and archaeologists have often extrapolated uncritically into the past—is rapidly changing, for instance, as various species continue to expand and adjust to dynamic oceanic conditions and the alteration of marine ecosystems caused by overfishing, habitat changes, and other human impacts (see Burton et al. 2001, 2002; DeLong and Melin 1999; Estes et al. 1998; Etnier 2004).

Marine ecologists desperately need archaeological colleagues to help expand their historical horizons, and coastal archaeologists desperately need marine ecologists to help interpret the ecological implications of our data and understand the broader import of our work. What are the ecological implications of changes in faunal remains found within archaeological sites? How do we distinguish between natural ecological fluctuations and those caused by humans? How susceptible is a particular marine ecosystem to human interference? These are questions ecologists are much more qualified and capable of answering than archaeologists are. How do we identify evidence for resource depletion in marine species? Intertidal shellfish beds are often considered to be highly susceptible to human overexploitation, but shellfish (and other) populations can also be destroyed or depleted by disease, nonhuman predation, sedimentation, heavy storms, changes in water temperature, and other problems unrelated to humans. For these and other reasons, we need to look for evidence of human impacts not just in individual archaeological sites but in regional records. To most effectively examine the impacts of humans on marine ecosystems, we should focus on long and nearly continuous sequences within relatively small areas, such as the 7,300-year-old sequence at Otter Point on San Miguel Island (Figure 1.2).

Paying particular attention to problems of temporal resolution and geographic scale, we must also find ways to compare archaeological data more effectively—often anchored by radiocarbon chronologies with resolution measured in centuries—to historical and ecological data that are often much more fine grained. For instance, northern elephant seals *(Mirounga angustirostris)*

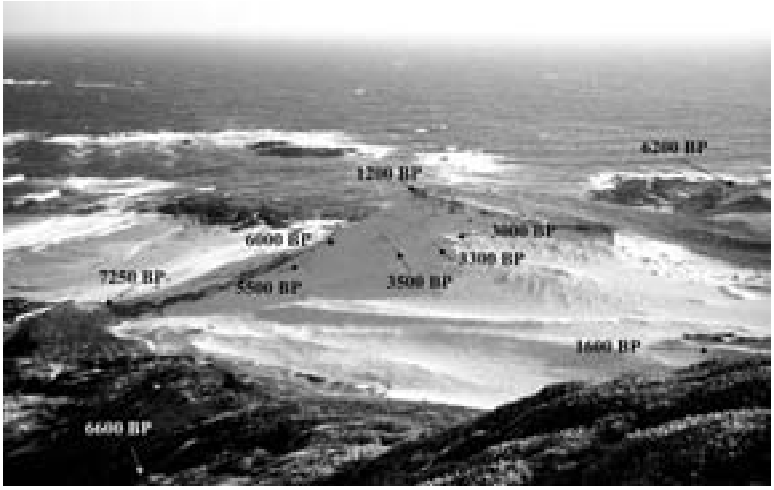

FIGURE 1.2. A Holocene dune in the Otter Point area on California's San Miguel Island, where at least 10 stratified shell midden components spanning the past 7,300 years have been identified; note figures atop dune for scale (photo by J. Erlandson).

were abundant along the Baja and Alta California coast before being driven nearly to extinction during the first half of the nineteenth century by hunters who rendered their blubber into a commercial oil. Since Mexico officially protected a tiny relict population on Guadalupe Island in AD 1911, however, elephant seal populations along the Pacific Coast have recolonized much of their historical range and expanded to over 150,000 animals (Ellis 2003:193). Such a dramatic recovery, similar to the story of the California sea otter *(Enhydra lutris)*, is heartening for conservationists but raises fundamental questions about the articulation of archaeological, historical, and ecological records. If California Indians temporarily eradicated sea otters or elephant seals from their hunting territories or even the entire Channel Islands, could we recognize such rapid decline and recovery cycles in the archaeological record? These and other problems are yet to be resolved, but some of the primary methods archaeologists and ecologists are using to identify and understand human impacts on marine ecosystems are briefly summarized below.

Resource Depletion and Depression

For archaeologists, one of the most visible types of evidence for localized human impacts on marine fisheries may be found in cases of resource depression, or other changes in the types of resources people used through time. As predicted by foraging theory, humans entering a given environment will initially focus on harvesting a suite of optimal or "high-ranked" resources that provide relatively high nutritional or other (furs, raw materials for tools, etc.) yields (Grayson 2001). Although high-ranked resources are often assumed to be large animals, this is not always the case in aquatic environments, where relatively small shellfish or fish can often be mass harvested in large quantities. Because human groups often contain a diverse array of individuals (of different ages, sex, craft specialists, social class, etc.), and many coastal ecosystems offer a wide array of foods, the range of resources considered "optimal" by coastal groups may be diverse and related to population size. If intensive harvesting of high-ranked resources reduces their productivity (density, size, accessibility, etc.), people may choose to spend more travel time to access them, switch to lower-ranked alternatives closer to home, or a develop a combination of strategies. Eventually, however, a depletion of local resources and the increased travel time invested in making a living may lead to the movement of a village or other residential base.

As mentioned earlier, cases of localized resource depression are relatively common in the archaeological record, especially in coastal areas where people were often relatively sedentary. Changes in the diversity or relative importance of subsistence resources harvested through time, especially within a single occupational component, may provide evidence for localized resource depression. Archaeologists must be careful, of course, to evaluate other possible causes of such changes, as numerous natural processes (storms, sedimentation, disease, other predators, water temperature, etc.) can lead to a reduction in the density of local marine populations. Noncultural variables such as climate change have recently been documented in two interior regions and appear to have affected human hunting and encounter rates (Byers et al. 2005; Wolverton 2005). Nonetheless, when combined with other evidence for human predation pressure, cases of people switching to different resources or resource depression may provide valuable evidence for human impacts on marine communities. We cannot automatically assume, however, that evidence for localized depletion is equivalent to wider degradation of an ecosystem, as heavy local exploitation can be combined with residential mobility in a sustainable economic strategy.

Size or Age Changes in Marine Populations

Historical data suggest that heavy fishing pressure on many fish and shellfish species often reduces the average size or age of local or regional populations. Such changes can have a disproportionate effect on the productivity of a species, since larger and older individuals nearly always are breeding adults and tend to lay more eggs or have more offspring than younger or smaller adults. In the past, such effects may sometimes have been alleviated by technological limitations such as the size or stability of boats, the strength of nets or fishing line, and so forth. The size and age structure of marine populations can also be affected by a variety of noncultural factors alluded to earlier, including predation by other animals, storm events, changes in water temperature, and marine productivity. Even the life histories of certain species, including changes in growth and maturation rates, can be altered by intensive predation (Reitz and Wing 1999:314).

Despite these problems, temporal changes in the average size or age of individuals from a particular fish or shellfish species are one of the simplest, most common, and valuable measures used by archaeologists to reconstruct shifts in human predation pressure and impacts in marine or aquatic ecosystems (see Broughton 2002; Butler 2001; Claassen 1998; Erlandson et al. 2004; Jerardino 1997; Koike 1986; Lightfoot et al. 1993; Mannino and Thomas 2002; Swadling 1976). [AU4] Sample size is a critical issue in such analyses, so that they are best focused on major prey species that are well represented in a series of strata or sites. Geographic and temporal variability in the size and age of local populations can also be a problem, so such analyses may best be applied to long and relatively continuous sequences within a single site or a relatively small area. However, Klein et al. (2004) recently used variation in average shellfish size from a relatively broad area of the South African Coast to effectively identify changes in predation intensity between Middle and Late Stone Age peoples. One of the great advantages of average size or age studies for zooarchaeological assemblages is that they can be readily compared to paleontological, historical, and recent ecological data sets to construct relatively long and continuous records of change in marine ecosystems (see Steneck and Carlton 2001).

Reductions in Geographic Range

One of the reasons marine animals have historically been more resistant to extinction caused by humans is that they often had geographic refuges where humans were incapable of capturing them, either in deeper offshore waters, remote and inaccessible stretches of coastline, or on offshore islands. As humans expanded around the globe and developed increasingly effective maritime technologies, these refuges gradually shrank and were probably increasingly limited to deeper waters and more remote islands that humans had not yet reached. Remote island populations of pinnipeds, seabirds, sea turtles, and other animals that spent part of their life cycle on land were especially vulnerable to human impact, as they often bred, laid eggs, roosted, or rested in terrestrial landscapes devoid of large predators. When maritime peoples first arrived on such islands, or recolonized them after sustained absences, they often had a heavy impact on such vertebrate populations.

If we can accurately reconstruct the distribution of such animal populations prior to the arrival of humans, the study of faunal assemblages from archaeological sites has great potential for understanding the impacts that both prehistoric and historic peoples had on the distribution of seabird colonies, pinniped rookeries, and other animal aggregations. A number of studies have implicated human hunting as the cause of impacts on the prehistoric distribution of pinniped rookeries and haul-outs in the Pacific (e.g., Anderson 2001; Bryden et al. 1999; Burton et al. 2002; Hildebrandt and Jones 1992, 2002; Jones and Hildebrandt 1995; Lyman 1995), for instance, and archaeological and historical accounts have both contributed to an understanding of the reduction in the geographic range of walrus in the North Atlantic (see Mowatt 1984).

We should be cautious about attributing changes in the distributions of such animals solely to human impacts, however, because a variety of other processes can affect both their density and distributions. Along the Pacific Coast of North America, the geographic range, feeding patterns, and behavior of marine mammals have been altered by the historical decimation of their own populations as well as those of their predators and prey (see Burton et al.
[AU5] al. 2002; Estes 1998; Etnier 2004). Hildebrandt and Jones (1992) proposed that early hunting by Native Americans eradicated numerous mainland rookeries, for instance, but mainland rookeries were probably always rare because of their vulnerability to grizzly bears and other predators (Erlandson et al. 1998:12). Coastlines are also extremely dynamic and were even more so with rapidly rising postglacial sea levels, so that coastal erosion may also have destroyed many small islets or islands that once contained nesting colonies, rookeries, and haul-outs. Finally, it is not always clear that the naive behavior of some modern animal populations would have persisted under sustained human hunting, and some seabird, pinniped, or other colonies may have been abandoned for more remote locations, without a regional depletion of an animal population.

Trophic Cascades

One of the basic tenets of ecology is that the components of an ecosystem are inextricably linked—one component does not change without affecting others—although the linkages may not always be immediate or easily recognized. Given this fact, we should expect heavy human predation on a particular marine species to have a corresponding effect on the competitors, prey, or predators that the depleted species strongly interacted with (Suchanek 1994). In some cases, including those pinnipeds or seabirds that feed in very deep waters or far offshore, a reduction in local population may have only minor effects on nearshore coastal ecosystems. In others cases, however, a reduction in some "keystone" species can have dramatic effects that set off "trophic cascades" or create "alternative stable states" within coastal ecosystems.

Trophic cascades caused by human overfishing have been documented in North American kelp forest ecosystems from the Aleutians, California, and the Gulf of Maine (Estes et al. 1998;
Jackson et al. 2001; Simenstad et al. 1979; [AU6]
Steneck et al. 2002, 2004), where the removal of apex predators such as cod and sea otters caused dramatic regime shifts in local and regional nearshore ecosystems. These case studies demonstrate the diversity of responses

to human impacts in similar ecosystems found in various regions. In the North Pacific, the most profound and immediate impacts appear to have occurred in Aleutian kelp forest ecosystems, where species diversity is relatively low and the removal of a single "keystone" predator (sea otters) can have dramatic effects, creating trophic cascades and alternative stable state communities. In the Aleutians, the removal of sea otters by Aleut and Russian hunters allowed a rapid proliferation of sea urchins that overgrazed nearshore kelp forests and created "urchin barrens" that support a much less productive and diverse suite of marine resources. Several cycles of kelp deforestation have been documented in the Aleutians, the most recent being the result of heavy killer whale predation on sea otters (Estes et al. 1998; Steneck et al. 2002).

In the more diverse food webs of the southern California Coast, in contrast, the eradication of sea otters from much of their historical range during the early 1800s had dramatic effects on nearshore ecosystems but never caused the wholesale collapse of kelp forests, probably because other predators such as sheephead and lobsters helped keep urchin populations in check. On San Miguel Island, however, understanding the dynamics of such trophic interactions has allowed us to tentatively identify some ecological changes that may signal localized impacts by Chumash Indians thousands of years ago. One of these is found in the proliferation of large red abalone middens between about 7,500 and 3,000 years ago, an archaeological site type that modern ecological data suggest could not exist unless sea otters populations were held in check, probably by native hunting (Erlandson et al. 2005).

In cases like that of the sea otter, which strongly influence the structure of nearshore biological communities, understanding the ecological consequences of heavy marine fishing or hunting of keystone species in coastal ecosystems can help develop a series of predictions for what related changes might be visible in the archaeological record. In many cases, such predictions can be developed from modern ecological studies and historical fisheries data that can also provide strong support for archaeological inferences about ecological changes in marine ecosystems caused or contributed to by humans. In our experience, however, the active participation of marine ecologists is a crucial component of such modeling and analyses.

Fishing Down Foodwebs

A relatively new quantitative method for understanding human impacts on fisheries was introduced by Pauly et al. (1998) in an influential quantitative synthesis of marine fishing practices in recent historical times. Using twentieth-century fisheries and ecological data on the average trophic level of economically important species, Pauly et al. (1998) identified a pattern of declining average trophic level in regional and global fisheries over time. They argued that this pattern reflected an intensive early focus of most commercial fisheries on relatively large and long-lived carnivores (e.g., cod, haddock, tuna, swordfish). When these fisheries declined or collapsed, the emphasis of commercial fishing switched to higher proportions of smaller fish (herring etc.), invertebrates (lobster, shrimp, shellfish, etc.), and other organisms that generally fill the lower trophic levels of ecosystems. Historically, sustained overfishing of some key predatory species (cod etc.) can lead to "ecological extinction" or "ecological ghosts," where a species is still present in an ecosystem but its numbers are so depleted that it no longer fills its normal ecological role. In cases like that of the sea otter, this can lead to the creation of trophic cascades and dramatic phase shifts in marine ecosystems, such as those described above for the Aleutian Islands (Estes et al. 1998; Simenstad et al. 1978; Steneck et al. 2002). Another classic example is the historical overexploitation of the Atlantic cod *(Gadus morhua)* and other large apex predators in the Gulf of Maine and the western North Atlantic (see Jackson et al. 2001; Steneck et al. 2002, 2004). Here, the ecological extinction of large nearshore fish released predatory controls on herbivorous sea urchins, which then greatly reduced the productive three-dimensional kelp forest habitats that appear to have dominated a relatively stable ecosystem for thousands of years. After heavy commercial fishing of sea urchins began in the late 1980s, however, kelp forests returned to the ecosystem, but the apex predator role is now filled by invertebrates (crabs). In this process of "accelerating trophic-level dysfunction," the average trophic level of marine fisheries has declined substantially (Steneck et al. 2004).

It is still not clear how much such historical examples may apply to prehistoric fishing practices, but the use of quantitative trophic level analysis has the potential to help bridge the gap between archaeological, historical, and ecological data on human impacts to marine fisheries (see Morales and Rosello 2004; Reitz 2004:63). For ecologists and fisheries managers, it provides a technique to explore changes in marine fisheries over much greater time depths and reexamine the shallow historical baselines on which fisheries management policy has long been based. As Reitz (2004:63) noted, the technique provides archaeologists a new perspective for understanding changes in archaeological fish faunas and an opportunity to use archaeological data to help restore marine ecosystems. So far, archaeological applications of trophic level analysis have been limited, but work by Reitz (2004) and Steneck et al. (2004) has provided important case studies for coastal archaeologists and marine ecologists to build on. We should not expect, however, that the patterns of the twentieth century will necessarily hold true through long periods of archaeological time. On California's Channel Islands, for instance, one of the secrets to the relative stability of indigenous fisheries over 10,000 years (Erlandson et al. 2005; Rick et al., this volume) may be that the Chumash and their ancestors appear to have focused first on the lower trophic levels, relying heavily on shellfish and smaller nearshore fish during the Early and Middle Holocene.

SUMMARY AND CONCLUSIONS

Throughout human history, the oceans generally appear to have been more resistant to human impact and degradation than terrestrial ecosystems. This fact is probably due to a combination of factors, including the longer history of hominid exploitation of terrestrial landscapes, the susceptibility of terrestrial landscapes to fire, the limited physiological and technological ability of humans (or their dogs, rats, pigs, etc.) to access deeper or more remote aquatic habitats, and the greater resistance of most marine organisms to diseases carried by humans and our domesticated companions. Our hominid ancestors may have used marine and aquatic resources to some extent for millions of years, but archaeological and anthropological data suggest that the intensity, diversity, and technological sophistication of aquatic resource use increased significantly after the appearance of anatomically modern humans roughly 150,000 years ago (Erlandson 2001; Erlandson and Fitzpatrick 2006).

Through the comparative approach of historical ecology, archaeologists have the opportunity to evaluate the evolution of human impacts on marine ecosystems through time and space. In the process, we can contribute valuable insights into one of the most important ecological problems currently facing humanity. In so doing, we can strengthen the relevance of archaeology in the modern world, as well as the arguments for increased protection of archaeological sites and increased research on the archaeology of coastal societies around the world. In the process, however, we should be cautious in how we interpret archaeological evidence for human impacts in marine ecosystems. We should be equally cautious in our use of historical and ecological data on the demography of marine species and the structure of past ecosystems, for in many cases historical or modern patterns have been affected by centuries or millennia of anthropogenic influence. Differences in both temporal and spatial scales should also be carefully considered, and further work needs to be done on the methods and theory required to effectively integrate paleontological, archaeological, historical, and ecological data sets.

For archaeologists and ecologists, evidence for human impacts on marine fisheries may be found in cases of resource depression, depletion, or shifting, changes in abundance and geographic distribution, reductions in size or age profiles for specific populations, in trophic cascades, or in changes in the average trophic level of marine species harvested. Understanding the nature of trophic cascades or other recent impacts documented with historical or ecological data can provide models that can help us understand the potential impacts of humans on marine ecosystems. On California's Channel Islands, for instance, marine ecologists have provided new insights on old archaeological problems by helping us better understand the dynamic historical ecological linkages between humans, sea otters, abalones, and sea urchins, and some previously unsuspected impacts of the Island Chumash on kelp forest ecosystems (Erlandson et al. 2004, 2005; Rick and Erlandson 2003). At the same time, we have learned that the biological diversity of Channel Island kelp forests makes them considerably more resistant to ecological collapse than the less-diverse kelp forest ecosystems of the Aleutian Islands and Gulf of Maine (Jackson et al. 2001; Steneck et al. 2002), helping explain why the Chumash and their ancestors may have had relatively limited impacts during a history of systematic fishing and hunting that spans more than 10,000 years (see Erlandson et al. 2005; Rick et al. this volume). [AU7] Anderson (2001) and Kirch (1999) have made similar points about variation in the productivity, diversity, and resilience of different Pacific Island ecosystems. Before we indict some human societies for excessive environmental degradation and celebrate others for their sustainability, we would do well to thoroughly understand the ecological and historical underpinnings of their successes and failures (see Rainbird 2002).

Despite tremendous variation in coastal cultures and ecosystems around the world—and what we suspect are a variety of adaptive trajectories that vary widely in their success—it seems reasonably clear that there is a general geographic expansion of human impacts to marine ecosystems over time. These began in supratidal and intertidal zones, expanded to subtidal and nearshore waters, then to pelagic zones not far from land, to island arcs more and more distant from the continents, to the vast and relatively empty expanses of the Atlantic, Pacific, and Indian oceans, and other oceans. Although these large oceanic expanses were traversed by Austronesians/Polynesians, Vikings, and others, their resources were largely untouched by humans until the advent of whaling and other industrial fishing technologies of the eighteenth, nineteenth, and twentieth centuries. Archaeology is obviously positioned to illuminate the expansion of marine, estuarine, and freshwater fisheries during prehistoric times, but it may also shed considerable light on some poorly documented fisheries of the historic era, such as the Chinese abalone fishers of Alta and Baja California in the mid- to late 1800s (see Braje et al. 2007). As a variety of studies have shown (see Jackson et al. 2001; Steneck et al. 2002, 2004; and the case studies that follow), archaeological data can play a key role in defining the acceleration of human impacts to marine ecosystems through time, the development of more realistic notions of the abundance of past populations prior to industrialized fishing, and the reconstruction of more effective historical baselines for the future restoration and management of aquatic fisheries and ecosystems. With this volume, we hope to highlight that potential, encourage further interdisciplinary work between coastal archaeologists and marine ecologists, and inspire ecologists, archaeologists, and others to pursue new directions in their research.