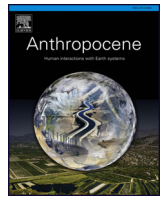




Contents lists available at [ScienceDirect](#)

Anthropocene

journal homepage: www.elsevier.com/locate/ancene



Archeology, deep history, and the human transformation of island ecosystems

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ARTICLE INFO

Article history:

Received 2 May 2013

Received in revised form 30 July 2013

Accepted 6 August 2013

Keywords:

Historical ecology

Paleoecology

Global change

Polynesia

Caribbean

California

ABSTRACT

Island ecosystems and peoples face uncertain futures in the wake of predicted climate change, sea level rise, and habitat alteration in the decades and centuries to come. Archeological and paleoecological records provide important context for understanding modern environmental and sociopolitical developments on islands. We review and analyze human interactions with island ecosystems in Polynesia, the Caribbean, and California during the last several millennia. Our analysis demonstrates that human impacts on island ecosystems and cases of highly managed anthropogenic landscapes extend deep in the past, often beginning at initial settlement. There are important issues of scale and island physical characteristics, however, that make human ecodynamics on islands variable through space and time. These data demonstrate that current environmental problems have their roots in deeper time and suggest that the Anthropocene likely began by the onset of the Holocene, if not earlier.

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1. Introduction

We live in a time of rapid global environmental change as earth's ecosystems and organisms adjust to decades, centuries, or more of anthropogenic perturbations (Jackson, 2010; La Sorte and Jetz, 2010; Zalasiewicz et al., 2010) and climate change threatens to create even greater instability (U.S. Global Change Research Program, 2009). The magnitude of these environmental and climatic changes has prompted some researchers to propose that we now live in a new geologic epoch, the Anthropocene. The onset of the Anthropocene has been linked to the Industrial Revolution, with its dramatic increases in CO₂ production (Crutzen and Stoermer, 2000; Crutzen, 2002; Zalasiewicz et al., 2010), and a host of other events ranging from release of human made radionuclides to human induced sedimentation (Zalasiewicz et al., 2011a). The Anthropocene concept has focused scholarly and popular discourse on human domination of Earth's ecosystems, becoming a catchall phrase used to define human environmental impacts and the modern ecological crisis. The definition and implications of the Anthropocene, however, are the subject of much debate. Some geologists find it improbable that the Anthropocene will leave any kind of geologic signature in the rock record, for instance, questioning how this epoch will be characterized in ensuing

centuries and millennia (Autin and Holbrook, 2012; Gale and Hoare, 2012).

Archeologists are also debating the nature of the Anthropocene and the relationship of modern environmental problems to deeper time human–environmental impacts. Smith and Zeder (2013) argue that the Anthropocene is an extension of the Holocene, which began about 10,000 years ago when domestication and the origins of agriculture ushered in millennia of human environmental impacts that have continued to the present day. With substantial evidence that hunter-gatherer, pastoral, and agricultural peoples have profoundly altered terrestrial and marine ecosystems for millennia (Redman, 1999; Kirch, 2005; Erlandson and Rick, 2010), archeology provides unique tools to help contextualize human–environmental interactions in the past and present. This deep historical record also supplies insights that can assist modern conservation biology, restoration, and management (Lotze et al., 2011; Lyman, 2012; Rick and Lockwood, 2013; Wolverson and Lyman, 2012; Lyman, 2006; Wolverson et al., 2011).

In this paper, we evaluate the Anthropocene concept by investigating archeological and historical data from islands around the world. Globally, islands and archipelagos are often important reservoirs of biological and ecological diversity. Archeologically, islands offer a means to evaluate human environmental interactions on a circumscribed and smaller scale than continents. As Kirch (1997, 2004) noted, islands often serve as microcosms of the larger processes operating on continents. Once viewed as scientific

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laboratories and more recently as model systems (see [Evans, 1973](#); [Kirch, 2007](#); [Fitzpatrick and Anderson, 2008](#); [Vitousek, 2002](#)), islands around the world have been inhabited by humans for millennia and have long been affected by human activities, including over-exploitation, burning and landscape clearance, the introduction of exotic flora and/or fauna, and increased productivity ([Kirch, 2005](#); [Erlandson and Fitzpatrick, 2006](#); [Fitzpatrick and Keegan, 2007](#); [McGovern et al., 2007](#)). As some scholars have noted, the generally more limited terrestrial biodiversity and circumscription on islands have made human impacts more obvious than those on continents ([Grayson, 2001](#); [Steadman and Martin, 2003](#); [Wroe et al., 2006](#)). There are also examples of people actively managing or enhancing ecosystems on islands and continents, and researchers are now revisiting classic cases of human environmental degradation, including Rapa Nui (Easter Island; [Hunt and Lipo, 2009](#)) and the Maya collapse at Copan ([McNeil et al., 2010](#)), demonstrating the complexities of environmental change and the role of people in influencing such changes and responding to them. Much remains to be learned about the implications of island archeology and paleoecology for helping understand the potential environmental, social, and political consequences of the Anthropocene.

After reviewing the chronology of human settlement of islands around the world, we present case studies from three heavily studied island groups. These include Polynesia occupied by maritime agriculturalists, the Caribbean occupied by agriculturalists and hunter-gatherers, and California's Channel Islands occupied entirely by hunter-gatherers. We explore three interrelated questions. What are the types of impacts that ancient peoples had on island ecosystems and how do these vary spatially, temporally, and cross-culturally? How do archeological and paleoecological data contribute to an understanding of human domination of Earth's ecosystems, including extinction, invasive species ecology, habitat degradation, and climate change? Finally, how do these archeological examples help inform the definition, timing, and implications of the Anthropocene as a geological epoch?

2. Island colonization, prehistory, and the environment

In recent decades, our understanding of human colonization and prehistory of the world's islands has dramatically increased. Once seen as the margins of our planet (see [Kirch, 1997](#)), islands have emerged as centers of early human interaction, demographic expansion, and exploration ([Erlandson and Fitzpatrick, 2006](#); [Rainbird, 2007](#); [Fitzpatrick and Anderson, 2008](#)). Islands are important both as microcosms of the patterns and processes operating on continents and as distinct locations with often greater isolation and unique biodiversity. Data from the Americas, Australia, Southeast Asia, the Pacific, North Atlantic, Mediterranean, and Caribbean demonstrate a deep history of maritime voyaging that suggests that for anatomically modern humans (*Homo sapiens*), the ocean was often a pathway of human interaction and discovery rather than a major obstacle or barrier ([Anderson et al., 2010a](#); [Erlandson, 2001, 2010a,b](#)). In other cases, ocean currents, winds, and other processes can influence travel across the waters surrounding islands ([Fitzpatrick and Anderson, 2008](#); [Fitzpatrick, 2013](#)). Understanding when humans first occupied islands is important for understanding the geography and ramifications of ancient human environmental interactions. Here we outline the antiquity of island colonization in major island groups around the world to contextualize our discussion of Polynesia, the Caribbean, and California.

The earliest evidence for island colonization by hominins may be from Flores in Southeast Asia, which appears to have been

colonized by *Homo erectus* 800,000 or more years ago ([Morwood et al., 1998, 2004](#)). Evidence for maritime voyaging and island colonization is very limited, however, until after anatomically modern humans spread out of Africa about 70,000–60,000 years ago ([Erlandson, 2010a,b](#)). Australia and New Guinea were colonized roughly 45,000–50,000 years ago ([O'Connell et al., 2010](#); [O'Connor, 2010](#)) in migrations requiring multiple sea voyages up to 80–90 km long. Several island groups in Southeast Asia were also settled between about 45,000 and 30,000 years ago, and some of these early maritime peoples appear to have had significant marine fishing capabilities ([O'Connor, 2010](#); [O'Connor et al., 2011](#)). Additional long sea voyages were required for humans to colonize the Bismarck Archipelago in western Melanesia between 40,000 and 35,000 years ago ([Erlandson, 2010a](#)). Further north, several of the Ryuku Islands between Taiwan and Japan were also settled by Late Pleistocene hunter-gatherers between about 38,000 and 18,000 years ago ([Takamiya, 2006](#); [Habu, 2010](#)). In Japan, the main island of Honshu also has several sites that contain obsidian obtained from Kozu Island (Izu Islands) by 32,000 years ago ([Habu, 2010](#)). Overall, the evidence from Sunda and Sahul demonstrates significant maritime voyaging, ocean navigation, and island colonization by the Late Pleistocene.

Somewhat later in time, colonization of California's Channel Islands at least 11,000 B.C. (all B.C./A.D./B.P. dates are calibrated calendar ages unless otherwise noted) required boats and was achieved by some of the earliest people to live in the Americas ([Erlandson et al., 2011a,b](#)). Early coastal sites in California, elsewhere on the Pacific Rim, and in Chile have helped support the coastal migration theory for the initial peopling of the Americas ([Erlandson et al., 2007](#)). Colonization of several Mediterranean islands occurs about this same time, with hunter-gatherers or early agriculturalists expanding to several islands and traveling to Melos to obtain obsidian during the Terminal Pleistocene and Early Holocene ([Cherry, 1990](#); [Patton, 1996](#); [Broodbank, 2006](#)).

During the Middle and Late Holocene, there is an explosion of maritime exploration and island colonization, facilitated by major advances in sailing and boat technology ([Anderson, 2010](#)). The Austronesian expansion of horticulturalists out of island Southeast Asia, through Near Oceania and into Remote Oceania (ca. 1350 B.C.) begins several millennia of island colonization in the vast Pacific, culminating in the Polynesian colonization of Hawaii, Easter Island, and New Zealand during the last millennium ([Kirch, 2000](#); [Anderson, 2010](#)). Human settlement of Caribbean islands began at least 7000 years ago, initially by hunter-gatherers and later by horticulturalists expanding primarily, if not exclusively, out of South America ([Keegan, 2000](#); [Fitzpatrick and Keegan, 2007](#); [Wilson, 2007](#)). In the North Atlantic, Mesolithic peoples began an expansion into the Faroes and elsewhere that increased during the Viking Age, with voyages to Iceland, Greenland, and northeast North America (see [Dugmore et al., 2010](#); [Erlandson, 2010a](#)). Other islands in southern Chile and Argentina, northeast Asia, the Indian Ocean, and beyond were all colonized by humans during the Holocene, each starting a new anthropogenic era where humans often became the top predator and driver of ecological change. A final wave of island colonization occurred during the era of European exploration, when even the smallest and most remote island groups were visited by commercial sealers, whalers, and others ([Lightfoot et al., 2013](#)).

Early records of human colonization of islands are often complicated by a small number of archeological sites and fragmentary archeological record, which is hindered by interglacial sea level rise that left sites submerged offshore. Consequently, the early environmental history of colonization can be difficult to interpret. However, the translocation of animals and plants, including both domesticated and wild species, extends back into deep prehistory. For instance, some 20,000 years ago people are

Table 1
Physical characteristics of islands discussed in the text.

Polynesia	Size ^a (km ²)	Geologic age (Ma)	Earliest date ^b	Caribbean	Size (km ²)	Geologic age ^d (Ma)	Earliest date	Caribbean	Size (km ²)	Geologic age ^c (Ma)	Earliest date
Mangaia	52	4.6	AD 900–1000	Bahamas Archipelago (<i>n</i> = 700+)	169	161–145	AD 600	Anacapa	2.9	>5	3200 BC
Tikopia	4.6	0.08	950 BC	Greater Antilles (<i>n</i> = 4)	207,727	130	~5300 BC	Santa Cruz	249	>5	9000 BC
Tongatapu	259	0.20–0.25	880–896 BC	N. Lesser Antilles (Leewards) (<i>n</i> = 15+)	3346	40–50	~3000 BC	Santa Rosa	217	>5	11,000 BC
Hawai'i	10458	0.6	AD 1000	S. Lesser Antilles (Windwards) (<i>n</i> = 10+)	2899	40–50	~3100 BC	San Miguel	37	>5	10,200 BC
Maui	1887	1.3–0.8	AD 1000	Adjacent to South America (<i>n</i> = 6+)	7202	90	~6200 BC	Santa Barbara	2.6	>5	2200 BC
O'ahu	1574	3.4–2.2	AD 1000					Santa Catalina	194	>5	>4000 BC
Kau'i	1433	5.6–3.8	AD 1000					San Nicolas	58	>5	>4000 BC
Moloka'i	676	1.8–1.3	AD 1000					San Clemente	145	>5	7500 BC

^a Size is for present day island size. For the Caribbean we provide the size for several island groups and list approximate numbers of islands used to calculate these totals.

^b The earliest date refers to the earliest dated archeological site.

^c Age estimates for the Channel Islands are minimum values because ages are difficult to determine for this highly tectonically active area.

^d Age estimates for the Caribbean Islands are derived from Pindell and Barrett (1990).

thought to have introduced a few small mammals to islands in the Bismarck Archipelago (White, 2004). Island agriculturalists often brought 'transported landscapes' along with them, including a suite of domesticated plants and animals that make human colonization signatures on many islands easy to identify (see Kirch, 2000; McGovern et al., 2007; Zeder, 2008). In the sections that follow, we explore these issues, relying on extensive archeological and ecological research in Polynesia, the Caribbean, and California's Channel Islands. A key component of our discussion is the importance of how island physical characteristics (size, age, isolation, etc.), in tandem with human decision making, shape ancient environmental developments on islands (Table 1).

3. Polynesian Islands: colonization and transformation

The Polynesian islands include 10 principal archipelagoes (Tonga, Samoa, Society, Cook, Austral, Tuamotu, Gambier (Mangareva), Marquesas, Hawai'i, and New Zealand) and many other isolated islands within a vast triangle defined by apices at New Zealand, Hawai'i, and Easter Island. Eighteen smaller islands within Melanesia and Micronesia, known as Polynesian Outliers, are also occupied by Polynesian-speaking peoples. Archeological, linguistic, and human biological research has confirmed that the Polynesian cultures, languages, and peoples form a monophyletic group within the larger family of Austronesian cultures, languages, and peoples (Kirch and Green, 2001). The immediate homeland of the Polynesians was situated in the adjacent archipelagoes of Tonga and Samoa (along with more isolated Futuna and 'Uvea), which were settled by Eastern Lapita colonists ca. 880–896 B.C. (2830–2846 B.P.; Burley et al., 2012). Ancestral Polynesian culture and Proto-Polynesian language emerged in this region by the end of the first millennium B.C. (Kirch and Green, 2001). A significant diaspora of Polynesian peoples beginning late in the first millennium A.D. then led to the discovery and colonization of the remainder of the Polynesian triangle and Outliers. The last archipelago to be settled was New Zealand, around A.D. 1280 (Kirch, 2000; Wilmshurst et al., 2008).

The Polynesian islands all lie within Remote Oceania, which had no human occupants prior to the dispersal of Austronesians who possessed outrigger sailing canoe technology, a horticultural subsistence economy, and sophisticated knowledge of fishing and marine exploitation (Kirch, 2000). Ranging in size from diminutive Anuta (0.8 km²) to sub-continental New Zealand (268,680 km²), the Polynesian islands span tropical, subtropical, and temperate climatic zones. They also vary in geological age and complexity, and in their terrestrial and marine ecosystems. Many

of the Polynesian islands exhibit striking cases of adaptive radiation and markedly high endemism in plants, insects, terrestrial mollusks, and birds. In Hawai'i, for example, approximately 90% of the flora is endemic at the species level and more than 762 endemic species of land snail are known (mostly as extinct taxa represented by subfossil specimens) (Ziegler, 2002). Polynesia thus offers a remarkable set of model systems for investigating the role of humans in modifying initially pristine island ecosystems, transforming these into often highly managed and human dominated landscapes. In short, the Polynesian islands are model systems for the transition from the Holocene to the Anthropocene at different scales and under differing environmental parameters (Vitousek, 2002).

Recognizing the signals of initial human presence on Polynesian islands and dating these colonization events has engendered some debate. In Western Polynesia, direct evidence for human arrival in the form of sites containing Lapita pottery, has been less contentious than in Eastern Polynesia where the lack of ceramics makes identification of early settlements more problematic. For some Eastern Polynesian islands, such as Hawai'i and New Zealand, the best evidence for human arrival comes not from archeological habitation sites, but from proxy evidence such as the presence of the Polynesian introduced Pacific rat (*Rattus exulans*) or sharp influxes of microscopic charcoal particles and abrupt changes in pollen frequencies in sediment cores (Athens, 1997; Athens et al., 2002; Wilmshurst et al., 2008)

The impacts of colonizing Polynesians on island ecosystems can be heuristically divided into *direct* (intentional) and *indirect* (unintended) kinds. Among the most common direct impacts were: (1) harvesting and predation on wild food resources, including marine turtles, fish and shellfish, terrestrial birds, and nesting or roosting seabirds, often leading to changes in the population structures of these species, and in some cases to local extirpation or global extinction (Steadman, 2006); (2) forest clearance for horticulture, often involving the use of fire in systems of shifting cultivation, but also burning of forests to drive game, particularly in New Zealand; (3) the purposive introduction of a suite of economic plants and domestic animals (including pig, dog, and chicken); and (4) the physical modification and manipulation of landscapes through the construction of irrigation complexes, dryland field systems, and other artificial facilities. Indirect impacts included: (1) the introduction of invasive species such as weeds, geckos, skinks, the Pacific rat (which may have been purposefully introduced for food), and ants and other insects, some of which appear to have had significant negative impacts on the indigenous and endemic biota of the islands; (2) the effects of pigs

which became feral on some islands; and (3) most likely—although this requires further research—the effects of introduced disease pathogens. In aggregate, all of these constitute what Anderson (1952) termed ‘man’s transported landscapes’, a concept especially applicable to islands. A full review of the evidence for these impacts from throughout Polynesia is beyond the scope of this article. Here we limit our review to the archeological and paleoecological evidence for transformation—from pristine ecosystems to anthropogenic landscapes—of three representative Polynesian islands and one archipelago: Tonga, Tikopia, Mangaia, and Hawai’i.

Burley et al. (2012) pinpointed the initial human colonization of Tongatapu Island, using high-precision U–Th dating, to 880–896 B.C. From this base on the largest island of the Tongan archipelago, Lapita peoples rapidly explored and established small settlements throughout the Ha’apai and Vava’u islands to the north, and on isolated Niuatoputapu (Kirch, 1988; Burley et al., 2001). This rapid phase of discovery and colonization is archeologically attested by small hamlet sites containing distinctive Early Eastern Lapita pottery. Excavations in these hamlet sites and in the more extensive middens that succeeded them in the Ancestral Polynesian period (marked by distinctive Polynesian Plain Ware ceramics) reveal a sequence of rapid impacts on the indigenous and endemic birds and reptiles (Pregill and Dye, 1989), including the local extinction of an iguanid lizard, megapodes, and other birds (Steadman, 2006). Burley (2007) synthesized settlement-pattern data from Tongatapu, Ha’apai, and Vava’u to trace the steady growth of human populations, demonstrating that by the Polynesian Plainware phase (700 B.C. to A.D. 400) these islands were densely settled. The intensive dryland agricultural systems necessary to support such large populations would have transformed much of the raised limestone landscapes of these “makatea” type islands into a patchwork of managed gardens and secondary growth. Historically, native forest is restricted to very small areas on these islands, primarily on steep terrain not suitable for agriculture.

The prehistory and ecology of Tikopia, a Polynesian Outlier settled by a Lapita-pottery making population at approximately the same time as Tongatapu (ca. 950 B.C.), was intensively studied by Kirch and Yen (1982). As in the Tongan case, the initial phase of colonization on this small island (4.6 km²) was marked by a significant impact on the island’s natural biota, including extirpation of a megapode bird, introduction of rats, pigs, dogs, and chickens, and presumably a suite of tuber, fruit, and tree crop plants. The zooarchaeological record exhibits dramatic declines in the quantities of fish, mollusks, sea turtles, and birds over the first few centuries, the result of intensive exploitation (Kirch and Yen, 1982; Steadman et al., 1990). Pigs, which were introduced at the time of initial colonization, became a major food source during the first and early second millennia A.D., but were extirpated prior to European contact. Kirch (2001) argued that trophic competition between the high-density human population and the pig herds, combined with the necessity of impounding and feeding pigs (which would otherwise devastate the gardens), ultimately necessitated their elimination from the subsistence system.

Stratigraphic sequences on Tikopia reveal extensive burning (marked by charcoal in sediments), erosion of the volcanic slopes, and deposition of terrigenous sediments on the coastal plain as the island’s forest was cleared for gardening during the Kiki Phase (950–100 B.C.). During the island’s Sinapupu Phase (~100 B.C. to A.D. 1200) the use of fire in agriculture gradually declined as the population developed the sophisticated system of arboriculture or “orchard gardening” for which Tikopia is known ethnographically. This arboricultural system mimics the multi-story layering of the tropical rainforest, allowing for extremely high population densities (~250 persons/km²). Virtually every hectare of the

Tikopia land surface consists of intensively managed orchard gardens, a classic case of the total transformation of an island landscape into an anthropogenic ecosystem.

Mangaia, like other islands within central Eastern Polynesia, was not colonized by Polynesians until ca. A.D. 900–1000. With a land area of 52 km², the island consists of a 20-million year old central volcanic core surrounded by a ring of upraised coral limestone or *makatea*. The old, laterized volcanic terrain is nutrient depleted and was highly vulnerable to intensive human land use activities. Archeological investigation of several stratified rockshelters (especially the large MAN-44 site) and sediment coring and palynological analysis of valley-bottom swamps and lakes revealed a detailed history of land use and human impacts on Mangaia (Steadman and Kirch, 1990; Ellison, 1994; Kirch et al., 1995; Kirch, 1996). The sediment cores and pollen records reveal rapid deforestation following Polynesian colonization, with an initial spike in microscopic charcoal particles indicative of anthropogenic burning, probably in an effort to cultivate the volcanic slopes using shifting cultivation. Once the thin organic A horizon had been stripped off of hillslopes through erosion, the lateritic soils were incapable of supporting forest regrowth; the island’s interior became a pyrophytic fernland dominated by *Dicranopteris linearis* fern and scrub *Pandanus tectorius*. Agricultural efforts were then directed at the narrow valley bottoms, which were developed into intensive pondfield irrigation systems for taro (*Colocasia esculenta*) cultivation.

The faunal record from the Mangaia rockshelters, especially site MAN-44, exhibits an especially well-documented sequence of significant impacts on the native biota, as well as the introduction of invasive and domestic species (Steadman and Kirch, 1990; Steadman, 2006). Of 17 species of native land birds present in the early phases of the sequence, 13 became extinct or extirpated. Similarly, of 13 seabird species, three were extirpated and most of the others became highly endangered on the island. A fruitbat, *Pteropus tonganus*, shows significant declines in frequency, although it survived on the island. Similar impacts are recorded for marine fish and shellfish (Butler, 2001), including measurable resource depression in several species. These impacts on the local biota were accompanied by the introduction of the Pacific rat, pig, dog, and chicken. Pig husbandry became important during the island’s middle phase, but as with the Tikopia case, pigs were later eliminated from the subsistence system. This is presumed to reflect trophic competition with humans for carbohydrates as human population densities increased (Kirch, 2001).

Whereas Tonga, Tikopia, and Mangaia are all relatively small islands, the Hawaiian Islands are a subtropical archipelago rich in a variety of microenvironments and resources that incorporate eight major islands and many smaller islets with 16,698 km² of land area. Unsurprisingly, the extent of Polynesian impact on the Hawaiian Islands was not as total as on the smaller islands; significant parts of the Hawaiian landscape remained relatively unaffected by human land use and resource exploitation at the time of initial European contact. Nonetheless, the lowland zones (i.e., land below ca. 600–900 m) of the main islands exhibited extensive anthropogenic modification, in some areas with almost complete human conversion and manipulation of the land surface in intensive food production systems.

Extensive multidisciplinary research on Polynesian ecodynamics in Hawai’i has resulted in a richly documented record that we cannot do full justice to here (Olson and James, 1984; Athens, 1997; Burney et al., 2001; Athens et al., 2002; Vitousek et al., 2004; Kirch, 2007; Kirch et al., 2012). Pollen records from O’ahu and Kaua’i islands document major transformations in the lowland vegetation communities of those islands soon after Polynesian arrival ca. A.D. 1000, including the elimination of coastal *Pritchardia* palm forests on O’ahu. These dramatic

vegetation changes were probably due to a combination of clearing for gardens and other land use activities, combined with the effects of introduced rats on vulnerable native seeds and seedlings. Such forest clearance also led to localized erosion and deposition of sediments in the lowlands, in-filling valley bottoms and embayments. The lowland forests were habitats for a number of flightless birds, including four endemic genera of anatids (ducks or geese) and one ibis, all of which became extinct within a relatively short period following Polynesian arrival. The Hawaiian land snails, a classic case of adaptive radiation and high degree of endemism (in such families as Achatinellidae, Amastridae, and Endodontidae), also saw significant extinction or local extirpation episodes related to forest clearance, and possibly to direct predation by Polynesian introduced ants (Christensen and Kirch, 1986). As on other Polynesian islands, pigs, dogs, and chickens were purposefully introduced as food items, and their stocks increased dramatically over time.

Around A.D. 1400, the Polynesian population in Hawai'i began to expand out of those zones best suited to the tropical tuber and root crops (especially taro), which had been introduced at initial settlement. By this time period, the "salubrious core" regions with alluvial soils and permanent streams had already been converted to extensive pondfield irrigation systems. The new phase of expansion into more marginal landscapes—lacking the water resources for irrigation, but amenable to intensive dryland farming—may have been spurred by a late introduction of the sweet potato (*Ipomoea batatas*) of South American origin. Certainly, the sweet potato along with dryland taro became the main staple base for large populations that began to convert the leeward regions of the islands into vast field systems. The most intensively studied of these systems is the Leeward Kohala Field System (LKFS) on Hawai'i Island, covering a continuous area of at least 60 km² (Vitousek et al., 2004). Expansion and intensification of the LKFS was closely linked with exponential growth in farming households (Field et al., 2011), and with the emergence of an archaic state whose political economy was based on the extraction of surplus from this and other intensive dryland field systems on the island. By the time of European contact (A.D. 1778–79), the Hawaiian population probably numbered in excess of half a million people, and the lowland zones of all of the main islands had been transformed into thoroughly managed anthropogenic ecosystems.

The four Polynesian cases summarized above—which we stress are representative of many other islands and archipelagoes throughout this vast region—share a number of features relevant to the issue of dating the Holocene/Anthropocene transition. The timing of human arrival ranges from ca. 880–896 B.C in Tonga to as late as A.D. 1280 for New Zealand. But in each case, anthropogenic modifications of the environment begin soon after colonization, and are detectable in: (1) changes in pollen spectra and increased charcoal deposition in swamps and lakes; (2) the presence of Polynesian introduced taxa, especially the Pacific rat; (3) increased rates of erosion and sedimentation; and (4) extirpation or extinction of endemic and indigenous fauna, such as birds and land snails. If a criterion for recognition of the Anthropocene is that it should be detectable in the stratigraphic and paleontological (or zooarchaeological) records, then the lesson from Polynesia is that the arrival of humans and the onset of the Anthropocene are effectively coeval.

4. Caribbean Islands: colonization and transformation

Compared to other island groups, few archeological studies have investigated how humans affected Caribbean environments through time (Fitzpatrick and Keegan, 2007; Fitzpatrick et al., 2008; but see Steadman et al., 1984, 2005). There has been increasing interest in the Pre-Columbian settlement of the region

over the last 20 years, however, which has pushed back the antiquity of settlement on many islands and resulted in larger datasets with which to explore the interactions between Amerindian colonists and the once pristine insular environments they encountered.

The Caribbean is one of the world's largest seas, stretching over 1700 km from Florida to Panama, and between 2300 and 2800 km from Central America in the west to the Lesser Antilles archipelago in the east. It is approximately the same size as the Mediterranean at over 2.75 million km² and contains dozens of islands of varying size, ranging from Cuba (the largest at around 111,000 km²) to hundreds of smaller sand islets and cays (keys), with a total land area of approximately 230,000 km². As noted by Conservation International, the Caribbean is distinguished for its high levels of biodiversity and endemism. Of the 13,000 known plant species, a remarkable 6500 are single-island endemics, with more than 200 plant genera and one plant family, which are found nowhere else. Of the more than 600 bird species recorded, over 25% of which are endemic, 13 are extinct and dozens more are threatened. While many island regions have an impoverished mammalian biota, the Caribbean is home to more than 90 mammal species, nearly half of which are endemic, including many species of rodents such as rare giant shrews and 20 species of Capromyidae (hutia). The reptilian and amphibian fauna are also diverse, with almost 95% of the former's 500 recorded species being endemic. All 170 species of frogs are also endemic, many to single islands. In addition, more than 1500 species of fish, 25 coral genera, 630+ mollusc species, and numerous crustaceans, sea mammals, echinoderms, and sponges have been recorded. Many of these are threatened or have already been driven to extinction in historic times—the Caribbean monk seal (*Monachus tropicalis*), the region's only endemic pinniped, was declared extinct in 1996 after having not been seen in four decades as a result of overhunting. Manatees (*Trichechus manatus*) and sea turtles are threatened as well, and the recent introduction of the non-native, rapidly spreading, and voracious lionfish (*Pterois volitans* and *Pterois miles*) is also causing widespread ecological damage (Schofield, 2009; Albins and Hixon, 2011).

A plethora of evidence from the Caribbean demonstrates a high level of biodiversity that has been transformed since European contact, but scholars are only now beginning to grasp how humans affected these island environments prehistorically (Fig. 1). Archeological evidence, though ephemeral in many places, suggests that hunter-gatherers (termed the "Lithic" or Ortoiroid) settled the Greater Antilles first ca. 5000–3000 B.C., though it is debated whether they came from Mesoamerica (Keegan, 2000; Wilson et al., 1998) or South America (Callaghan, 2003). This was followed by another migration by Archaic (Casimiroid) peoples that originated from South America as early 3000 B.C., though some islands such as Trinidad that skirt the northern South American Coast were settled even earlier when sea levels were lower. Archaic groups settled islands primarily in the northern Lesser Antilles and Puerto Rico, particularly Antigua with its high quality lithic materials (Keegan, 2000). Archaic groups apparently bypassed or quickly moved through nearly all of the southern islands except for Barbados (Fitzpatrick, 2012) for reasons that are not well understood, though it could be related to high levels of volcanism in the region (Callaghan, 2010).

Archaic populations, once thought to have been mostly aceramic and nomadic foragers who targeted seasonally available foods (Hofman and Hoogland, 2003; Hofman et al., 2006), are now known to have produced pottery (Rodríguez Ramos, 2005; Keegan, 2006), and brought with them a number of plant species from South America, including the Panama tree (*Sterculia apetala*), yellow sapote (*Pouteria campechiana*), wild avocado (*Persea americana*), palm nutshells (*Acrocomia media*), primrose

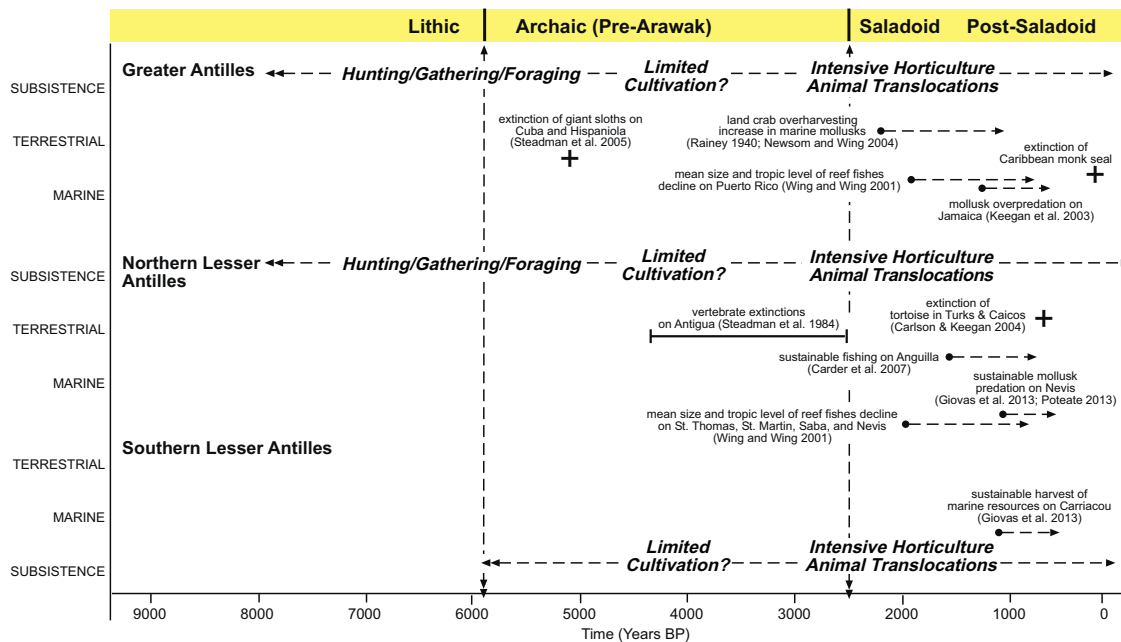


Fig. 1. Archeological evidence for anthropogenic impacts, or instances of possible sustainable exploitation, of both terrestrial and marine animals in the Antillean chain of islands. While the sample size is relatively small, the majority of documented cases of prehistoric human impact occur in the Greater Antilles and northern Lesser Antilles.

(*Oenothera* sp.), wild fig (*Ficus* sp.), and West Indian cherry (*Malpighia* sp.) (Newsom, 1993; Newsom and Pearsall, 2002; see also Keegan, 1994:270; Newsom and Wing, 2004:120). Archaic groups also exploited marine and terrestrial vertebrates and invertebrates, though the number of species harvested was generally few in number; there is no good evidence that these groups translocated animals to the islands. While population densities during the Archaic Age were probably low, there are signs that these groups affected local environments to some degree, including the extinction of giant sloths (Genus *Phyllophaga* and *Senarthra*) (Steadman et al., 2005) and nine taxa of snakes, lizards, bats, birds, and rodents from sites on Antigua dating to between 2350 and 550 B.C., which are either extinct or were never recorded historically (Steadman et al., 1984). For both cases, the timing of vertebrate extinctions is coincident with human arrival independent of major climatic changes. Given that Antigua also has the densest concentration of Archaic Age sites in the Lesser Antilles (with over 40 recorded, compared to other islands which may have only a few at most), these impacts to native fauna are much more likely to be anthropogenic (Davis, 2000).

During the early phase of the Ceramic Age (ca. 550 B.C.–550 A.D.), another group known as Saladoid settled the Lesser Antilles and Puerto Rico. While there is ongoing debate about their modes of colonization and direction they may have taken in moving into the islands (Keegan, 2000; Callaghan, 2003; Fitzpatrick, 2006; Fitzpatrick et al., 2010), it is clear that these groups were related to those in South America based on the translocation of native South American animals and a wide array of stylistic and iconographic representations in rock art, pottery, and other artifacts such as lapidary items. The rapid expansion of Saladoid groups and establishment of permanent villages was achieved, in part, by an intensive horticultural regime, that included cassava (*Manihot esculenta*), maize (*Zea mays*), marunguey (*Zamia* sp.), sweet potato (*Ipomoea batatas*), and a variety of seeds, fruits, and other cultivars (see Newsom and Wing, 2004; Mickleburgh and Pagán-Jiménez, 2012). Land clearance was necessary to create gardens and fields for growing crops, but the effects commonly seen on other island regions (e.g., increased erosion, sedimentation, and eutrophication)

are not well understood in the Caribbean, largely due to a lack of research on the subject.

There are clear signs that initial Saladoid peoples and their descendants during the Ceramic Age (ca. 550 B.C.–A.D. 1400) impacted terrestrial and marine environments in many different parts of the Caribbean. This was something Rainey (1940) identified more than 70 years ago, noting that early occupation layers at Saladoid sites in Puerto Rico and the Virgin Islands had an abundance of land crabs, but then steadily decreased, only to be replaced by a commensurate increase in marine mollusks (see also Newsom and Wing, 2004:110–111). Carlson and Keegan (2004:88) attribute this change to both enhanced aridity and human overexploitation.

Changes in marine resource exploitation have also been observed during the Ceramic Age, including a decline in reef fish biomass and mean trophic level; more intensive harvesting of herbivorous and omnivorous species as compared to carnivorous species such as grouper; and an increase in the capture of pelagic fish on several islands in the northern Lesser Antilles (Wing, 2001; Wing and Wing, 2001; Newsom and Wing, 2004:111). It is important to note, however, that Carder et al. (2007) found no evidence of overharvesting marine fish on Anguilla during the same general period of time, suggesting that some groups were not having an adverse effect on finfish populations, possibly due to differential levels of reef bank productivity.

In terms of shellfish, Keegan et al. (2003) found evidence of peoples on Jamaica between ca. A.D. 750 and 1300 overexploiting certain shellfish species or shifting consumption from one to another. They suggested that this resulted from over-predation of strombids (particularly queen conch [*Eustrombus* (*Strombus*) *gigas*]) along with a decline in seagrass habitats which were replaced by mangrove and muddier conditions. Like finfish exploitation, however, there are examples of Amerindian groups on different islands who intensively exploited a greater number of species through time and/or the same suite of species in a sustainable fashion. On Carriacou, Giovas (2013; Giovas et al., 2013) found that the tessellated nerite (*Nerita tessellata*), a small gastropod heavily exploited in many parts of the Caribbean, increased in size over time while continuing to be harvested more

intensively. Research on a large assemblage of mollusks (MNI = 58,000+) at the Late Ceramic Age site of Coconut Walk on Nevis also demonstrated that despite an increase in the number of key species over time, there was nothing to support a predicted model of over-exploitation (Poteate, 2013).

Terrestrial animals, while not nearly as important to the diets of prehistoric Amerindians as marine fauna, were nonetheless exploited when available. These included native species of iguanas, birds, lizards, and rodents, as well as several which were translocated from South America such as the agouti, opossum, armadillo, guinea pig, and peccary (Giovas et al., 2012). These translocated species never appear to have been moved in great numbers, however, and their general paucity and patchiness suggest they may have been prestige or status oriented foods. It is not known what environmental impacts these had on Caribbean island environments, though given their generally low numbers, it may have been limited. Of these animal translocations, only the opossum and agouti persist today.

Overall, there is mounting evidence that ancient Amerindians adversely affected their island environments, though the impacts varied through space and time (Fitzpatrick and Keegan, 2007; Fitzpatrick et al., 2008). Prehistoric impacts were generally dwarfed by what happened after European arrival in A.D. 1492, when the transmission of diseases, introduction of hundreds of non-native plants and animals from the Old World, large scale human population replacement, intensifying exploitation of marine resources (e.g., whales, sea turtles), and plantation economies devastated local flora and fauna. Regardless, the Caribbean follows a similar pattern seen worldwide, in which even small, pre-industrial populations exacted a toll on previously uninhabited island ecosystems, but some groups seem to have effectively used local resources over the long-term.

5. California's Channel Islands: hunter-gatherers and ecosystems

With a long tradition of archeological and ecological research, California's Channel Islands provide important datasets to evaluate long-term human ecodynamics and the nature of Holocene and Anthropocene cultural and environmental developments. Many of the trends apparent on Caribbean and Pacific Islands—including over-harvest, landscape burning and clearing, translocation, as well as long-term continuity in the harvest of some key resources—are also apparent on the Channel Islands. California's islands, however, were occupied entirely by Native American hunter-gatherers until the 19th century, when sea otters and several pinnipeds were hunted nearly to extinction, Chinese abalone fishers visited the islands, and Euroamerican ranching commenced (see Kennett, 2005). We focus on the Native American hunter-gatherer occupation of the Channel Islands, which provides comparative data that build on the Polynesian and Caribbean examples.

The Channel Islands are composed of eight islands that are divided into northern and southern groups and are considerably less isolated than Polynesian and most Caribbean islands. Currently situated between San Diego and Point Conception, the islands are between 20 and 98 km offshore and range in size from 2.6 to 249 km². During the Last Glacial Maximum and up to about 10,000 years ago, the four northern Channel Islands (San Miguel, Santa Rosa, Santa Cruz, and Anacapa) were connected into a single landmass known as Santarosae Island, separated from the mainland by a watergap of about 7–8 km (Erlandson et al., 2011b). This separation from the mainland led to distinct island ecosystems and numerous endemic and relict species.

In general, the biodiversity of terrestrial plants and animals is reduced compared to the mainland, with the largest

post-Pleistocene land mammals being the diminutive island fox (*Urocyon littoralis*) found on six islands and the island spotted skunk (*Spilogale gracilis*) found on two islands. Only *Peromyscus maniculatus* (island deer mouse) is found on all eight of the Channel Islands. Deer, elk, and large to medium sized predators common on the mainland were all absent from the islands, until some were introduced during the historic period. Terrestrial plants were also less diverse than the mainland, with a smaller amount of oak woodland and other plant communities. Freshwater was limited on some of the islands, but the large islands of Santa Cruz, Santa Rosa, Santa Catalina, and San Miguel are all relatively well watered. Our perspective of both island plant communities and freshwater availability, however, is changing as the islands recover from more than a century of overgrazing from introduced livestock and both freshwater and terrestrial plants appear to have been more productive than once presumed. Although ethnobotanical research has been limited on the islands, recent research demonstrates the exploitation of blue dick corms and other plant foods throughout the Holocene (Reddy and Erlandson, 2012; Gill, 2013).

Humans colonized the northern islands by at least 11,000 B.C., while the northern islands were still one landmass and there were more conifers and other trees scattered around the islands. Native Americans appear to have lived on the islands more or less continuously until about A.D. 1820, when they were removed to mainland missions. Following Native American occupation, the islands were occupied sporadically by Chinese abalone fishermen with the ranching period beginning in the mid-19th century. Today, the northern Channel Islands and Santa Barbara Island comprise Channel Islands National Park, while San Nicolas and San Clemente have naval installations, and Santa Catalina is privately owned with the only formal city (Avalon) on the islands. Each of these human occupations had different influences on island ecosystems, with distinct signatures that help inform contemporary environmental issues, conservation, and restoration.

Population growth is one of the key factors related to increased human impacts on ecosystems. Estimating Native American population sizes for the islands is complicated, with some researchers suggesting a population of over 1000 people at the time of European contact and others considerably more. Radiocarbon date frequencies through time provide another relative indicator of human population changes through time. A plot of all dated components from the Northern Channel Islands through 2006 suggests that Native American populations remained relatively steady through much of the Holocene, with a dramatic increase in human populations around A.D. 500 followed by a decline during the Medieval Climatic Anomaly, an increase after about A.D. 1300, and a decline at European Contact (Fig. 2a; Culleton et al., 2006). Far fewer people occupied the islands during the ranching period, but livestock numbered in the hundreds to tens of thousands, leaving a devastating and lasting impact on the landscape. These demographic trends form the background for understanding human environmental impacts through time, and suggest that archeologically we should expect some of the most dramatic changes during the last 3000 years, especially after 1500 years ago when human populations were at their height (Erlandson et al., 2009; Braje, 2010).

Near shore marine ecosystems around the Channel Islands were a focus of human subsistence since colonization and recent research documents a range of impacts that Native Americans had on island marine organisms including shellfish, marine mammals, and finfish. Erlandson et al. (2008, 2011a,b) measured thousands of California mussel (*Mytilus californianus*), red and black abalone (*Haliotis rufescens* and *H. cracherodii*), and owl limpet (*Lottia gigantea*) shells, documenting size changes in each of these taxa across the Holocene. Average size distributions for California

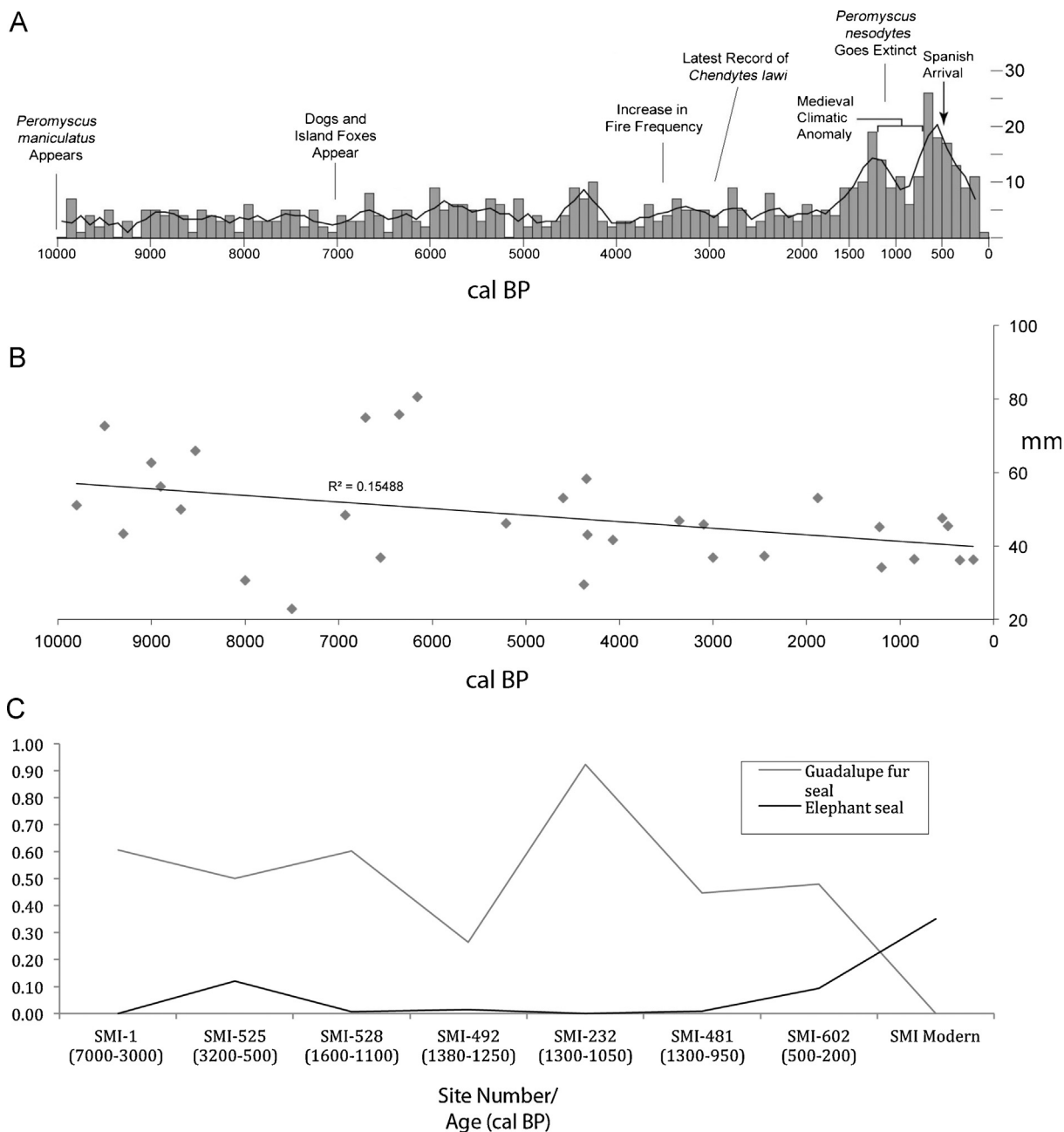


Fig. 2. (A) Radiocarbon distribution across the last 10,000 years (adapted from Braje, 2010) showing relative human population growth, especially during the last 1500 years, and the approximate timing of key human ecological events on the Channel Islands. (B) Plot of California mussel average size distributions through time, showing biggest decline during Late Holocene (adapted from Erlandson et al., 2008). (C) An abundance index of Elephant seals and Guadalupe fur seals in San Miguel Island sites. Far right point shows modern abundance which stands in contrast to the Holocene.

mussels, red abalones, and owl limpets each document size declines through time (Fig. 2b), with the steepest declines occurring during the Late Holocene when human populations were also at their zenith (Erlandson et al., 2008, 2011a; Braje et al., 2009). These size distributions were also plotted against a fine-grained record of sea surface temperature and marine productivity, which suggests little correlation to natural climatic changes and human predation as the driving force for these reductions (see also Thakar, 2011). Raab (1992) also demonstrated a pattern of resource depression through time on San Clemente Island as people switched from higher ranked black abalones to smaller black turban snails (*Chlorostoma funebris*) and there is evidence for possible human overexploitation of Pismo clams (*Tivela stultorum*) on Santa Cruz Island (Thakar, 2011).

Humans also appear to have influenced the demographics and abundance of seals and sea lions (pinnipeds). Six pinniped species occupy the Channel Islands, including California and Stellar sea lions (*Zalophus californianus* and *Eumetopias jubatus*), harbor seals (*Phoca vitulina*), elephant seals (*Mirounga angustirostris*), and northern and Guadalupe fur seals (*Callorhinus ursinus* and *Arctocephalus townsendi*), with California sea lions and elephant seals the most common today. Humans hunted seals and sea lions since at least the Terminal Pleistocene, but early records of pinniped hunting are scarce, with dramatic increases at some locations beginning around 1500 years ago (Braje et al., 2011a,b; Erlandson et al., 2013). One of the more interesting trends in pinniped demographics during the Holocene compared to today is the changing abundance of Guadalupe fur seals and elephant seals

(Fig. 2c; Rick et al., 2009a, 2011). For much of the Holocene, Guadalupe fur seals are the most abundant taxa found in archeological sites, suggesting they were frequently encountered when hunting and scavenging. In contrast, elephant seals are rarely found in archeological sites, with just a handful of bones found in island (or mainland) sites. Both of these species were hunted to near extinction during the 18th–19th century global fur and oil trade. Following federal protection in the 1970s, populations have grown exponentially and there are now more than 50,000 elephant seals in Alta California waters. Guadalupe fur seals, however, are very rare north of Mexico, with only a few observations during the last decade (Rick et al., 2009a). These dramatic differences in abundance between Holocene seal and sea lion populations and those of today suggest that recovered pinniped populations are not 'natural' and are largely an artifact of management and conservation (see Braje et al., 2011a,b; Erlandson et al., 2013). Seal and sea lion conservation can lead to debate between conservationists focused on the management of marine mammal populations and commercial fisheries concerned about shellfish and fish stocks that are common prey of pinnipeds and sea otters. Such conflicts have also begun in Hawaii with debate over monk seal conservation and the effects on Hawaiian fisheries and recreation. Finally, the extensive growth of some pinniped populations in California demonstrates the conflicts between natural and cultural resource management, with pinnipeds hauling out on, disturbing, and destroying non-renewable archeological sites located on the shoreline of the Channel Islands and elsewhere (see Braje et al., 2011a,b).

The records of finfish and seabirds are just beginning to be explored in detail, but Braje et al. (2012) recently documented size changes in rockfish (*Sebastes* spp.), including estimates that many prehistoric specimens were larger than modern fishes. *Chendytes lawi*, an extinct flightless duck, appears to have been slowly pushed to extinction on the Channel Islands and mainland by human predation and other variables over several millennia (Jones et al., 2008; Rick et al., 2012a). Along with human hunting, the extinction of *C. lawi* and reductions of other ground nesting birds at the Pleistocene-Holocene transition may be related to the introduction of domestic dogs and the island fox (Rick et al., 2008, 2009b; Rick, 2013). Fig. 2a documents the timing of some human ecological events on the Channel Islands relative to human population densities. We can say with confidence that Native Americans moved island foxes between the northern and southern Channel Islands (Collins, 1991; Vellanoweth, 1998) and there is growing evidence that humans initially introduced mainland gray foxes to the northern islands (Rick et al., 2009b). Genetic, stable isotope, and other studies are under way to test this hypothesis.

Another island mammal, *Peromyscus maniculatus*, appears in the record on the northern Channel Islands about 10,000 years ago, some three millennia after initial human occupation, and was a likely stowaway in human canoes (Walker, 1980; Wenner and Johnson, 1980; Rick, 2013). On the northern Channel Islands, *Peromyscus nesodytes*, a larger deer mouse had colonized the islands prior to human arrival, sometime during the Late Pleistocene. The two species of mice co-existed for millennia until the Late Holocene when *P. nesodytes* went extinct, perhaps related to interspecific competition with *P. maniculatus* and changing island habitats (Ainis and Vellanoweth, 2012; Rick et al., 2012a).

Although extinction or local extirpation of island mammals and birds is a trend on the Channel Islands, these declines appear to be less frequent and dramatic than those documented on Pacific and Caribbean Islands, a pattern perhaps related to the absence of agriculture on the Channel Islands and lower levels of landscape clearance and burning (Rick et al., 2012a). Fires have been documented on the Channel Islands during the Late Pleistocene and Holocene (Anderson et al., 2010b; Rick et al., 2012b), but we

are just beginning to gain an understanding of burning by the Island Chumash. Ethnographic sources document burning by Chumash peoples on the mainland (Timbrook et al., 1982), but say little about the islands. Anderson et al. (2010b) recently presented a Holocene record of fire history on Santa Rosa Island, which suggests a dramatic increase in burning during the Late Holocene (~3000 years ago), attributed to Native American fires. Future research should help document ancient human burning practices and their influence on island ecosystems. For now, we can say that the Island Chumash strongly influenced Channel Island marine and terrestrial ecosystems for millennia. The magnitude of these impacts is considerably less dramatic than those of the ensuing Euroamerican ranching period (Erlandson et al., 2009), a topic we return to in the final section.

6. Conclusions: Islands and the Anthropocene

Archeological and paleoecological records from islands provide context and background for evaluating the Anthropocene concept, determining when this proposed geological epoch may have begun, and supplying lessons for modern environmental management. Human impacts on island ecosystems extend deep into the past and people were significant driving forces since colonization in the Pleistocene or Holocene. In the case of Polynesia, the Caribbean, and the Channel Islands, human transformation of island ecosystems began at initial colonization and often accelerated through time as populations grew and human activities intensified. The maritime agriculturalists that occupied Polynesia and the Caribbean often had a similar pattern of occupation with early records documenting significant anthropogenic burning and landscape clearance, a new suite of intentionally and accidentally introduced plants and animals that were part of transported landscapes, followed by soil erosion and later highly managed anthropogenic landscapes. The pattern identified in these two island regions is similar to the records of islands in the North Atlantic occupied by Neolithic and Viking Age peoples (McGovern et al., 2007; Perdikaris and McGovern, 2008) and Mediterranean islands (Patton, 1996; Zeder, 2009).

Island archeology also reveals important differences in the scale and magnitude of human environmental impacts. On the Channel Islands and some Caribbean islands, initial human occupations were by maritime hunter-gatherers. The environmental impacts of these early peoples is often not as rapid, easy to discern, or as clear as those of pastoralists or agriculturalists. Without domesticated plants and animals (except dogs) or the need to clear land for horticulture, for example, early records of human occupation from California's Channel Islands generally lack the initial burning, landscape clearing, and soil erosion typical of many Polynesian sequences. Anthropogenic burning is evident on the Channel Islands in the past, but these events are not easy to differentiate from natural fires (Anderson et al., 2010b). Still hunter-gatherers transformed their island ecosystems in major ways, including the translocation of animals, direct and indirect influences on the extinction of mammals and birds, fire and burning, and significant impacts on marine resources. On the Channel Islands, these include translocation of island deer mice, island foxes, and perhaps other organisms (Rick, 2013), and strong influences on island marine ecosystems and organisms (Erlandson and Rick, 2010). The early record of some Caribbean islands also documents extinction of island sloths and other vertebrates, and translocation of plant resources by hunter-gatherer populations (Newsom and Wing, 2004:128; Steadman et al., 2005).

These data suggest that there was no single, overarching human influence or impact on island ecosystems in the past—the patterns and processes on islands were complex and related to the subsistence strategies of people occupying the island (i.e., agriculturalists, hunter-gatherers), the population densities of

those people, their sociocultural systems and technologies, differences in island physical characteristics (size, age, nutrients, etc.), and the collective decisions made by individual societies. There is evidence, especially in Polynesia, that people also actively managed island landscapes, suggesting that human environmental interactions on islands in the past were complex, with both negative and positive effects. Although the similarities between island systems are remarkable, with most islands showing at least some human impact, another key lesson from island archeology is the variability in human occupation and environmental interactions through time. The cases of Tikopia and Mangaia currently provide the best examples of this (Kirch, 1997), where differences in island physical characteristics (island size, age, and productivity) coupled with human decision making and cultural changes (e.g., banishing pigs, instituting a highly managed system of aboriculture, and enforcing population control measures on Tikopia) led to similar initial patterns of environmental degradation, but dramatically different end results for both island ecosystems and human sociocultural development.

A key lesson from islands is that the record of extinction and declining biodiversity, invasive species dynamics, habitat degradation, and alteration that define many island (and continental) ecosystems today extend deep into the past and blur the divisions between natural and anthropogenic changes. In most cases, archeological and paleoecological records on islands around the world contain evidence for significant anthropogenic change well before the beginning of the industrial era. In some cases (e.g., California's Channel Islands and some Caribbean islands), they also document an acceleration through time in human influence on island ecology, with more recent historical changes, like the global fur and oil trade, often much sharper and more dramatic than those of prehistoric times.

These deep historical records raise the question: from a global islands perspective, when did the Anthropocene begin? Debate continues on when (if at all) the Anthropocene era should begin, with estimates ranging from relatively recent nuclear testing, pesticide use, etc. to as early as the Late Pleistocene megafaunal extinctions (Doughty et al., 2010; Zalasiewicz et al., 2011b). In many ways, setting the onset of the Anthropocene is somewhat arbitrary, with most researchers offering compelling events (Industrial Revolution, megafaunal extinction, the development of agriculture, global erosion and sedimentation, etc.) that mark major human induced alterations on a global scale. In our view, all of these events are a continuum in the same process of human transformation of Earth's ecosystems that began millennia ago, at least by the onset of the Holocene. During the Holocene, initial domestication of plants and animals, massive human migrations to virtually all parts of the planet, growing human populations, and widespread environmental impacts are discernible on a global scale (see Smith and Zeder, 2013). From a comparative analysis of islands around the world, what should not be questioned is whether future scientists will be able to detect significant changes in island flora, fauna, and landscapes that are distinct from the changes that marked the onset of the Holocene. By the Late Holocene, such changes are global and pervasive in nature.

The deep histories provided by archeology and paleoecology do not detract from our perceptions of the major environmental changes of the post-Industrial world. Instead, they add to them, showing a long-term trend in the increasing influence of humans on our planet, a trajectory that spikes dramatically during the last 100–200 years. They also illustrate the decisions past peoples made when confronted with ecological change or degradation and that these ancient peoples often grappled with some of the same issues we are confronting today. Archeology alone does not hold the answer to when the Anthropocene began, but it provides valuable insights and raises fundamental questions about defining

a geological epoch based on narrowly defined and recent human impacts (e.g., CO₂ and nuclear emissions).

While debate will continue on the onset, scope, and definition of the Anthropocene, it is clear that Earth's ecosystems and climate are rapidly deteriorating and that much of this change is due to human activities. As issues such as extinction, habitat loss, pollution, and sea level rise grow increasingly problematic, we need new approaches to help manage and sustain the biodiversity and ecology of our planet into the future. Archeology, history, and paleobiology offer important perspectives for modern environmental management by documenting how organisms and ecosystems functioned in the past and responded to a range of anthropogenic and climatic changes. Return to pristine "pre-human" or "natural" baselines may be impossible, but archeological records can help define a range of desired future conditions that are key components for restoring and managing ecosystems. As we grapple with the politics of managing the "natural" world, one of the lessons from archeology is that attempts to completely erase people from the natural landscape (Pleistocene rewilding, de-extinction, etc.) and return to a pre-human baseline are often not realistic and may create new problems that potentially undermine ecosystem resilience. Given the level of uncertainty involved in managing for future biological and ecological change, we need as much information as possible, and archeology and other historical sciences can play an important role in this endeavor. A key part of this will be making archeological and paleoecological data (plant and animal remains, soils data, artifacts, household and village structure, etc.) more applicable to contemporary issues by bridging the gap between the material record of archeology and modern ecological datasets, an effort often best accomplished by interdisciplinary research teams.

Acknowledgments

This paper was originally presented at the 2013 Society for American Archaeology Annual Meeting in Honolulu, Hawai'i. We thank Todd Braje and Jon Erlandson for organizing the session and the participants for a stimulating set of papers. Funding for our research has been provided by our home institutions and grants from the National Science Foundation, National Geographic Society, Wenner Gren Foundation, and other sources. We thank the editors, Todd Braje, and two anonymous reviewers for help in the review and production of this manuscript.

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