



Archaeology Meets Marine Ecology: The Antiquity of Maritime Cultures and Human Impacts on Marine Fisheries and Ecosystems

Jon M. Erlandson¹ and Torben C. Rick²

¹Department of Anthropology and Museum of Natural and Cultural History, University of Oregon, Eugene, Oregon 97403-1224; email: jerland@uoregon.edu

²Archaeobiology Program, Department of Anthropology, National Museum of Natural History, Smithsonian Institution, Washington, DC 20013; email: rickt@si.edu

Annu. Rev. Mar. Sci. 2010. 2:165–85

The *Annual Review of Marine Science* is online at marine.annualreviews.org

This article's doi:
10.1146/annurev.marine.010908.163749

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1941-1405/10/0115-0165\$20.00

Key Words

fishing, deep history, hunter-gatherers, agriculturalists, shifting timelines

Abstract

Interdisciplinary study of coastal archaeological sites provides a wealth of information on the ecology and evolution of ancient marine animal populations, the structure of past marine ecosystems, and the history of human impacts on coastal fisheries. In this paper, we review recent methodological developments in the archaeology and historical ecology of coastal regions around the world. Using two case studies, we examine (*a*) a deep history of anthropogenic effects on the marine ecosystems of California's Channel Islands through the past 12,000 years and (*b*) geographic variation in the effects of human fishing on Pacific Island peoples who spread through Oceania during the late Holocene. These case studies—the first focused on hunter-gatherers, the second on maritime horticulturalists—provide evidence for shifting baselines and timelines, documenting a much deeper anthropogenic influence on many coastal ecosystems and fisheries than considered by most ecologists, conservation biologists, and fisheries managers.

INTRODUCTION

Among marine scientists, there is a broad consensus that earth's oceans, fisheries, and marine ecosystems are in deep trouble (see Jackson 2008, Jackson et al. 2001, Lotze et al. 2006, Myers & Worm 2003, Pauly et al. 1998, Pew Oceans Comm. 2003, U.S. Comm. Ocean Policy 2004). Recent studies have concluded that overfishing, pollution, filling of estuaries and other shoreline modifications, the introduction of invasive species, global warming, ocean acidification, and other ecological impacts have reduced marine ecosystems to shadows of their former selves. There continue to be uncertainties and debates, however, about how to more effectively manage and sustain the world's fisheries and restore marine ecosystems.

Some uncertainty derives from a lack of historical perspectives on what is natural in the world's oceans and from the shifting baselines on which management and restoration goals are often based (Dayton et al. 1998, Jackson 2001, Knowlton & Jackson 2008, Pauly 1995, Pinnegar & Engelhard 2008). There is broad agreement that establishing protected marine areas is crucial to restoring marine fisheries and ecosystems, but questions remain about what states we aim to restore these populations or systems to. Do the marine ecosystems of 50, 100, or 1000 years ago represent pristine states that we should strive to recreate? Are there lessons from the deeper past that might guide us in managing our present and restoring our future? The interdisciplinary study of archaeological records can provide valuable data on the distribution and ecology of past marine populations, the nature of ancient marine ecosystems, the deep history of human impacts on marine fisheries, and the acceleration and geographic expansion of such impacts through time.

In this paper, we explore how archaeology can help better understand the past, present, and future of marine fisheries and ecosystems. We start by reviewing the history of anthropological thought regarding the development of fishing and seafaring societies, some problems associated with understanding the antiquity of human fishing, and recent discoveries that suggest that humans have fished and foraged in many coastal and island ecosystems for much longer than once believed, with earlier and greater impacts on marine fisheries and food webs than most scientists typically imagine.

THE ANTIQUITY OF FISHING

Until recently, even most archaeologists doubted that prehistoric humans had significant effects on marine fisheries and ecosystems. The oceans were considered by some as inexhaustible and by others as largely inaccessible to early humans—until the development of the industrialized and commercialized fisheries of historic times. Still others viewed current environmental crises as relatively recent problems caused by exponential human population growth, the invention of modern technologies, and the emergence of global markets. Such perspectives result from the tendency of recent generations to minimize the ecological impacts of preindustrial peoples and demonize recent industrial advances, as well as the mistaken notion that ancient peoples were not sophisticated or numerous enough to significantly alter their natural environments (Kay & Simmons 2002, Krech 1999, Kirch 2005). For most of the twentieth century, such notions were encouraged by anthropological theory suggesting that boats, seafaring, and intensive fishing developed only in the past 10,000 years or so (Washburn & Lancaster 1968, Osborn 1977, Yesner 1987)—less than one percent of the history of the genus *Homo*.

Understanding the antiquity of coastal settlement, marine fishing, and maritime migrations is difficult because global sea levels have risen ~125 m in the past 20,000 years, drowning ancient shorelines and vast coastal landscapes (Bailey et al. 2007, van Andel 1989). Recent efforts to better understand the importance of marine and freshwater ecosystems in human evolution have focused

on (a) submerged terrestrial sites (Flemming 2004), raised interglacial shorelines or coastlines with steep bathymetry (Erlandson 2001), (b) evidence for fishing in freshwater systems (Stewart 1994, Yellen et al. 1995), (c) oceanic islands colonized during the Pleistocene (Erlandson 2002), (d) modern and ancient human DNA (e.g., Wells 2002), and (e) human biochemistry (Broadhurst et al. 1998). These approaches are changing scholarly perspectives on the antiquity of fishing societies, seafaring, and human impacts on marine ecosystems.

Recent archaeological research suggests that fishing may have much more ancient origins than previously believed (Bailey 2004, Erlandson 2001). Stewart (1994) argued that *Homo habilis* and *H. erectus* populations in East Africa harvested fish from freshwater lakes, for instance, and that *H. erectus* also collected shellfish and may have made short sea crossings in Island Southeast Asia as many as 800,000 years ago (Morwood et al. 1998). In Gibraltar and the Mediterranean, there is evidence for coastal foraging by Neanderthals between approximately 125,000 and 30,000 years ago (Garrod et al. 1928, Stiner 1994, Stringer et al. 2008). Even earlier evidence comes from Middle Stone Age sites in South Africa, where marine shellfishing and hunting (or scavenging) date back at least 160,000 years (Marean et al. 2007).

South Africa's Middle Stone Age shell middens, deposited by early *H. sapiens sapiens* and associated with new technologies, shell beads, red ochre, and other so-called modern human behaviors (Henshilwood et al. 2001), offer some of the earliest archaeological evidence for relatively intensive marine foraging in the world (see Klein et al. 2004, Parkington 2003, Singer & Wymer 1982). The broader resource base offered by combining the systematic use of terrestrial and marine resources may have fueled the demographic and geographic expansion of anatomically modern humans (AMH) out of Africa, who migrated along the southern shores of Asia between approximately 70,000 and 50,000 years ago (Bulbeck 2007, Wells 2002). These coastal peoples then used boats in seafaring voyages to Island Southeast Asia, Australia, and New Guinea at least 50,000 years ago, western Melanesia and the Ryuku Islands 35,000–40,000 years ago, and California's Channel Islands at least 13,000 years ago (Erlandson 2009)—maritime migrations that brought humans to new continents and many islands for the first time.

ARCHAEOLOGY AS HISTORICAL ECOLOGY

Archaeologists study past living and processing sites to reconstruct ancient environments and human adaptations. Many coastal sites contain accumulations of marine shell and other refuse (animal bones, tools, etc.) left behind by fishing and foraging peoples. In optimal locations, people sometimes lived continuously for centuries or returned repeatedly over the millennia, leaving stratified records of changes in local ecosystems through time. In such cases, shell middens can provide long sequences of information on human demography, technology, ecology, and impacts on coastal ecosystems.

Zooarchaeological assemblages are structured by human foraging choices, differential preservation, and recovery techniques, but many shell middens contain diverse biological assemblages collected by humans for dietary purposes, along with epifauna or stomach contents associated with prey species as well as remains left in occupation sites incidentally by other predators (dogs, birds, etc.). Stratigraphic variation in the relative abundance of major food species can indicate changes in their economic importance or natural abundance over time and may provide important clues about the effects of humans on local ecosystems.

There is also growing use of stable isotopes, trace elements, and ancient DNA from floral and faunal remains to obtain information about ancient humans, as well as the biological populations and ecosystems they interacted with. Stable carbon and nitrogen isotopes in human bone collagen illuminate ancient diets, for example, and analysis of stable isotopes and trace elements also allows

the study of changes in local food webs through time—including the reconstruction of trophic levels and historical perturbations caused by anthropogenic interference in marine ecosystems. DNA studies can be used to identify population bottlenecks in the past and estimate the size of specific populations (e.g., Roman & Palumbi 2003).

THE ARCHAEOLOGY OF ANTHROPOGENIC ECOLOGICAL CHANGE

There is growing interest in the archaeological study of human impacts on ancient ecosystems, including the dynamic roles humans have played in the extinction of animal species, habitat changes, and the collapse of complex cultures (Diamond 2005, Lyman & Cannon 2004, Redman et al. 2004). Far from living in harmony with their natural environments, the arrival of *H. sapiens sapiens* in newly colonized lands was often associated with accelerated habitat changes and extinction rates. Proving that humans were the primary cause of ancient animal extinctions can be complicated (Grayson 2001), but significant human contributions to extinctions or other environmental impacts have been proposed for late Pleistocene Australia (Miller et al. 1999, Roberts et al. 2001) and the Americas (e.g., Martin 2002), some Caribbean Islands in the early Holocene (Steadman et al. 2005), and many Pacific Islands in the late Holocene (Anderson 1989, Kirch & Hunt 1997, Steadman 2006). The initial arrival of behaviorally modern and technologically sophisticated humans seems to have been particularly problematic in regions where endemic species had not previously been subject to hominid predation.

Continental and island landscapes have played important roles in studying the impacts of early humans, but discussions of anthropogenic extinctions are limited almost exclusively to vertebrate species that live, nest, feed, or breed on land. In compiling a list of large animals potentially driven to extinction by our ancestors, Martin (2002) listed scores of terrestrial genera, but no marine or aquatic species. The dearth of human-induced extinctions in marine ecosystems does not mean that early maritime peoples had no effect on those ecosystems, however, especially in intertidal and nearshore habitats they had been actively hunting, fishing, and foraging in for millennia.

IDENTIFYING AND MEASURING ANCIENT HUMAN IMPACTS TO MARINE ECOSYSTEMS

Archaeologists and other scientists use a variety of methods to explore the effects of past humans on marine fisheries and ecosystems: (a) changes in the geographic ranges of species, (b) reductions in their abundance or mean size/age profiles (resource depression), (c) signatures of trophic cascades, and (d) studies of mean trophic levels in marine fisheries (see Bailey et al. 2008, Erlandson & Rick 2008, Reitz 2004). Archaeological, paleontological, historical, and ecological data are often collected via different methods, however, and issues of differential resolution, scale, and comparability of data sets from different disciplines still pose thorny issues for the field of historical ecology.

Archaeologists can reconstruct very long time series, but their resolution is generally limited to decadal or centennial scales. Because even long-term ecological records rarely span more than a few decades, we do not know the full extent of cyclical fluctuations in most ecosystems that operate on decadal scales or longer. The historical range and behaviors of some marine species have also changed significantly as their populations were devastated by early historical exploitation or, in some cases, have recovered in ecosystems fundamentally changed by a variety of historical impacts. Knowledge of the geographic range and behavior of marine mammals along the Pacific Coast of North America, for instance, is rapidly changing as various species adjust to dynamic oceanic

conditions and the alteration of marine ecosystems caused by overfishing, habitat changes, and other anthropogenic effects (see Burton et al. 2002, Estes et al. 1998).

Intertidal shellfish beds are often highly susceptible to human overexploitation, but shellfish (and other) populations can also be destroyed or depleted by disease, nonhuman predation, storms and sedimentation, changes in water temperature, and other processes. The rapid nature of ecological change can also be problematic for coastal archaeological records, wherein changes are rarely charted on scales finer than approximately 50 to 100 years. Along the California Coast, for instance, northern elephant seals (*Mirounga angustirostris*) were driven nearly to extinction in the nineteenth century by commercial hunters. Since 1911, however, a small relict population on Guadalupe Island has expanded to over 150,000 animals (Ellis 2003, p. 193). Such rapid changes in geographic range and demography may be difficult to identify in relatively coarse-grained archaeological records.

Cases of localized resource depression may have been common in many coastal ecosystems in the past (see Broughton 2002, Butler 2001, Nagaoka 2002), especially where people were relatively sedentary. If natural causes can be ruled out, these cases can provide convincing evidence for human impacts on marine communities. Localized depletion is not necessarily equivalent to the degradation of a wider ecosystem, however, as heavy local exploitation can be combined with residential mobility in a sustainable economic strategy. Humans entering a new environment may initially focus on harvesting an optimal suite of resources that provide high nutritional and other yields. These may be large animals, but some small shellfish or fish can also be mass-harvested efficiently in marine ecosystems. If intensive harvesting of a species reduces its productivity, people may spend more travel time to access it, switch to a lower-ranked resource, or move their residential base to a more productive location.

Because intensive human predation has been shown to reduce the average size or age of individuals in many modern populations of shellfish and other marine taxa, tracking such size changes in ancient fisheries offers a relatively simple and valuable measure used by archaeologists to identify possible evidence for human predation pressure and impacts in marine ecosystems (Jerardino et al. 1992, Mannino & Thomas 2002). One advantage of such studies is that they can be readily compared to paleontological, historical, and recent ecological data sets to construct long records of change in marine populations and ecosystems (see Roy et al. 2003). Larger and older individuals also tend to lay more eggs or have more offspring so that reducing the average size or age of a population can also have a disproportionate effect on species recruitment and abundance.

One reason marine animals were more resistant to extinction caused by prehistoric humans is that they often had geographic refuges—deep offshore waters, remote and inaccessible coastlines, or offshore islands—where people could not capture them. With the development of increasingly sophisticated maritime technologies and expansion of people to new and increasingly remote regions, these refuges shrank over time and were largely limited to deeper waters and more remote islands. Island populations of pinnipeds, seabirds, sea turtles, and other animals that spent part of their lives on land were especially vulnerable to humans, as they often bred, roosted, or rested in terrestrial landscapes. When people first arrived on such islands, or revisited them after long absences, they often rapidly depleted such animals or drove them to extinction. Prehistoric humans may have contributed to reductions in the geographic ranges of the walrus and great auk in the North Atlantic, for example, but the habitat, distributions, and abundances of such animals were also affected by climate change, postglacial sea-level rise, and coastal erosion that destroyed many small islands that once contained nesting colonies, rookeries, and haul-outs.

The components of ecosystems are intricately linked, with changes to one component generally affecting others. The strength of these linkages varies, however, and the effects may not always be immediate or easily recognized. Heavy human predation on a marine species generally has

corresponding effects on the competitors, prey, or predators with which the depleted species strongly interacted. The effects of human predation on so-called keystone species can trigger trophic cascades or alternative stable states in coastal ecosystems. Intensive hunting of sea otters by Aleuts and Russians in the Aleutian Islands, for instance, allowed a proliferation of sea urchins that overgrazed nearshore kelp forests and created urchin barrens with lower biodiversity and productivity of marine resources (Simenstad et al. 1978, Steneck et al. 2002). The nineteenth-century extinction of sea otters from most California waters also spawned highly productive historical fisheries focused on abalones and urchins, two of the main prey species of otters. In such cases, historical and ecological accounts of the consequences of heavy fishing or hunting in coastal ecosystems can provide models for what related changes might be expected in archaeological records.

Pauly et al. (1998) introduced a technique for quantifying human impacts on fisheries that analyzes changes in the average trophic level of fisheries over time. In a global analysis, they identified a pattern of declining average trophic level in human fisheries through the twentieth century, arguing that most commercial fisheries generally target relatively large and long-lived carnivores (whales, cod, tuna, etc.) first. After these fisheries decline or collapse, commercial fishing often switches to smaller species (herring, lobster, shrimp, etc.) that generally fill the lower trophic levels of ecosystems. Ultimately, such overfishing of key predatory species can cause ecological extinctions (or “ghosts”), where a species is still present but its numbers are so reduced that it no longer fills its normal ecological role (Dayton et al. 1998). This can cause trophic cascades and phase shifts in marine ecosystems, similar to the historical overexploitation of the Atlantic cod (*Gadus morhua*) in the Gulf of Maine (Steneck et al. 2002), where the ecological extinction of cod released predatory controls on herbivorous sea urchins, greatly reducing the productive kelp forest habitats that dominated a relatively stable ecosystem for thousands of years. In this process of accelerating trophic-level dysfunction, the average trophic level of marine fisheries declined substantially through time (Steneck et al. 2004).

Trophic-level analyses can help bridge the gap between archaeological, historical, and ecological data on human impacts to marine fisheries. For ecologists and fisheries managers, it provides a technique with which to explore changes in marine fisheries over much greater time depths and to reexamine the shallow historical baselines on which fisheries management policy has long been based. 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 (e.g., Bourque et al. 2008). We should not expect the patterns of the twentieth century to hold true through long periods of archaeological time, however, as environmental conditions, human population levels, available technologies, and adaptive strategies often change through the millennia.

VARIATION THROUGH DEEP TIME: A CALIFORNIA CHANNEL ISLANDS CASE STUDY

We have spent much of the past decade using archaeological methods and data to study the historical ecology of California’s Channel Islands, focusing on understanding the dynamics of human environmental interactions through long expanses of time (e.g., Braje 2007, Braje et al. 2007, Erlandson et al. 2005, Rick et al. 2008). First colonized by humans at least 13,000 calendar years (cal BP) ago (Erlandson et al. 2008a, Johnson et al. 2002), the Channel Islands are an ideal laboratory for such research because they provide one of the longest continuous sequences of human coastal occupation in the Americas. Channel Island archaeological sites are also relatively well preserved and can be compared to high-resolution paleoecological records from varved sediments

of the Santa Barbara Basin (Kennett & Ingram 1995, Kennett & Kennett 2000). The juxtaposition of these two records allows the exploration of relationships between environmental changes (climate, marine upwelling, sea-surface temperatures, sea-level rise, etc.), changes in marine and terrestrial ecosystems, and cultural developments ranging from human subsistence, demography, technology, and social organization (see Arnold 2001, Kennett 2005, Rick 2007).

California's Channel Islands (**Figure 1**), sometimes described as the American Galapagos, include eight major islands broken into southern and northern groups. The southern islands (San Clemente, Santa Catalina, San Nicolas, and Santa Barbara) are relatively isolated and dispersed, lying 32 to 98 km offshore and having been separated from the mainland and one another throughout the Quaternary. The northern islands (Anacapa, Santa Cruz, Santa Rosa, and San Miguel) are tightly clustered, lying 19 to 42 km off the mainland. The northern islands coalesced into one larger island known as Santarosae during the last glacial maximum (LGM), but they also remained separate from the mainland throughout the Quaternary (Johnson 1983, Orr 1968). Channel Island terrestrial floras and faunas are considerably less diverse than those of the adjacent mainland, but the larger islands have greater terrestrial biodiversity. In the late Pleistocene, the northern islands contained a population of pygmy mammoths (*Mammuthus exilis*) (Agenbroad et al. 2005) and a diverse avifauna (Guthrie 1993, 2005).

Recent research on the Northern Channel Islands has focused on using archaeological and paleontological records to understand the historical ecology of the islands since the LGM. On land, studies have examined changes in the size and shape of the islands (Kinlan et al. 2005), the history of dune formation (Erlandson et al. 2005), the extinction of endemic fauna (Jones et al. 2008), the human introduction of animals (Rick et al. 2008, 2009), and the dynamics of native plant communities (West & Erlandson 1994). The geography of the Northern Channel Islands has changed dramatically since the LGM; specifically, major vegetation changes and the loss of vast lowland areas to postglacial sea-level rise and coastal erosion have occurred. The extinction of mammoths ~13,000 cal BP—attributed to human hunting (Agenbroad et al. 2005, Orr 1968), environmental change, or even an extraterrestrial impact (Firestone et al. 2007, Kennett et al. 2009)—undoubtedly altered terrestrial vegetation communities (Johnson 1980). The appearance of humans—along with the dogs, foxes, and more frequent fires that accompanied them—may have had equally profound effects on the ecology of the islands.

In the marine ecosystem, faunal data from island shell middens provide insights into spatial and temporal variation in local intertidal, nearshore, and (to a lesser extent) pelagic habitats, as well as the interactions of dynamic human societies with them over large expanses of time. On the Northern Channel Islands, home to the Island Chumash people for millennia prior to European contact in AD 1542, the archaeological record is nearly continuous from ~10,000 cal BP until approximately AD 1820, when the Island Chumash were removed to the mainland. More limited data are available for human occupations between ~13,000 and 10,000 cal BP and from AD 1820 to the present. Recent efforts to bridge the historic period—crucial to linking archaeological, historical, and ecological records—have focused on nineteenth century Chinese abalone middens (Braje et al. 2007) and a bald eagle nest/midden near Point Bennett that produced roughly 10,000 faunal elements deposited between ~AD 1850 and 1950 (Collins et al. 2005).

In the Santa Barbara Channel area, paleoecological records and modeling suggest that the temperature and productivity of marine waters have fluctuated since the LGM, changes that affected the nearshore marine ecosystems and the maritime peoples who depended on them (see Kennett 2005, Kennett & Ingram 1995). General marine productivity in the region is driven by upwelling of nutrient-rich water that fuels primary and secondary productivity in continental shelf waters. Another driver of marine productivity, especially in nearshore ecosystems, are vast and fast-growing kelp forests of *Macrocystis pyrifera*, *Nereocystis leutkeana*, and other species, which

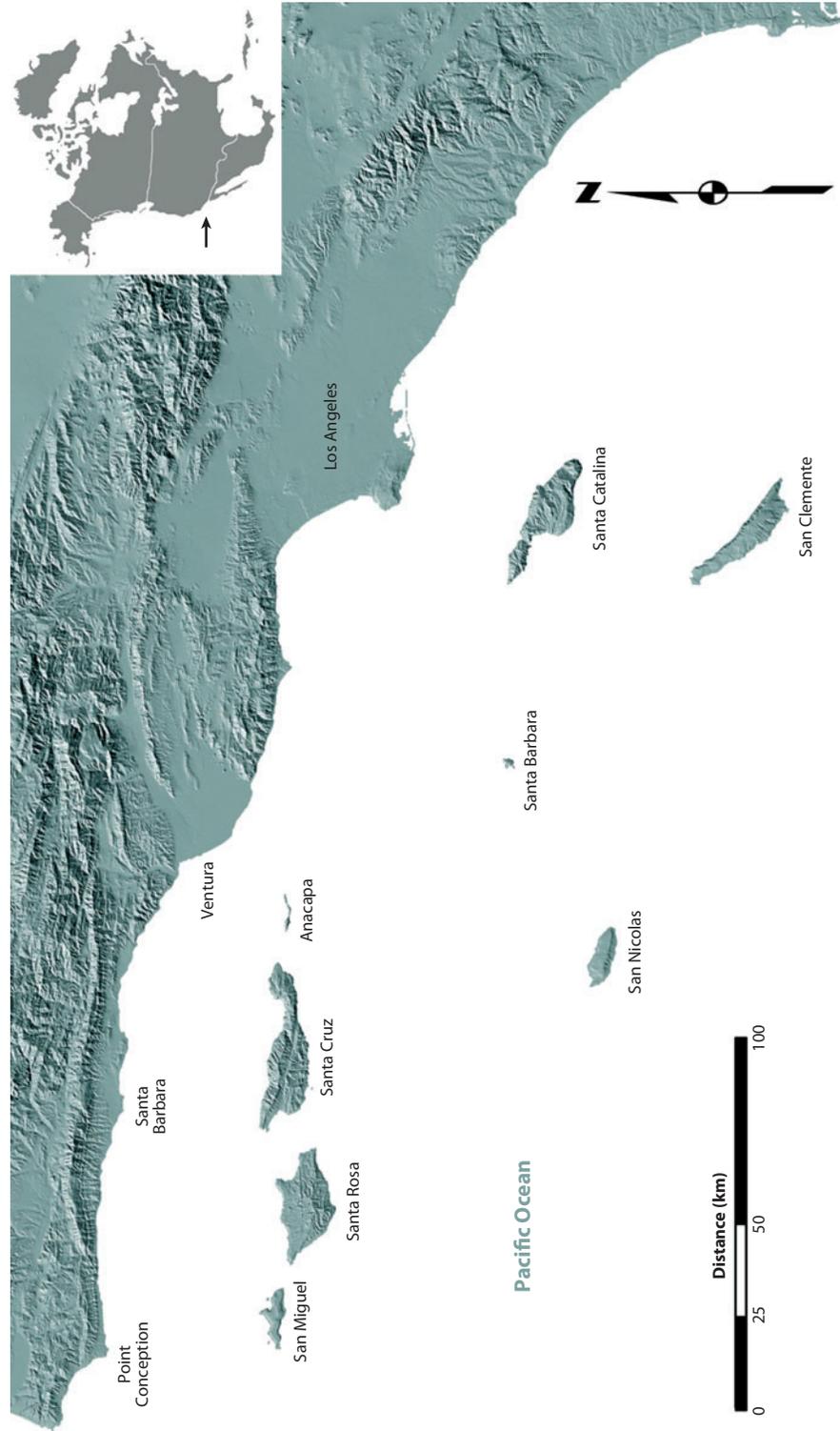


Figure 1
California's Northern Channel Islands.

produce huge quantities of organic matter and provide three-dimensional habitat that supports a diverse food web (Steneck et al. 2002). In modeling the coastlines and nearshore habitats around the Channel Islands since the LGM, Kinlan et al. (2005) concluded that kelp forests were considerably more extensive during the terminal Pleistocene and early Holocene, when Paleocoastal peoples occupied the islands.

Kelp Forests, Sea Otters, and Shellfish: Evidence for Anthropogenic Trophic Cascades

Some of the nearshore organisms that depend on these kelp forests include red and black abalones (*Haliotis rufescens*, *H. cracherodii*), mussels (*Mytilus californianus*), sea urchins (*Strongylocentrotus* spp.), turban snails (*Tegula funebris*, *T. brunnea*), and other shellfish that feed on kelp, kelp spores, or kelp detritus. These shellfish are preyed upon by a host of organisms from higher trophic levels, including lobsters (*Panulirus interruptus*), a variety of marine birds, fish such as the California sheephead (*Semicossyphus pulcher*), California sea otters (*Enhydra lutris*), and humans. Sea otters are predators that strongly influence the structure of kelp forests and other nearshore habitats around the North Pacific Rim (Simenstad et al. 1978, Estes & Palmisano 1974). Recent ecological studies show that where sea otters are abundant, abalone and urchin populations are limited in size and live mostly in cryptic habitats that are difficult to access.

Many Channel Island archaeological sites dating between approximately 8000 and 3500 cal BP contain impressive numbers of large red abalone shells, assemblages that suggest that otters were relatively rare in local waters. Sea otter bones have been found in island sites spanning the past 9000 years—documenting that they were actively hunted by early island peoples—and their pelts were highly valued by the Chumash in historic times. The abundance and large size of red abalone shells in many early Channel Island shell middens suggests that sea otter populations were limited by Native American hunters beginning ~8000 cal BP (Erlandson et al. 2005), a resource depression that released abalone populations and triggered anthropogenic trophic cascades. A number of Channel Island sites, including some red abalone middens, also contain dense accumulations of sea urchin tests and spines, further evidence for a depression of otter populations. Another major predator of urchins in Channel Island kelp forests is the California sheephead, which was also heavily fished by early islanders (Rick et al. 2001). When released from predation, sea urchin populations can explode, denuding kelp forests and creating urchin barrens (Steneck et al. 2002). Current evidence suggests that ancient barrens were probably localized and short lived, similar to historical examples in California waters outside the modern range of sea otters, as organisms closely associated with kelp forests continue to be abundant throughout the sequence.

Human Predation and Declining Shellfish Size

Further evidence for an early human impact on Channel Island intertidal and nearshore ecosystems comes from studies of changes in the mean size of several shellfish species through the Holocene (Roy et al. 2003). An initial study, based on a small sample of California mussels from eight sites spanning the past 10,000 years, found little evidence for a patterned reduction in shell size (Erlandson et al. 2004). However, a more comprehensive study measuring more than 11,000 whole shells from 41 archaeological components identified progressive declines in the average size of red abalones and California mussels over the past 10,000 years (Erlandson et al. 2008b).

On San Miguel Island, the earliest assemblage of red abalone shells dates to ~7500 cal BP, with a mean length of 189 mm. Overall, the length of 548 red abalone shells dated between 7300

and 4350 cal BP averaged 166 mm, with no assemblages having means of less than 124 mm. In seven sites dated from 3350 to 200 cal BP, in contrast, red abalone shells averaged 94 mm long, with no assemblages having means greater than 99 mm. Thus, over a 7000-year period, the mean length of red abalone shells harvested was reduced by 50 percent. In nineteenth-century middens created primarily by Chinese fisherman in response to a boom in abalone populations after the local extinction of sea otters, the mean size of red abalone shells is 192 mm. California mussel shells also declined over a period of 10,000 years—with a mean length for the early Holocene of 47 mm compared to 39 mm for late Holocene sites. A similar decline occurs in the mean length of giant owl limpet (*Lottia gigantea*) shells after ~8,000 cal BP.

Because these reductions in mean shell size show no correlation with changing patterns of water temperature, marine productivity, or other environmental changes, they seem most likely to result from intensifying human predation caused by human population growth over time. Along with declining shell size, there is a gradual reduction in the dietary contribution of shellfish through time—from >80% in most early Holocene sites to <15% in most late Holocene sites—and an increase in the contributions of sea mammals and marine fish. These patterns suggest that Channel Islanders, at least during the Holocene, focused initially on lower trophic levels, then shifted to animals from higher trophic levels through time (Erlandson et al. 2009)—unlike historical fisheries, which generally “fish down food webs” (Pauly et al. 1998).

Reassembling Channel Island Pinniped Populations

Today, California’s Northern Channel Islands shelter more than 150,000 pinnipeds from six different species (DeLong & Melin 2002). These pinnipeds were hunted nearly to extinction in historic times, but they recovered rapidly under federal protection, expanding into an ecological vacuum altered by millennia of accelerating anthropogenic manipulation and change. Like the dense abalone populations that many marine biologists and ecologists consider emblematic of a natural state in California’s coastal waters, expanding pinniped populations have congregated near the west end of the Northern Channel Islands, including the huge Point Bennett rookery on western San Miguel Island (DeLong & Melin 2002). Archaeological work in the midst of this pinniped rookery, however, documented the presence of a Chumash village site containing a cemetery and the remnants of several large houses occupied between approximately AD 1450 and 1650 (Walker et al. 2002). Midden deposits at this site, which could not possibly have coexisted with a large pinniped rookery, are dominated by marine fish remains. Of the many archaeological sites in the Point Bennett area that span the past 10,000 years, moreover, very few contain large amounts of pinniped bone.

Channel Islands zooarchaeological data have also played a key role in documenting a major shift in the distribution of pinniped species along the Pacific Coast of North America. Today and in historic times, Guadalupe fur seals (*Arctocephalus townsendi*) rarely haul out on California’s Channel Islands, where northern elephant seals (*Mirounga angustirostris*) and other species dominate extant pinniped populations. In a recent synthesis of data from California and the Pacific Coast, however, Rick et al. (2009) demonstrated that Guadalupe fur seals dominate the pinniped remains found in Channel Island archaeological assemblages from the last 7000 years. Conversely, archaeological data suggest that northern elephant seals are relatively rare in Native American archaeological sites on the Channel Islands, despite the vulnerability of modern populations to human hunting. These two studies suggest that the natural distribution and ecology of Pacific Coast pinnipeds as they recover under federal protection may differ dramatically from the patterns that existed for millennia prior to the ecological changes caused by intensive commercial exploitation under the globalized European and Euro-American economies of historic times.

Comparing Native American Versus Euro-American Impacts

Archaeological evidence suggests that the Chumash and their ancestors transformed Channel Island marine and terrestrial ecosystems long before Europeans explored and settled California. Over the millennia, through a combination of intensive fishing and hunting, the introduction of dogs and foxes, and more frequent fires, island ecosystems became increasingly anthropogenic. Sea otter populations may have been dramatically reduced by 7500 cal BP, to the benefit of local shellfish populations, but archaeological evidence suggests that otters continued to be hunted in local waters into historic times. The distribution, abundance, and ecology of many shellfish, fish, pinnipeds, and birds were altered, but the same suite of species continued to be harvested through the millennia. This contrasts sharply with the ecological impacts of the past 240 years, since the Spanish first settled the southern California Coast. Despite millennia of intensive harvests, the Spaniards described Chumash societies and fisheries as remarkably rich. Within decades, however, the Chumash were removed from the islands; sea otter, whale, many pinniped species, bald eagles, and other species were driven to the brink of extinction; Channel Island landscapes were denuded and eroded after sheep and other livestock were introduced to the islands; and local fisheries entered an extended period of serial depletion and collapse. Comparing the impacts of Native Americans who lived on the islands for millennia with those of the colonial powers that followed suggests that we have much to learn from the former.

VARIATION THROUGH SPACE: MARITIME AGRICULTURALISTS IN POLYNESIA

The human colonization of the Pacific Basin (**Figure 2**) is one of the great odysseys and milestones in human history. Voyages spanning thousands of kilometers and scores of widely scattered islands occurred over a relatively short period, beginning with the colonization of Micronesia and near Oceania ~4000–3000 years ago and reaching Hawai'i, New Zealand, and Easter Island roughly 1000 years ago (Anderson & Sinoto 2002, Hunt & Lipo 2006, Wilmschurst et al. 2008). Each Pacific Island group has a unique history of colonization and transformation, providing important lessons for understanding human impacts on island ecosystems around the world (Kirch 1997, 2007).

Using sophisticated watercraft and navigation, Polynesians sailed to distant islands carrying suites of domesticates—so-called transported landscapes of exotic plants and animals that transformed Pacific Island ecosystems (Kirch 2000). It is now clear that the Pacific Islands, once viewed as tropical paradises with limited human influence, were affected by ancient peoples, who manipulated and shaped the land and seascapes around them (Anderson 2008, Kirch 1997, Kirch et al. 1992). The transformations varied between islands, with scholars debating the role people played in the deterioration of ancient ecosystems such as Easter Island (also known as Rapa Nui; see Diamond 2007, Hunt 2006, Rainbird 2002).

The best-documented ancient environmental impacts resulted from landscape clearing and burning for agriculture and the introduction of pigs, chickens, dogs, and rats that altered island habitats and preyed on or out-competed insular fauna. Because of their distance from continental landmasses, most of the Pacific Islands had impoverished terrestrial faunas, often dominated by birds, some of which evolved flightlessness or other unique behaviors due to the lack of predators (Steadman 2006). On many Pacific Islands, sea and land birds were rapidly depleted after human colonization, with numerous species driven to extinction (Steadman 2006). The demise of flightless moa species on New Zealand provides an example of direct (hunting) and indirect (rats eating moa eggs) human activities causing extinction prior to European colonization (Anderson 1989, 2008;

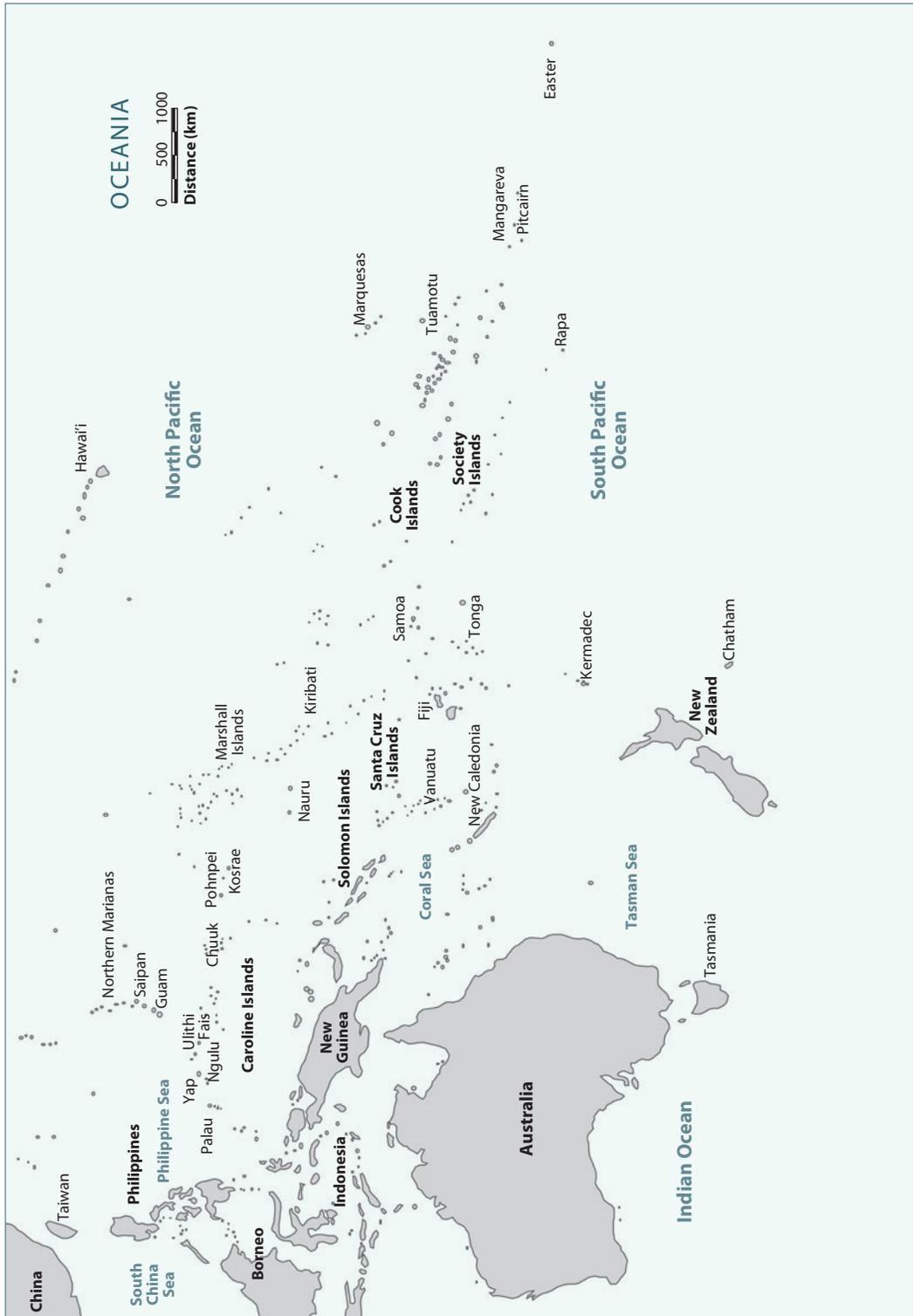


Figure 2
Map of Oceania showing major island groups.

Nagaoka 2002). Kirch (1997) noted that human activities also altered entire ecosystems. The fern forests of Mangaia, once thought to be a natural habitat, are now seen as anthropogenic landscapes formed through centuries of human landscape alteration.

Although a considerable body of data now exists on Polynesian transformations of Pacific Island landscapes, we know less about the impacts of Polynesians on marine ecosystems. Recent studies are filling this gap, with data from tropical and subtropical islands documenting the influence of humans on finfish, shellfish, marine mammals, and birds (e.g., Allen 2002, Anderson 2008, Dye & Steadman 1990, Morrison & Hunt 2007, Jones et al. 2008, Kirch et al. 1995, Nagaoka 2002).

Perspectives from the Tropical Pacific

Recent studies on ancient human impacts on tropical Pacific Island marine ecosystems have focused on specific faunal classes (e.g., shellfish, finfish, and birds). An ethnoarchaeological study of contemporary shellfish foragers in Micronesia's Gilbert Islands showed that human predation often results in significant pressure on mollusk communities (Thomas 2001), suggesting that similar processes may have operated in the past. On Mangaia in the Cook Islands, Kirch et al. (1995) identified human predation pressure on *Turbo*, including size declines in *Turbo setosus* through time. In studying ~46 kg of marine shell from Kaua'i sites dating between AD 1410 and 1800, Morrison & Hunt (2007) documented an increase in diet breadth (the number of shellfish taxa exploited) through time and a decline in exploitation of the Hawaiian top shell, *Turbo sandwicensis*, from subtidal/coral reef habitats relative to smaller and more abundant conch, *Strombus maculatus*, from intertidal shoreline habitats. They suggest that declines in coral reef/subtidal taxa may have driven people to focus more on smaller shoreline taxa, but that changes in shellfish exploitation on Kaua'i are subtle with no evidence of dramatic depletion or extinction (Morrison & Hunt 2007, p. 341).

Other studies from the tropical Pacific have investigated the effects of Polynesian peoples on finfish from coral reefs, lagoons, and other habitats. With data from Mangaia, Butler (2001) investigated human predation pressure on fish remains from a rockshelter sequence dated from ~AD 1000 to 1700. She noted a decline in high-ranked fish (e.g., Serranidae, Carangidae, and *Anguilla* sp.) from marine and freshwater habitats, with a decrease in Serranidae body size/age, suggesting that human predation significantly affected these species' population.

Allen (2002) also investigated finfish exploitation on Aitutaki in the Cook Islands, with a ~700-year-long rockshelter sequence and a 1000-year sequence from three other sites. She identified a decline in large-bodied inshore fish and modest increases in offshore fish at one site, but large-bodied inshore fish appeared to increase through time at the rockshelter. Allen (2002) argued that changes in technology or a decline in pearl shells used to make fishhooks may have influenced this trend, which suggests that fishing costs increased through time. On Rotuma, northwest of Fiji, Allen et al. (2001) suggested that foraging range and fishing intensity declined from ~AD 600 to 1000, possibly due to an intensification of agriculture and animal husbandry and perhaps resource depression.

In Micronesia, Fitzpatrick & Donaldson (2007) and Fitzpatrick & Kataoka (2005) investigated ancient human fishing practices and impacts on Palauan coral reefs after 1700 cal BP. Like Allen et al. (2001), they suggested that fishing decreased through time, possibly due to overfishing or changes in agriculture or other subsistence practices. Finfish and shellfish data from Palau are limited, and distinguishing the effects of anthropogenic impacts from those of climate change is still difficult, but ancient people did influence the structure and composition of some fish and shellfish communities (Fitzpatrick & Donaldson 2007).

For Fiji's Lau group, Jones (2007, 2009) is building one of the most comprehensive historical ecological studies of a marine ecosystem in the world. Relying on zooarchaeological analyses

of finfish assemblages, interviews of local fishermen, and biological surveys of fish biomass, abundance, and diversity in local reefs, Jones demonstrates the complexity of identifying ancient human impacts on marine ecosystems. Interviewing contemporary Lauans, Jones (2009) found that people do not always target large fish, that food preferences may account for the presence of some smaller fish in the record, and that size alone may not be the best archaeological indicator of human predation pressure. Jones (2009) argues for continuity in resource use spanning ~3000 years, demonstrating considerable resilience in Lau marine ecosystems. Collectively, these data suggest that changes in finfish populations noted in the archaeological record result from multiple cultural and environmental variables that can work in concert with human predation pressure.

Beyond these studies and Steadman's (2006) work on Pacific Island birds, there are few published accounts of human impacts on marine mammals or other resources in the tropical Pacific. Reviewing data from sites on Moloka'i, O'ahu, Hawai'i, and Tonga, Dye & Steadman (1990) discussed evidence for Polynesian impacts on native fauna. Similar to Steadman, they noted the extirpation or extinction of several sea and land birds. In Tonga, sea turtles first appear to decline abruptly, then reach a stable but lower level of hunting. Overall, Dye & Steadman (1990) concluded that marine animals were a more stable resource than were terrestrial animals.

Perspectives from the Subtropical and Temperate South Pacific

Several researchers have investigated human impacts on marine and terrestrial ecosystems in New Zealand and other subtropical Pacific Islands, with data on pinnipeds, seabirds, and other resources available in different habitats of southern Polynesia. Lying mostly in a temperate zone, New Zealand is vastly different from other Pacific Islands. It contains ~90% of the terrestrial landmass of all Pacific Islands and was home to a diverse suite of marine resources. The southern and, to some extent, northern islands contained large numbers of seals and sea birds. Seals would have been a particularly attractive source of meat, fat, and oil for the Maori people of New Zealand, especially because traditional Polynesian crops such as taro were difficult or impossible to grow on the south island. The Maori probably had significant impacts on terrestrial and marine ecosystems, causing or contributing to the extinction of moas and the depletion of fur seals and, possibly, breeding sea birds (Anderson 2008, Nagaoka 2002).

Anderson (2008) synthesized the record of human impacts on New Zealand and other South Polynesian islands, noting that moas disappeared and marine mammals declined significantly early on, but that patterns for other resources varied. Declines in some shellfish taxa were noted, but it is not always clear whether these result from human activities or climate change. Fishing trends also vary, with climate probably playing a role. There is some evidence for localized snapper depletion, but prehistoric Maori fishing apparently had no clear effect on the size or abundance of finfish (Anderson 2008, p. 31; Leach & Davidson 2001). Prehistoric muttonbirding (i.e., hunting petrel, prion, and shearwater chicks) was common in New Zealand, but Anderson (2008) noted no archaeological evidence of depletion or extinction from this activity. Bovy (2007) reported a decline in sooty shearwater (*Puffinus griseus*) remains at the Minard site in Washington State, however, which may be related to Maori muttonbirding. New Zealand's sooty shearwaters migrate to North America annually, leading Bovy to hypothesize that prehistoric hunting on New Zealand may have caused a global decline in this seabird.

For pinnipeds, a southward retreat in the breeding range of New Zealand fur seals (*Arctocephalus forsteri*) from AD ~1250 to 1850 may be due to human predation and other activities. Climate change could also be involved, but human hunting appears to have played an important role (Anderson 2008, Smith 2005). At Shag River Mouth in southern New Zealand, Nagaoka (2002)

documented a decline in Hooker's sea lions (*Phocarctos hookeri*), elephant seals (*Mirounga leonina*), and fur seals from AD ~1200 to 1400. Anderson (2008, p. 26) also linked reductions in seals on Norfolk Island, the Kermadecs, and eastern Polynesia to human predation and disturbance after initial colonization. Overall, there seemed to be a shift from seals, moas, and sea birds toward shellfish and finfish as people depleted or reduced the most desirable resources (Anderson 2008, p. 38).

For the so-called mystery islands (Norfolk, Pitcairn, Henderson, etc.), Anderson (2001) noted that human colonization and later abandonment between AD ~800 and 1650 may have resulted from the marginal nature of marine shellfish, fish, and mammals compared with that of tropical islands. He suggested that early colonists overexploited the marine resources available, failed to establish sustainable agriculture, and ultimately abandoned the islands or died out.

The Pacific Islands provide a complex picture of ancient humans transforming marine and terrestrial ecosystems with varying outcomes. Alteration of terrestrial habitats from vegetation clearing and the introduction of rats, pigs, dogs, chickens, and plant crops profoundly influenced Pacific Island ecosystems and shaped the evolution of Polynesian societies (Kirch 1997, 2007). Less is known about human impacts on marine resources, but a few trends are emerging. Except for seals in South Polynesia and seabirds throughout the region, there is no clear evidence of massive human alteration of ancient Pacific Island marine ecosystems. People probably caused localized declines in the size and abundance of finfish and shellfish (Butler 2001, Morrison & Hunt 2007), but many patterns observed in the record can also be attributed to cultural developments such as agricultural intensification or changes in technology (see Allen 2002). As Jones (2009) noted, in some parts of the Pacific marine resources appear to have been relatively resilient to centuries or even millennia of harvest by growing Polynesian and Micronesian populations.

CONCLUDING REMARKS

A growing body of data from archaeology, molecular genetics, and human biology and biochemistry suggests that our ancestors relied more heavily on marine and aquatic resources for much longer than the anthropological theory of the twentieth century once suggested. Nonetheless, the intensity of fishing, marine foraging, seafaring, island colonization, and human impacts on nearshore ecosystems appears to have increased significantly with the appearance of AMH after ~200,000 cal BP (Erlandson 2001). Facilitated by the development of new technologies, the intensified use of marine and aquatic fisheries may have fueled the demographic expansion of AMH in southern and eastern Africa. Coastlines and rivers also served as important corridors for humans migrating from Africa into Eurasia roughly 70,000 years ago (Bulbeck 2007), and the development of systematic seafaring later led to the colonization of Island Southeast Asia, Australia, Western Melanesia, and the Ryukyu Islands between ~55,000 and 40,000 years ago. There is growing evidence that Pleistocene seafaring also contributed to a coastal colonization of the Americas, including settlement of some offshore islands. Yet another major wave of seafaring agriculturalists settled hundreds of the more remote islands of Oceania between roughly 4000 and 1000 years ago (Kirch 2000).

This deeper history of human fishing, obscured by postglacial sea-level rise and anthropological theory, suggests that our ancestors measurably influenced coastal and island ecosystems much earlier than previously thought and that some nearshore marine ecosystems became increasingly anthropogenic long before the era of industrialized fishing and globalization. As a result, fisheries managers and conservation biologists need to consider not just the shifting baselines of historical times (Dayton et al. 1998, Pauly 1995, Pauly et al. 1998), but also the shifting timelines provided by archaeological perspectives. Case studies from several areas of the world demonstrate that humans sometimes altered coastal and island habitats thousands of years prior to European contact, long

before the introduction of industrial fishing methods (see Rick & Erlandson 2008). Such ancient human impacts on marine ecosystems, however, appear to vary widely through time and space, with people influencing the structure and function of ecosystems in both positive and negative ways.

On California's Northern Channel Islands, evidence for anthropogenic trophic cascades in kelp forests beginning ~8000 cal BP has been identified, along with substantial reductions in the size of shellfish prey species between ~8000 and 3000 years ago, and significant long-term shifts in human fishing and subsistence resulting from local fishery depletion and island-wide patterns of resource depression. Despite the evidence for extensive Native American alterations of Channel Islands ecosystems through time, there is only limited evidence for human-caused extinctions. A trans-Holocene pattern of relatively sustainable fisheries is emerging, facilitated by a strategy of fishing up the food web featuring an early emphasis on shellfish collection followed by the gradual intensification of fishing and sea mammal hunting focused on higher-trophic level organisms (Erlandson et al. 2009). The evidence for long-term persistence of marine habitats and fisheries in Channel Island ecosystems contrasts with patterns of rapid and serial extinctions, collapsing fisheries, and ecosystem degradation caused by the introduction of European or Euro-American practices of land and sea use during the past two centuries. Do these different exploitation patterns hint at the development of conservation practices by the Chumash and their ancestors in the millennia prior to European contact, or are they simply the result of the more industrialized and globalized commercial economies brought to bear on the Channel Islands by Europeans in historic times? Such questions are difficult to answer with archaeological data alone, but they are worthy of further study.

In the Pacific, agricultural peoples spread relatively rapidly through a vast oceanic realm, exploring and colonizing a diverse array of islands and archipelagos. As Kirch (1997, 2005) has shown, the outcomes of such settlement varied tremendously, depending on the productivity, biodiversity, and resilience of local islands or archipelagos as well as on the decisions humans made as their populations grew and environmental challenges loomed. Although such impacts varied, ancient human influence on Pacific Island ecosystems was often dramatic, leading to the extinction of numerous birds, transformations of relatively fragile island ecosystems for agriculture and human settlement, the reduction of marine mammals and sea birds in parts of the temperate South Pacific, and impacts on finfish and shellfish in the tropical Pacific.

Other evidence is emerging as archaeologists increasingly engage with marine ecologists, including numerous examples of prehistoric depression of marine fish, shellfish, birds, and sea mammal populations by indigenous peoples (see Rick & Erlandson 2008). There is much to be done, however, to bridge the gaps between archaeological, historical, and ecological data often collected in very different spatial and temporal scales. At this point, any methodology for measuring human impacts across prehistoric, historic, and recent times must be considered a work in progress, given that historical ecology is a young discipline and interaction between archaeologists and marine scientists is still relatively limited.

DISCLOSURE STATEMENT

The authors are not aware of any affiliations, memberships, funding, or financial holdings that might be perceived as affecting the objectivity of this review.

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