

Rethinking Easter Island's ecological catastrophe

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Abstract

Rapa Nui (Easter Island) has become a paragon for prehistoric human induced ecological catastrophe and cultural collapse. A popular narrative recounts an obsession for monumental statuary that led to the island's ecological devastation and the collapse of the ancient civilization. Scholars offer this story as a parable of today's global environmental problems. In this paper, I review new and emerging Rapa Nui evidence, compare ecological and recently acquired palaeo-environmental data from the Hawaiian and other Pacific Islands, and offer some perspectives for the island's prehistoric ecological transformation and its consequences. The evidence points to a complex historical ecology for the island; one best explained by a synergy of impacts, particularly the devastating effects of introduced rats (*Rattus exulans*). This perspective questions the simplistic notion of reckless over-exploitation by prehistoric Polynesians and points to the need for additional research.

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"It ain't what you don't know that gets you into trouble. It's what you know for sure that just ain't so." Mark Twain

Easter Island (Rapa Nui) has become the paragon for prehistoric human induced ecological catastrophe and cultural collapse. Today a popular narrative recounts an obsession with monumental statuary—a mania for *moai*—that led to the island's ecological devastation and the collapse of the ancient civilization. Scholars offer this story as a parable for our own reckless destruction of the global environment.

In this paper, I critically examine the historical and popular narrative of human-induced environmental change, its causes and consequences, for Rapa Nui. I review new and emerging Rapa Nui evidence, compare ecological and palaeo-environmental data from the Hawaiian and other Pacific Islands, and offer some perspectives for the island's prehistoric ecological transformation and its consequences. I argue here that a revised, later chronology for Rapa Nui calls into question aspects of the current model for the island's ecological history. A critical examination of the paleo-environmental and

archaeological records also reveals a more complex historical ecology for the island; one best explained by a synergy of impacts, rather than simply the reckless over-exploitation by prehistoric Polynesians. While my focus is on the palaeo-environmental record, it is essential to disentangle the related notion of prehistoric "*ecocide*" with the demographic collapse (i.e., post-contact *genocide*) that would come centuries later with European disease, slave-trading, and the other abuses heaped upon the Rapanui people. Contrary to the now popular narratives (e.g., Diamond, 1995, 2005), prehistoric deforestation did not cause population collapse, nor was it associated with it. Such an argument can be based only on facile assumptions and an uncritical faith in contradictory accounts from the island's oral histories; but this is a critical subject worthy of detailed, continued examination (see Metraux, 1957; Peiser, 2005; Rainbird, 2002).

1. Rapa Nui

Rapa Nui is small (171 km²) and isolated in the remote southeastern Pacific (Fig. 1). Ancient voyaging from the central islands of eastern Polynesia would have normally gone

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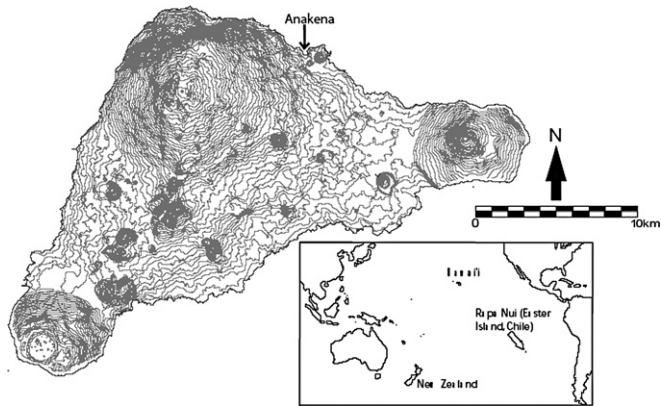


Fig. 1. The Pacific Islands and Rapa Nui, showing Anakena, site of recent early excavations.

against the prevailing trade winds, with the island forming only a small target, although westerly winds associated with periodic ENSO may have carried Polynesian colonists to the island (Anderson et al., 2006; Caviedes and Waylen, 1993; Finney, 1985, 2001).

Rapa Nui also has a relatively depauperate biota reflecting its young geological age, small size, great isolation, and importantly its biotic losses in recent ecological history. Describing the island Skottsberg (1956, p. 426) wrote “there is in the Pacific Ocean no island of the size, geology and altitude of Easter Island with such an extremely poor flora and with a subtropical climate favorable for plant growth, but nor is there an island as isolated as this, and the conclusion will be that poverty is a result of isolation—even if man is responsible for disappearance of part of the flora, it cannot have been rich.” Drawing on Skottsberg’s botanical study, Flenley (1993a) reports only 48 plant taxa for the island. Fourteen of these, including sweet potato (*Ipomoea batatas*) and the other cultigens, were prehistoric Polynesian introductions. More recent palynological work by Flenley and his colleagues and Orliac’s (2000) wood charcoal identifications on archaeological specimens, provide data suggesting many more woody plants once grew on Rapa Nui (see below). The island has few, if any, indigenous terrestrial vertebrates. Two lizard species may be native to the island (Klemmer and Zizka, 1993). Terrestrial birds found on the island today are historic introductions; while Steadman et al. (1994, p. 92) document 25 seabird species and six undescribed land bird taxa in a roster of prehistorically extinct or extirpated avifauna. Only a fraction of the seabirds can be found on Rapa Nui and its offshore islands today. DiSalvo and Randall (1993) and DiSalvo et al. (1988) report 164 species of fishes; a small number compared to those of archipelagos to the west. Sea mammals and turtles are known from Rapa Nui, but like the birds, their abundance was probably greater in prehistory. On present evidence, the only animals introduced by colonists were the Pacific rat (*Rattus exulans*) and the chicken (*Gallus gallus*).

Rapa Nui also lacks the endowment of abundant, regular rainfall, permanent streams, or a tropical climate. At 27° S, Rapa Nui is situated just outside the tropics, where common

Polynesian plants such as coconut and breadfruit would not have proven viable. The limited climatic record for the island shows that rainfall (ca. 1250 mm annual average) can fluctuate dramatically, most of the island’s soils are excessively well drained, and serious droughts could have been a significant problem in the island’s past (Genz and Hunt, 2003). Also significantly, the island is periodically plagued by strong winds with salt-spray devastating to the Polynesian cultigens of agricultural subsistence (S. Rapu, personal communication 2004).

2. The ecological parable

Jared Diamond (1995, p. 63) wrote: “In just a few centuries, the people of Easter Island wiped out their forest, drove their plants and animals to extinction, and saw their complex society spiral into chaos and cannibalism.” He continues (Diamond, 1995, p. 68):

“Eventually Easter’s growing population was cutting the forest more rapidly than the forest was regenerating. The people used land for gardens and wood for fuel, canoes, and houses—and of course, for lugging statues. As forest disappeared, the islanders ran out of timber and rope to transport and erect their statues. Life became more uncomfortable—springs and streams dried up, and wood was no longer available for fires.... As we try to imagine the decline of Easter’s civilization, we ask ourselves, ‘Why didn’t they look around, realize what they were doing, and stop before it was too late? What were they thinking when they cut down the last palm tree?’”

Rapa Nui’s demise is summed up by Diamond (2005, p. 118) as “the clearest example of a society that destroyed itself by overexploiting its own resources.” While Diamond’s is a popularized version, he derives this account from the work of professionals writing on the subject. Bahn and Flenley (1992, p. 214) wrote this explanation for Rapa Nui in their book, *Easter Island, Earth Island*:

“The person who felled the last tree could see that it was the last tree. But he (or she) still felled it. This is what is so worrying. Humankind’s covetousness is boundless. Its selfishness appears to be genetically inborn. Selfishness leads to survival. Altruism leads to death. The selfish gene wins. But in a limited ecosystem, selfishness leads to increasing population imbalance, population crash, and ultimately extinction.”

As some have argued for Rapa Nui, the efforts required to carve, construct, and transport the *moai* eventually led the population to deplete their own natural resources and go into a “downward spiral of cultural regression” and the achievements of the ancient culture crumpled “under pressures of over-population and environmental degradation” as Kirch (1984, p. 264) put it some time ago. A theme of self-inflicted, pre-European contact “ecocide” is common in published accounts (e.g., Gee, 2004; Gonick, 1996; Kirch, 1997, 2004; MacIntyre, 1999; Ponting, 1992; Redman, 1999; Rolett and Diamond, 2004; Young, 1991), and has inspired a second

tier of papers uncritically accepting “ecocide” and modeling the island’s population collapse or potential survival (e.g., Brander and Taylor, 1998; Dalton and Coats, 2000; Reuveny and Decker, 2000; Wilson, 1993).

3. The ecological evidence

3.1. Early observations

The accounts of early European visitors to Rapa Nui are remarkable in their lack of environmental details. They are also contradictory. The Dutch Expedition led by Jacob Roggeveen in 1722, expecting to relocate a “low and sandy island” reported by Captain William Dampier, wrote

“the reason why, at first, when at a farther distance off, we had regarded the said Easter Island as being of a sandy nature is that we mistook the parched-up grass, and hay or other scorched and charred brushwood for a soil of that arid nature, because from its outward appearance it suggested no other idea than that of an extraordinarily sparse and meager vegetation” (Ruiz-Tagle, 2005, pp. 23–24).

Following their visit to the island, the Dutch reported

“we found it not only not sandy but to the contrary exceedingly fruitful, producing bananas, potatoes, sugar-cane of remarkable thickness, and many other kinds of the fruits of the earth; although destitute of large trees and domestic animals, except poultry. This place, as far as its rich soil and good climate are concerned, is such that it might be made into an earthly Paradise, if it were properly worked and cultivated; which is now only done in so far as the Inhabitants are obliged to for the maintenance of life (Ruiz-Tagle, 2005, p. 37)”.

Members of the Dutch Expedition also mention seeing “small coconut palms,” houses “covered in palm leaves” (Behrens, 1903, p. 135), and “in the distance whole tracts of woodland” (Behrens, 1903, p. 137). More than 140 years later in 1868 Palmer visited the island and observed “boles of large trees, *Edwardsia*, coco palm, and hibiscus, decaying in some places” (Palmer, 1870, p. 168). As coconut trees were not introduced until later Palmer must have seen the last remnants of the extinct *Jubaea* palm. These early (1722) and late (1868) historic observations suggest the possibility that the process of deforestation, including the extinction of the palm, extended into the post-European era, a possibility mentioned by others (e.g., Flenley and Bahn, 2002, p. 161; Orliac, 2003; Rainbird, 2002).

3.2. Palynology

Olaf Selling examined pollen samples from the island’s lakes collected during Heyerdahl’s expedition in 1955. Selling reported that the native *toromiro* (*Sophora toromiro*) had once been more abundant (Flenley and Bahn, 2002, p. 79). He also noted the abundant pollen of a palm tree, which he suggested might be from the genus *Pritchardia* (Flenley and

Bahn, 2002, p. 79). The pollen evidence seemed to confirm Skottsberg’s earlier view that Rapa Nui once supported a forest. In their 1960 field work at Ahu Akivi, Mulloy and Figueroa (Mulloy and Figueroa, 1978, p. 22) noted the presence of “occasional tunnel-like tentacles ... interpreted as molds left by root activity.” They opined that, if correct, “it would seem the area was once covered with significantly more vegetation than has been reported in historic times” (Mulloy and Figueroa, 1978, p. 22).

The first detailed evidence for deforestation of Rapa Nui came from three sedimentary sequences collected, analyzed, and reported primarily by John Flenley (e.g., Dransfield et al., 1984; Flenley, 1996; Flenley et al., 1991). He collected sediment cores from Rano Aroi, a swamp in a crater near the island’s summit; from Rano Raraku, the crater-lake directly adjacent to the main statue quarry (Fig. 2); and from the large, deep lake in the crater of Rano Kao (Fig. 3).

For Rano Raraku Flenley (1993b) reports a radiocarbon date of 480 ± 60 BP for a deposit of coarse detritus (associated with human presence); below this sediment they found a striking change in the pollen spectra reflecting forest taxa such as *toromiro* (*Sophora toromiro*) and the giant palm (akin to *Jubaea chilensis*) (Grau, 2001) (Fig. 4). However, only one radiocarbon date exists from more than a meter of sediment in which dramatic, human-associated changes are represented by the pollen record.

Dumont et al. (1998) report their investigations of pollen, diatoms, chrysophyte stomacysts, and fossil plant pigments from a core taken from the lake sediments at Rano Raraku. They show major changes just prior to a single radiocarbon age of 590 ± 60 BP (Gif-9629). However, the investigations by Dumont et al. (1998) and the earlier work by Flenley and colleagues do not establish a reliable, fine-grained chronology for ecological changes associated with the island’s human history, an observation made by Mann et al. (2003, p. 139).

In efforts to better date ecological changes on the island, Mann et al. (2003) collected a 2-m deep core from Rano Raraku. Their analyses show a striking increase in magnetic



Fig. 2. View of Rano Raraku crater lake.



Fig. 3. View of Rano Kao crater lake.

susceptibility marking erosion and deposition of mineral material from the slopes of the crater (at 16 cm) occurring at or shortly before AD 1070–1280 (a range reported at two standard deviations from radiocarbon dating of *Scirpus californicus* seeds, and not from bulk sediment samples (Mann et al., 2003, pp. 147–148). Coincident with the spike in magnetic susceptibility is what they describe as a massive influx of charcoal (Mann et al., 2003, p. 147). This evidence likely reflects loss of vegetation, soil erosion (organic content declines in the sediment deposited), and eventually additional erosion of the slopes. Mann et al. (2003) do not report palynological analyses from the same core.

To date, Rano Kao has provided the best-documented palynological (and charcoal) sequence for the island (Fig. 3). Flenley (1993b) reports results from a 10.5-m core (KAO-1) dating to a time he believed was 1400 BP, based on five radiocarbon dates with a single anomaly near the base (ca. 9.5 m). From this sequence, Flenley (1993b, p. 43) concluded that

forest clearance began by at least 1200 BP (800 AD), and was largely complete by 800 BP (1200 AD), with the last remnants of forest destroyed by 500 BP (1500 AD). In a more recent analysis of the deeper core taken at Rano Kao (KAO-2, ca. 21 m deep), Butler and Flenley (2001) report three radiocarbon dates to 1600 BP for the top 15 m of sediment. In this core they show the transition from a dominance of trees and shrubs to herbs, and they quantify charcoal particles. They suggest that a revised chronology indicates major vegetation change occurred perhaps sometime after 1000 BP.

In a recent re-analysis of radiocarbon dating, however, Butler et al. (2004) (see also Flenley, 1979) reveal anomalies indicating that bulk sediment samples contain both old and young organic components that were deposited simultaneously. Butler et al. (2004, p. 395) conclude, “the depositional history of these cores is more complex than previously known.” Similar problems have occurred elsewhere, for example, McGlone and Wilmschurst (1999) (see also Anderson, 1994) document that lake and swamp core sediments are susceptible to in-washing of old carbon that can yield dates hundreds of years older than concurrent events dated in ombrogenous peat bog strata. The recent work by Butler et al. (2004) raises critical questions about the reliability and validity of dates reported in earlier publications. Indeed, radiocarbon results from bulk samples may be anywhere from a few hundred to several hundred years too old in dating human associated vegetation change on Rapa Nui. Consequently, the lake sequences and their record of deforestation are likely to be significantly younger than have been reported to date. The sequence of vegetation change documented at Rano Kao is the best analyzed from Rapa Nui, yet problems remain to be resolved with chronology, particularly a fine-grained analysis for the timing and associations of changes with human history on the island.

3.3. Stratigraphic and archaeological research

In recent years researchers have undertaken a variety of palaeo-environmental studies, including taxonomic identification of charcoal from archaeological contexts, as well as of field analysis of ancient soil erosion and geomorphic events, with a focus on the consequences of deforestation. Catherine Orliac (Orliac, 2000, 2003; Orliac and Orliac, 1998; see also Arnold et al., 1990; Pearthree, 2003) has conducted remarkable palaeo-botanical research. From a sample of 32,960 carbonized fragments of wood, seeds, fibers, and roots, she identified 1478 specimens from three locales (La Perouse, Akahanga, and Orongo) over the island dated by 21 radiocarbon dates in a sequence from about 600 to 200 BP. In these assemblages she distinguished 21 taxa, 14 of which represent new discoveries for the island (note: six of these 14 taxa remain indeterminate). The newly discovered taxa represent mesophytic forest trees and shrubs also found in the southeastern Pacific (Merlin, 1985). Orliac (2003) also examines the chronology of *Jubaea* palm endocarp remains from archaeological and natural contexts. Palm endocarps with human associations (carbonized, rat-gnawed, and/or found in archaeological



Fig. 4. Mature *Jubaea chilensis* palms at La Campana National Park (32°51' South), mainland Chile.

contexts) date to a period after AD 1250 (Fig. 5);¹ palm endocarps collected from caves date to comparable, and slightly earlier times (Orliac, 2003, p. 196). Orliac's study of carbonized plant remains shows that from about AD 1300 to 1650 (or later), a relatively wide range of mesic forest vegetation still existed on the island and these woods were used for fuel. The large sample of nearly 33,000 specimens shows that herbaceous materials replace ligneous charcoal by about 1650 AD (ca. 300 BP). Orliac (2000) also shows that at least 10 forest taxa survived into the late prehistoric or protohistoric period, i.e., the last 200–300 years, raising questions about the timing for the completion of deforestation, and by association, the causes and consequences (see also Orliac, 2003; Orliac and Orliac, 1998).

Mann et al. (2003) report stratigraphic research from 19 coastal and interior locations across the island. With a series of 24 radiocarbon determinations from charcoal in colluvium overlying truncated primeval soils, Mann et al. (2003, p. 146) date soil erosion, assumed to be associated with deforestation, to a period after 1200 AD until about 1650 AD. They conclude that shortly after 1200 AD, primeval soils underwent severe erosion throughout the island. This event coincides with their lake-sediment core from Rano Raraku, with a drastic increase in both mineral sedimentation and charcoal particles about the same time. Their evidence suggests no clear geographic trend in soil erosion on the island, except that it is widespread.

Other recent stratigraphic research primarily on the Poike Peninsula (Bork and Mieth, 2003; Mieth and Bork, 2003, 2004, 2005; Mieth et al., 2002) focusing on prehistoric land use has provided a valuable localized history of deforestation. Based on work in multiple locations, Mieth, Bork, and colleagues provide evidence such as palm root molds, presence of charcoal particles, sedimentary changes, the context of archaeological features, with radiocarbon dates, and demonstrate that a dense *Jubaea* palm forest covered the peninsula and evidently grew over most of the island. Their research demonstrates that beginning about 1280 AD the deforestation began with indications of fire, rat-gnawed palm endocarps, and cultivation in the same areas. Their results show “no remnants of burnt [palm] trunks or stems older than AD 1280 on Poike” (Mieth and Bork, 2003, p. 39). Over perhaps 200 years they believe the evidence suggests fires destroyed the palm forest, and a humic soil horizon develops in grassland. They hypothesize that areas of the peninsula were abandoned after

¹ I compiled and plotted radiocarbon determinations made on *Jubaea* palm endocarps modified by rat gnawing, charring, or those found in clear archaeological context (Fig. 5). These radiocarbon ages span a period from approximately AD 1250 to 1500–1600. Orliac (2003, p. 196) provides comparable data with an age range given as AD 1200–1450, I have not plotted all of Orliac's dates for palm endocarps because I was unable to analyze them in a comparable way for inclusion in the plot shown in Fig. 5. Some of the palm endocarps shown by Orliac (2003, p. 196) are from non-archaeological contexts, including a natural stratum (Te Aheru) and from caves. My inspection of palm endocarp remains held in the collections at the P. Sebastian Englert Museum on Rapa Nui showed that all exhibited evidence of rat gnawing.

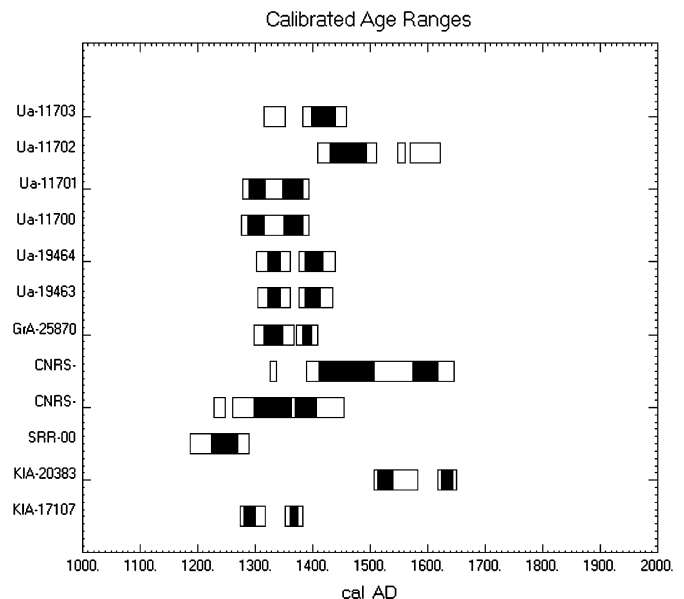
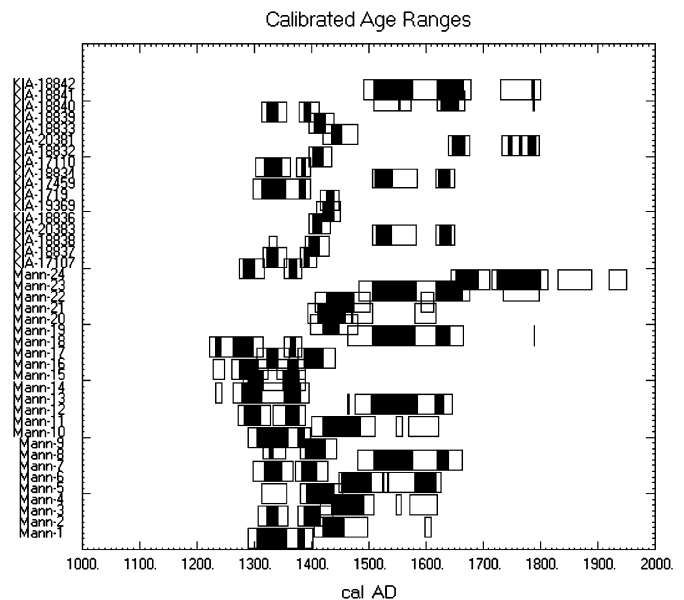


Fig. 5. Calibrated radiocarbon dates ($n = 12$) for *Jubaea* palm endocarps with cultural associations by context (archaeological, burned, and/or rat-gnawed (data from Dransfield et al., 1984; Martinsson-Wallin and Crockford, 2002; Mieth and Bork, 2003, 2004; Orliac, 2003).

1400 AD, while some areas saw a second period of use from about 1500 to 1675 AD.

The recent stratigraphic research from Poike Peninsula (Mieth and Bork, 2004) and similar work from multiple locations around the island (Mann et al., 2003) provides a coherent picture. Radiocarbon dates ($n = 42$) for *Jubaea* palm remains, or evidence of soil erosion, and their associations in human impacts consistently date nearly a century after 1200 AD. Fig. 6 plots 42 calibrated radiocarbon dates collated and compiled from these recent research projects. These environmental



impacts appear to have been abrupt and widespread. The researchers of these projects explain the apparent discrepancy between what they believe is the date of initial human colonization of the island at AD 400 or 800 and the impacts wrought by Polynesian agriculturalists. Mann et al. (2003, pp. 148–149) consider the apparent chronological discrepancy:

“Widespread burning and soil erosion began on Rapa Nui only after A.D. 1200, yet archaeological evidence suggests that initial Polynesian settlement occurred at least 400 years earlier.... and probably 700–900 years earlier. It is striking that our dates suggest that the island remain unburned and presumably uncleared of vegetation until as late as A.D. 1200.”

Mann et al. (2003, p. 149) consider the idea that little land was cleared because human populations remained small, yet they point out this seems unlikely because Rapa Nui has a high potential for the spread of wildfires. This is particularly true given the island's simple topography, droughty conditions, and frequent strong winds, but it remains unclear how readily the original vegetation would have carried fire. Instead, Mann et al. (2003, p. 150) postulate that Rapa Nui was occupied only transiently between AD 300 and 1200. Citing similar “peculiarities of the early phase of prehistoric land use,” Mieth and Bork (2004, p. 71) suggest that at least the first few centuries of settlement were characterized by a sustainable subsistence economy. They also suggest that deforestation was accomplished by what would eventually become a large workforce cutting and processing the giant palms at a rapid rate. Mieth and Bork argue that the discrepancy between earlier settlement and deforestation beginning only after AD 1200 can be explained by spatially limited clearing on the island (Mieth and Bork, 2004, p. 77). They also suggest that the abrupt changes of about AD 1250 came with a “new cultural impetus” (Mieth and Bork, 2004, p. 89) that initiated the “unstoppable process of degradation” (Mieth and Bork, 2004, p. 82).

The common perspective of an early, largely invisible, ecologically sustainable subsistence economy for Rapa Nui envisions a small founding population with remarkably slow population growth with few, if any, visible ecological impacts. Describing this notion for East Polynesia in general, Anderson (1995, p. 111) writes: “it is argued that colonising populations behaved in ways which created an incrementally slow and cryptic archaeological record (small initial populations, slow growth, residentially mobile swiddening), [and] that early remains have low probabilities of discovery.” From this perspective, researchers see a dichotomy of sustainable human adaptations in contrast to an ecological catastrophe and the self-inflicted prehistoric collapse of the population.

Several lines of evidence now point to initial Rapa Nui colonization much later than the conventional consensus of 400 or 800 AD. In growing contrast to other islands in eastern Polynesia, scholars long accepted an early date for Rapa Nui's first settlement, despite any solid evidence, based on long-standing linguistic models for Polynesian settlement order (e.g., Ayers, 1971; Green, 1966). Kirch succinctly expressed

the prevailing view for Rapa Nui: “a pollen core from Rano Kau suggests the onset of human-induced forest clearance by 1630 ± 130 B.P. (A.D. 147–676, calibrated), consistent with a radiocarbon date on charcoal from the Poike Ditch of A.D. 235–615. Such early dates mesh well with linguistic evidence” (Kirch, 2000, p. 271).

However, most now reject the validity of Heyerdahl's early Poike Ditch date; the oft cited AD 400 age (see sources questioning early colonization: Hunter-Anderson, 1998; Orliac, 2003, p. 193; Skjolsvold, 1996; Spriggs and Anderson, 1993). Martinsson-Wallin and Crockford (2002) recently rejected the earliest chronology and proposed settlement around AD 800 based on a compilation and analysis of radiocarbon dates; see also Flenley and Bahn (2002, p. 77) who made a similar argument. Butler et al. (2004) have also highlighted the serious problems of radiocarbon dates from bulk samples from lake cores on the island. Finally, the belief that Rapa Nui was settled early on linguistic subgrouping evidence relies on the facile assumption that ordering contemporary language relations provides a straightforward historical sequence. Instead such language trees summarize both historical and geographical influences, making settlement order illusionary (e.g., Biggs, 1972; Hunt and Terrell, 1997; Terrell et al., 1997).

Five lines of evidence now raise serious challenges to an early or mid-length (ca. 700–800 AD) chronology for the colonization of Rapa Nui (Hunt and Lipo, 2006). First, eight recently acquired radiocarbon dates from deep, stratified sand dune excavations by the University of Hawai'i archaeological field school at Anakena provide a chronology beginning only about AD 1200 (Hunt and Lipo, 2006). Samples dated to this age came from a clay substrate containing artifacts, charcoal, and introduced rat bones within the upper boundary of the basal clay, with *in situ* palm root molds directly below where there is a complete absence of artifacts, charcoal, bones, or other indications of human presence at Anakena. This clay substrate was probably the original deposit and surface (indicated by a paleosol) that saw initial Polynesian colonization of the island. Moreover, these early stratified deposits at Anakena contain abundant bones of the Pacific rat, sea mammals, birds, and fish in numbers (i.e., rank orders) similar to those reported by Steadman et al. (1994), Skjolsvold (1994) and Hunt and Lipo (2006) (see Fig. 12a–c).

Second, following the “chronometric hygiene” protocol advocated by Anderson (1991) and Spriggs and Anderson (1993), we can reject for purposes of establishing chronologies single dates (i.e., non-replicated age estimates from a particular deposit) and dates on material with unknown, mixed, or otherwise problematic isotopic fractionation (e.g., marine specimens, “charcoal and soil mixed” etc. (e.g., Beavan-Athfield and Sparks, 2001; Higham and Hogg, 1997). The dates remaining fall almost entirely within a range post-dating AD 1200, particularly when considered as a probability distribution (Hunt and Lipo, 2006).

Third, given the widely variable ages of bulk samples from the lake cores compared to recently acquired AMS dates of individual constituents (e.g., plant parts, pollen grains), we can no longer rely on the small number of dates cited as evidence

for the timing of colonization associated with pollen changes marking the inception of deforestation (Butler et al., 2004).

Fourth, the chronology compiled from the recent (and island-wide) stratigraphic studies of initial human impacts and deforestation consistently dates after AD 1200 (Figs. 5 and 6). If these sudden environmental changes do not represent initial Polynesian presence, then one must assume that colonizing human (and rat) population growth was unusually slow, that settlement, subsistence, and their impacts remained cryptic—indeed invisible—on this diminutive island for either 800 or 400 years. While some might imagine that human populations could have attained colonizing success with exceedingly low growth rates (e.g., a 1% growth rate), it is difficult, if not absurd, to imagine Pacific rat populations on an island with an estimated 16 million nut-bearing palm trees (Bork and Mieth, 2003) would constrain their populations to similarly low rates and have no visible impact on the island's vegetation.

Finally, renewed investigations of human settlement chronology throughout East Polynesia (Spriggs and Anderson, 1993), for example in the Hawaiian Islands (Burney and Burney, 2003; Tuggle and Spriggs, 2002), Marquesas Islands (Anderson and Sinoto, 2002), Society Islands (Anderson and Sinoto, 2002), Austral Islands (Rapa Island) (Kennett et al., 2006a), and New Zealand (Anderson, 1991; Higham and Hogg, 1997; Wilmshurst and Higham, 2004) have consistently demonstrated later chronologies than previously proposed. These revisions demonstrate not only the inherent problems in establishing radiocarbon chronologies, but that many sources of error can give the impression of misleadingly long chronologies until they are corrected with more careful analysis.

In sum, the ecological history emerging from field research on Rapa Nui indicates a mesophytic forest dominated by giant palms. The first Polynesian colonists arrived around AD 1200 from central eastern Polynesia (possibly from the Austral, or Gambier [Mangareva-Pitcairn] Group), based on multiple lines of evidence (e.g., Barnes et al., 2006; Chapman, 1997; Green, 1998, 2000). It appears deforestation began within a century. Thus, there was no extended period when humans, directly or indirectly, had little or no impact to the native forest. Instead, widespread, rapid deforestation and related consequences of soil erosion began within the first generations following colonization. While most associate the timing of deforestation with humans, a more detailed picture of causes and effects remains to be elucidated. Research elsewhere in the Pacific, particularly recent work in the Hawaiian Islands, provides some compelling parallels for better understanding Rapa Nui and its ecological and human history.

4. Hawaiian research

Athens et al. (2002) have recently published field research from the 'Ewa Plain on the Hawaiian Island of O'ahu. Their study of palaeo-environmental change on O'ahu provides evidence for deforestation that appears to have important parallels with Rapa Nui. Athens et al. (2002) analyzed archaeological and paleontological samples from limestone sinkholes, archaeological survey and excavations of prehistoric

sites, and a lake sediment core from Ordy Pond near Barber's Point. The record from Ordy Pond comprises 8.7 m of finely laminated sediment dating to 1500 BP (ca. 450 AD), a time clearly pre-dating the Polynesian colonization of O'ahu. Thirty-two pollen samples and three AMS radiocarbon dates show the rapid loss of forest, particularly for the endemic *Pritchardia* spp. and *Kanaloa kahoowawensis* (Fig. 7a, b). Indeed the Ordy sequence shows that the native lowland forest of the 'Ewa Plain declined precipitously over only 200 years from AD 900 to 1100. In the same area, excavations in multiple limestone sinkholes have yielded abundant remains of the Pacific rat and native avifauna, including birds that quickly went extinct. Multiple radiocarbon dates on rat bone document the presence of these commensal animals on the 'Ewa Plain beginning around AD 900. At about AD 1050 a prevalence of small (versus a larger size class) charcoal particles indicates distant fires on the Island of O'ahu. Large charcoal particles from local first make their appearance in sampling intervals after steep declines in native forest flora on the 'Ewa Plain (Fig. 7a, b).

Athens et al. (2002, p. 63) conclude that “both the stratigraphic position of the earliest charcoal particles with respect to pollen changes, and also the particle size data imply that forest decline on the 'Ewa Plain preceded human presence.” The Ordy Pond charcoal data show a drastic surge in larger size classes, indicative of local fire history, at about AD 1250–1300. Athens et al. (2002, pp. 63–64) report 194 radiocarbon dates from 'Ewa cultural contexts that firmly establish local land use and settlement beginning after AD 1250–1300. Thus, significantly, Hawaiian settlement of the 'Ewa Plain followed some 400 years after large-scale deforestation had already occurred. Athens et al. (Athens et al., 2002, pp. 64–65) posit that “the collapse of the native forest on the

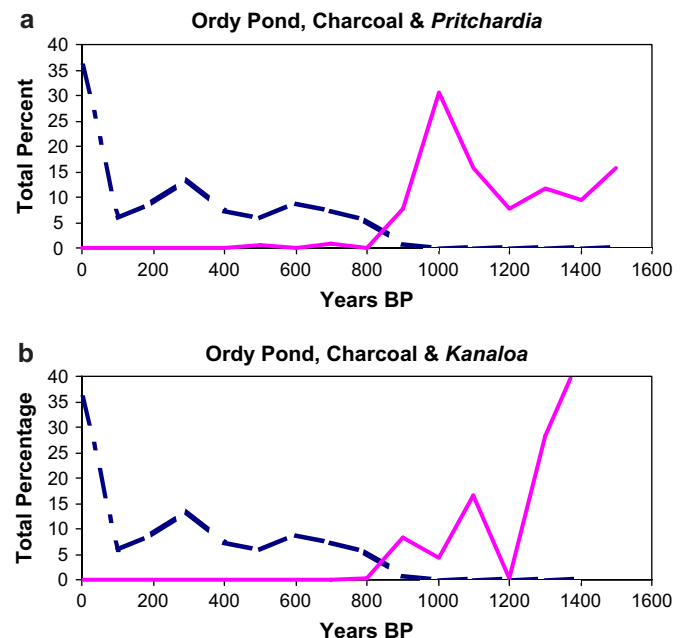


Fig. 7. Pollen (solid line) and charcoal particles (dashed lines) from Ordy Pond, 'Ewa Plain, O'ahu Island (a) *Pritchardia* pollen; (b) *Kanaloa* pollen. Data from Athens et al. (2002).

‘Ewa Plain began after human colonization of the Hawaiian Islands, but prior to rapid population growth and expansion ... and certainly before significant settlement of the ‘Ewa Plain.” The oft cited practice of deforestation by slash and burn, particularly for purposes of agricultural clearing, cannot account for the evidence on the ‘Ewa Plain. This habitat loss appears to be the cause of terrestrial avifaunal extinction or extirpation, particularly in the absence of evidence for human predation (Athens et al., 2002, p. 73).

In rare cases where pollen and charcoal particles from sediment cores are quantified in concert, evidence from elsewhere in the Hawaiian Islands reveals a similar pattern. For ‘Ohi’apilo Pond on the leeward coast of Moloka‘i, Denham et al. (1999) show that pollen from both *Pritchardia* spp., *Kanaloa kahoolawensis*, and other native forest elements declined steeply before the increase of charcoal particles in the same sedimentary sequence (Fig. 8a,b). A radiocarbon date in the upper sediments indicates that forest decline occurs sometime before about AD 1000. The authors note the relatively low frequency of charcoal particles, suggesting only minimal use of fire in the area (Denham et al., 1999, p. 41). Athens and Ward (2000) document a similar pattern in a core from Weli Pond at Fort Shafter on O‘ahu Island. Pollen of *Pritchardia* palm declines steeply over a period estimated to be 1000–1100 years ago, whereas charcoal concentrations peak slightly later. Other O‘ahu Island sites may reveal a similar pattern (Athens, 1997). In evidence from Maha‘ulepu on Kaua‘i’s leeward south coast, Burney et al. (Burney et al., 2001) and Burney and Burney (2003) document the rapid loss of *Pritchardia* and the subsequent rise in charcoal particles from the same stratigraphic sequence. The sequences

from these four Hawaiian leeward environments on three islands suggest that similar patterns, and similar underlying historical processes, have emerged from palaeo-ecological field research.

Athens et al. (2002) provide a compelling model to account for this emerging pattern of early forest loss and associated avifaunal extinctions in the absence of local fires. They hypothesize that the Pacific rat, *Rattus exulans*, was a serious destructive agent in the rapid demise of the Hawaiian native lowland forest. Radiocarbon dates on rat bone from the ‘Ewa Plain sinkholes show their presence at the time native forest disappeared, bird extinctions commenced, yet before human settlement of this portion of O‘ahu. Second, the bones of *R. exulans* are abundant in the sinkhole deposits, suggesting a high rat population density. Athens et al. (2002, pp. 73–74) point out that the commensal rat arrived in the Hawaiian Islands with few, if any, predators except perhaps the Hawaiian hawk, owl, or extinct eagle. The rat found little competition among native birds for plant food resources; *R. exulans* is an agile climber (McCartney, 1970) and opportunistic omnivore. Unlike birds, rats can penetrate hard, thick seed cases (even coconuts (Mosby and Wodzicki, 1973; Strecker, 1962; Wodzicki and Taylor, 1984) and destroy the reproductive potential of the majority of seeds they consume (e.g., Campbell, 1978, 2002; Campbell and Atkinson, 1999, 2002; McConkey et al., 2003; Pickard, 1980; cf. Hunter-Anderson, 1998, p. 93). Numerous studies have shown that plant materials are the primary food for *R. exulans* (e.g., Campbell et al., 1984; Mosby and Wodzicki, 1973; Storer, 1962; Williams, 1973). Direct predation of birds by *R. exulans* has been widely documented (Atkinson, 1985; Towns et al., 2006), but birds and their eggs normally comprise a secondary portion of the diet, or such predation occurs under resource stress (Atkinson, 1978, 1985; Wirtz, 1972).

Rats are remarkably fecund (Barnett, 2001; Egoscue, 1970; Moller and Craig, 1987), and given a nearly unlimited food supply such as the fruits and seeds of pristine native forest, they can irrupt into enormous, dense populations, as widely documented (Choquenot and Ruscoe, 2000; Roberts and Craig, 1990; Williams, 1973; Wirtz, 1972). Comparative research has also shown higher and more stable rodent population densities evolve rapidly on islands (Alder and Levins, 1994; Tamarin and Malecha, 1972).

The effects of rats on vegetation and their role in habitat destruction and vertebrate and invertebrate extirpations are well documented in several field studies from New Zealand (e.g., Atkinson, 1978, 1985; Campbell, 1978; Campbell and Atkinson, 1999, 2002; Towns et al., 2006; Wilson et al., 2003) as well as in the tropical Pacific (e.g., Drake, 1993; McConkey et al., 2003; Scowcroft and Sakai, 1984). For vegetation in particular, Campbell (1978, 2002) and Campbell and Atkinson (1999, 2002) show that even the ecologically diverse forests of New Zealand suffer serious impacts from seed predation by *R. exulans* (and today also by *R. rattus* and *R. norvegicus*). From field studies of northern offshore islands in New Zealand where only *R. exulans* is found, Campbell and Atkinson (2002) have documented depressed recruitment of 11 species of

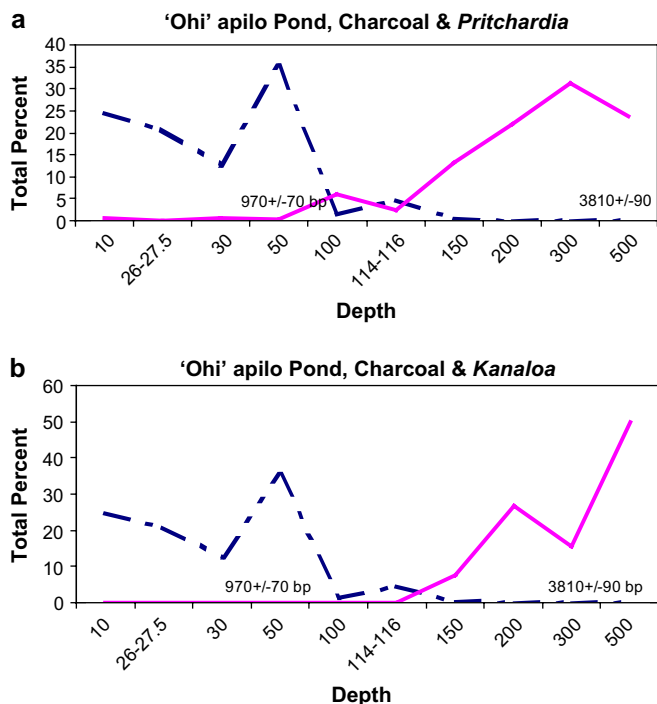


Fig. 8. Pollen (solid line) and charcoal particles (dashed lines) from ‘Ohi’ apilo Pond, Moloka‘i Island (a) *Pritchardia* pollen; (b) *Kanaloa* pollen. Data from Denham et al. (1999).

coastal trees among 17 studied; some to the point of *extirpation*. In an earlier study Campbell (1978) provides dramatic data for *R. exulans* impacts on the native nikau palm (*Rhopalostylis sapida*) from rat exclosures where palm seedlings increased 68% in just 2.5 years (Cuvier Island, 1964–1966). As Campbell and Atkinson (2002, p. 30) note for Cuvier Island, “3 years after rats had been eradicated, small seedlings of *R. sapida* were very abundant beneath mature palms where none had been seen previously.” For Inner Chetwode Island Campbell and Atkinson (1999, p. 283) report that following rat eradication “the total number of nikau seedlings on six quadrants increased from 25 in 1994 (a year after eradication), to 66 in 1995, and to 348 in 1996.” Experimental exclosures on Little Barrier Island show that Pacific rats strongly depress nikau seedlings by destroying seeds, underground stems, and leaves, making these palms doubly vulnerable (Campbell and Atkinson, 2002, p. 29). These effects are illustrated in Fig. 9 (after data from Campbell and Atkinson, 1999, p. 283). The rats’ impacts on nikau palms may find parallels in the *Pritchardia* palms of the Hawaiian Islands and the *Jubaea* palms of Rapa Nui (see also Pickard, 1980, concerning Lord Howe Island palms). Consistent with the ecological research and palaeo-environmental records, Athens et al. (2002, p. 74) propose, “*R. exulans*, quickly radiating throughout the islands ahead of human settlers who had brought them, destroyed much of the native Hawaiian lowland forests by consumption of the leafy and reproductive portions of the plants.”

The model for a major role of rats in island deforestation has some expectations in present vegetation patterns: First, islands where rats are absent, and likely never formerly established, should retain native forest, or elements of it given other impacts. This is the case with Nihoa Island, Northwest Hawaiian Group, where native vegetation persists, particularly dense stands of endemic *Pritchardia remota* (Fig. 10), even in the wake of prehistoric human settlement, the effects of anthropogenic fire, and the impacts of an intensive prehistoric agricultural landscape.² Second, as Athens et al. (2002, p. 74) document, the islets of Huelo and Mokapu just off Moloka’i’s north shore provide comparative cases. Huelo Island, where surveys document the absence of rats, is covered with a dense stand of young and mature endemic *Pritchardia hillerbrandii* and other native plants. In contrast, on nearby Mokapu Island, where the presence of rats has been documented, a few mature *Pritchardia*, and only a single immature palm, survive. Other conservation projects in the Hawaiian Islands have documented the recovery of native vegetation (and birds) where rats are removed, eradicated, and/or excluded from the area (e.g., Smith et al., 2006). Several field studies in New Zealand

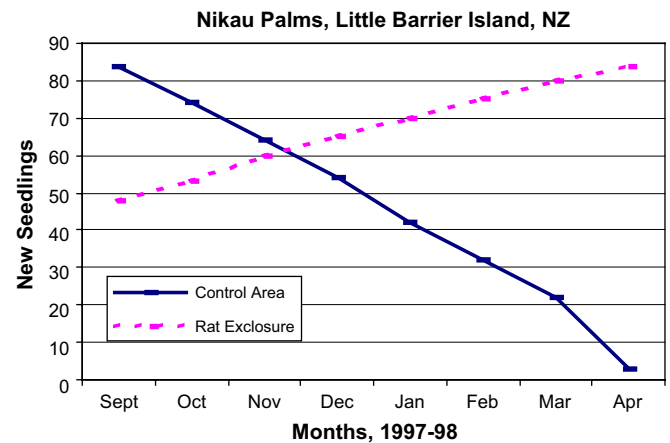


Fig. 9. Plot of changes in nikau palm seedlings showing the impact of rat predation in New Zealand. Data from Campbell and Atkinson (1999).

on offshore islands with and without rats show marked differences in vegetation patterns and the diversity and abundance of other species, including birds, reptiles, etc. (e.g., Campbell and Atkinson, 1999, 2002; Towns et al., 2006). Finally, Athens et al. (2002, p. 74) point out that native vegetation is relatively common at higher elevations (above ca. 1500 m) in the Hawaiian Islands. This appears to coincide with the elevation range for *R. exulans*, also about 1500 m, which may be limited by the absence of fruit-producing trees at higher altitudes, according to Jackson and Strecker (1962); “thus, the persistence of native vegetation at higher elevations (and consequently, the native avifauna), may owe much to the primarily lowland natural habitat range of rats” (Athens et al., 2002, p. 74).

5. Rats and Rapa Nui

The palaeo-environmental record for Rapa Nui documents a relatively simple ecosystem with vegetation once dominated by millions of *Jubaea* palms. The pollen record shows that the *Jubaea* palm has been established on the island since Pleistocene times (Flenley and King, 1984); thus persisting through



Fig. 10. View of endemic *Pritchardia remota* palm clusters on Nihoa Island, Northwest Hawaiian Islands.

² This simple observation is contrary to the attribution of Nihoa as “totally deforested” by Rolett and Diamond (2004, p. 443). As Conant (1985, p. 148) points out, the flora of Nihoa provides a unique remaining example of a native lowland coastal ecosystem in the Hawaiian Islands. Faunal assemblages excavated from rock shelters and habitation sites on Nihoa are currently under analysis (with Kelley Esh). The assemblages are dominated by sea birds. No rat bones are present.

significant climate changes and doubtless multiple environmental perturbations.³ Rapa Nui's native biota reflects a classic case of island biogeography where evolution in isolation accounts for a simple community with a comparatively small number of taxa, high endemism, and few if any predators. Together these features render an ecosystem particularly vulnerable to alien invasions (Elton, 1958; Wace, 1986). Moreover, as Green et al. (1997, p. 2474) point out, a dominant consumer (e.g., land crabs on Christmas Island, Indian Ocean, or Pacific rats introduced to Rapa Nui) can have marked effects on plant community structure and exhibit strong control in simple ecological communities on remote oceanic islands.

Although often described as stowaways, Matisoo-Smith et al. (1998) suggest that rats were intentional introductions, providing an almost immediate vast quantity of protein for colonists in new territories. Accidental or intentional, the consequences would be the same: rats reached an island with an almost unlimited high-quality food supply in millions of palms each producing abundant nuts. Quantitative data reveal that under ideal conditions rats reproduce at rates doubling every 47 days (Fenchel, 1974). For example, starting with only a single mating pair, rats can attain a population of nearly 17 million in about 1128 days, or just over 3 years.

At a latitude comparable to Rapa Nui, but perhaps with a lower abundance of food resources, Kure Atoll (28°24' N) in the Northwest Hawaiian Islands supports Pacific rat densities averaging 45 per acre, with maximum recorded densities reaching 75 (Wirtz, 1972, p. 457). At a density of just 45 rats per acre, Rapa Nui would have reached a rat population over 1.9 million. At 75 rats per acre, possible given the *Jubaea* nut and other forest resources, the rat population of Rapa Nui could have exceeded 3.1 million (see Wood, 1984). Such documented population growth rates and densities for rats on Pacific Islands suggest that Rapa Nui may have supported a huge number of rats within a very short time following their introduction. An initial maximum rat population boom would fall to a sustainable number in some equilibrium with the resources provided by mature palm trees and other resources.

If rats alone decimated the *Pritchardia* palm forest on the 'Ewa Plain of O'ahu (and by implication other lowland regions of the Hawaiian Islands) as Athens et al. (2002) document, then does it offer an analog for Rapa Nui? The Hawaiian research demonstrates that rats were capable, on their own, of deforesting large lowland coastal areas in about 200 years or less. This dramatic case begs the question of how rats, once introduced to Rapa Nui, would *not* have had a profound and immediate impact on the island's forest dominated by the productive *Jubaea* palms. Did the advent of humans and the commensal rat bring *invasional meltdown* to the Rapa Nui ecosystem (Simberloff and Von Holle, 1999; Traveset and

Richardson, 2006)? Similar to the impacts on *Pritchardia* of Hawai'i or the nikau palms of New Zealand, did rats consume the *Jubaea* nuts and seedlings that managed to sprout, greatly depressing palm recruitment; thus effectively halting the regeneration of the palm and other trees on the island (Table 1)? If so, impacts would have begun immediately and continued unabated. At the same time, despite an abundant supply of plant foods, a large rat population would also prey directly upon nesting seabirds, land birds, including their eggs and chicks (e.g., Atkinson, 1978, 1985; Diamond, 1985; Towns et al., 2006; Wirtz, 1972), land snails (e.g., Brook, 1999; Prece, 1998, p. 3650, as well as other taxa that may have been present, likely contributing to rapid extinction (Blackburn, 2004; Blackburn et al., 2004; Diamond, 1985; Gurevitch and Padilla, 2004; Steadman et al., 1994). As Towns et al. (2006, p. 883) report, there are ecosystem-level consequences that include "plants so heavily suppressed by Polynesian rats that successional pathways and forest structure have been modified." But as they point out, "the ecosystem effects of Polynesian rat invasions have yet to be [more fully] studied" (Towns et al., 2006, p. 883).

The idea that rats could have played a major role in Rapa Nui's deforestation is not new. Earlier researchers have noted the evidence for rat predation of the *Jubaea* palm nuts, but the relative contribution rats made to deforestation remains poorly understood. In 1968 anthropologist Grant McCall (personal communication 2005) recalls the resident Catholic priest and researcher on Rapa Nui, Sebastian Englert, telling him that he had found "little coconut seeds" (*Jubaea* palm endocarps) in "rat caves," making at least the association with rats and the evidence of gnawing (see Fig. 11). In reporting finds of the endocarps of the extinct palm from Rapa Nui, Dransfield et al. (1984, p. 750) noted their discovery in caves, that *all* had been gnawed by rodents "which could have helped to make the species extinct." Dransfield et al. (1984, p. 751) write "extinction of the Easter Island palm was caused by a combination of direct deforestation and prevention of reproduction, the latter resulting from eating the fruits by man and the introduced rats." Flenley et al. (1991, p. 104, *emphasis added*), suggested:

"the effects of introduced rodents on the biota of oceanic islands are known frequently to have been disastrous, ... and it seems that Easter Island may have been no exception. Whether the extinction of the palm owes more to the prevention of regeneration by rodents, or to the eating of the fruits by man, or to the felling of the mature trees, *remains an open question.*"

In the absence of effective predators as in continental or island ecosystems with biogeographically more complex biota, or other limiting factors such as seasonality, the impacts of rats alone could eventually result in deforestation. Thus, the question for Rapa Nui concerns the relative impacts of rats, felling, and fire. Further, how can we document these impacts with sufficient chronological precision to distinguish and measure their roles in deforestation? Presently, three lines of evidence fit the expectations of a model for the significant role of rats relative to other agents in deforestation on Rapa Nui.

³ The long history of *Jubaea* palms on Rapa Nui, including major climatic shifts from Pleistocene to Holocene conditions provides compelling evidence that recent climate fluctuations did not play a significant role in the decline or extinction of the palms or other plants on the island, contrary to the speculations offered (e.g., Hunter-Anderson, 1998; Orliac and Orliac, 1998). Although further research may reveal a role for climate change.

Table 1
Major native plants of Rapa Nui and their vulnerability to rat predation

ID	Taxon	Description	Fruits/seeds	Fruit/seed size	Rat predation	Expected rat impact	Refs.
Charcoal, pollen, etc.	<i>Jubaea</i> sp.	Large palm >30 m	Nuts, etc.	17–32 mm seeds (nuts)	Rapa Nui, Mainland Chile; rat-gnawed nuts	Major	Dransfield et al., 1984
Charcoal	<i>Elaeocarpus</i> cf. <i>E. rarotongensis</i>	Tree, 7–15 m	Fleshy fruits	ca. 20 mm fruit	Tongan husking stations; NZ	Major	Campbell and Atkinson, 2002; McConkey et al., 2003
Charcoal	<i>Alphitonia</i> cf. <i>A. zizyphoides</i>	Tree, 4–30 m	Non-fleshy drupes; 1 seed per locule	ca. 7 mm seed	Undocumented?	Major?	
Charcoal	<i>Xylosoma</i> cf. <i>X. suavolens</i>	Tree, 2–8 m	Fleshy fruit, berries	No data	Undocumented?	Major?	
Charcoal	<i>Pittosporum</i> sp.	Shrub, tree 6–10 m	Fruit, multiple seeds (30–50)	5–6 mm seed	NZ, rats depress recruitment	Major	Drake, 1993
Charcoal	<i>Psyrdrax</i> cf. <i>P. odorata</i>	Shrub, tree 2–10 m	Pulpy fruits, 2 seeds	ca. 6 mm seed	Undocumented?	Major?	
Charcoal	<i>Myrsine</i> sp.	Shrub, tree 3–7 m	Fleshy fruit, drupe, 1 seed	2–4 mm seed	NZ, rats do not seem to eat <i>M. australis</i> seeds; Hawaii, rats consume <i>Myrsine</i> spp. seeds (74.7%) ^a	Major?	Campbell, 1978, 2002; Drake, 1993
Charcoal	<i>Psychotria</i> sp.	Shrub, tree to 5m	Berries	≥3 mm seed	Undocumented?	Major?	
Charcoal	<i>Coprosma</i> sp.	Shrub, tree to 4 m	Fleshy fruit	ca. 5 mm seed	NZ, rats depress recruitment of several spp.; Hawaii, rats consume seeds (52.2%) ^a	Major	Campbell and Atkinson, 2002; Drake, 1993
Charcoal (extant)	<i>Syzygium</i> cf. <i>S. malaccense</i>	Shrub, tree <3 m	Fleshy fruit	ca. 5 mm seed	Undocumented?	Major?	
Charcoal	<i>Premna</i> cf. <i>P. serratifolia</i>	Shrub, tree <3 m	Fleshy fruit in clusters	2–4 mm seed	Edible leaves and seedlings	Major?	
Pollen	<i>Trema</i> sp.	Shrub, tree 10–20 m	Fleshy fruit, drupe, 1 seed	3–5 mm fruit	Undocumented?	Major?	
Pollen	<i>Metrosideros</i> sp.	Shrub, tree to 30 m	Numerous seeds	Nearly microscopic	Rats may disperse seeds (Hawaii? NZ?)	Minor, none?	
Extant (historic)	<i>Sophora toromiro</i>	Shrub, tree	4–5 seeds in woody pod	3.5–4 mm seed	NZ, rats do not affect recruitment; rats may disperse seeds	Minor, none?	Campbell and Atkinson, 2002
Extant	<i>Caesalpinia major</i>	Shrub, climber to 15 m	2–4 seeds	15–25 mm seeds	Undocumented?	Unknown?	
Extant	<i>Sapindus saponaria</i>	Shrub, tree to 12 m	Fruit, several in cluster, 1 seed	ca. 15 mm	Fruits/seeds poisonous to humans	Minor?	
Extant	<i>Triumfetta semitriloba</i>	Herb, subshrub	Fruit, 3 compartments, 3 seeds	6–8 mm	Undocumented?	Unknown?	

^a Percentages refer to quantity of seeds with evidence of rat predation in Drake's (Drake, 1993) Hawaiian field research.



Fig. 11. Prehistoric rat-gnawed *Jubaeba* endocarps from Rapa Nui (from collections at the P. Sebastian Englert Anthropological Museum, Rapa Nui). Note: all endocarps examined in the museum collections show signs of rat gnawing.

First, excavations in the early stratified deposits of the Anakena Dune show that the Pacific rat was abundant (Fig. 12a–c) (Hunt and Lipo, 2006; Skjolsvold, 1994; Steadman et al., 1994). The quantity of bone identified as *Rattus exulans* suggests that in a short time the rat population exploded, declined, and finally disappeared with the introduction of other rats by Europeans. The faunal data (Fig. 12a–c) from several excavations also show that bird was never abundant (similar to lowland Hawaiian archaeological faunal assemblages (Athens et al., 2002), and does not appear to have formed a primary part of early subsistence on Rapa Nui.

Second, direct evidence for the impact of rats is found in the vast majority of palm endocarps recovered from archaeological and natural contexts on Rapa Nui with the distinctive signs of gnawing and removal of the interior nut (Fig. 11). *Jubaeba chiliensis* endocarps from a forest preserve at La Campana in mainland Chile exhibit nearly identical evidence of gnawing and extraction by native rodents.

Finally, the pollen and charcoal records documented in Hawaiian palaeo-environmental research show forest decline preceded local fires. Does the single available sedimentary sequence of pollen and charcoal for Rapa Nui show a comparable history of forest decline preceding fires? The sedimentary sequence from Rano Kao shows that forest pollen (i.e., from trees and shrubs) may decline before the initial surge of charcoal particles (Butler and Flenley, 2001, Fig. 2) (see Fig. 13). Further detailed pollen and charcoal particle analysis may reveal, as on the Islands of O'ahu, Moloka'i, and Kaua'i, that forest decline preceded intensive use of fire, and does not appear to have been initially caused by burning. The pollen-charcoal evidence is critical, yet remains to be more fully documented for Rapa Nui.⁴

⁴ Researchers have quantified pollen and charcoal in tandem for only one sedimentary sequence, and I extracted these data from Fig. 2 in Butler and Flenley (2001). Finer scaled data will be critical to evaluating the timing and contributing causes of deforestation.

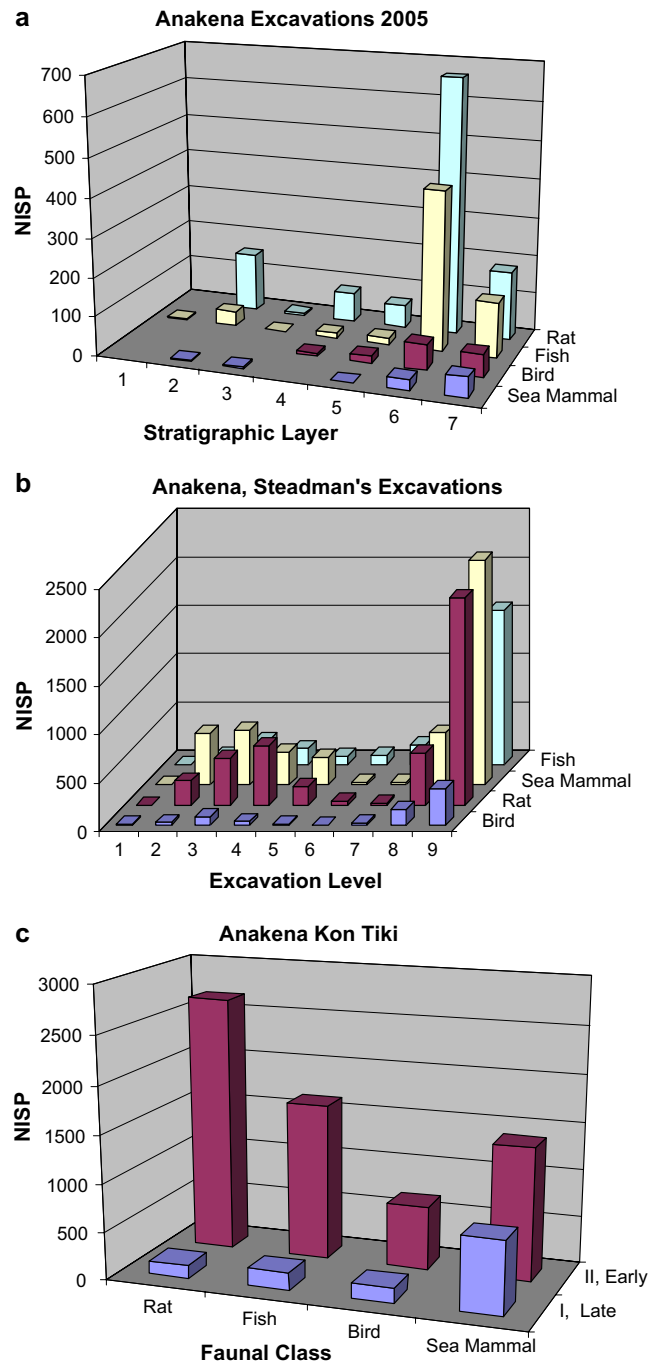


Fig. 12. Abundance of *R. exulans* and other faunal remains (by NISP) in archaeological deposits at Anakena; (a) from 2005 excavations, University of Hawai'i; (b) Steadman's excavations (Steadman et al., 1994); (c) Kon Tiki Museum excavations (Skjolsvold, 1994). Rats are found in large numbers in the early deposits and then decline, consistent with expectations of an initial phase of irruptive growth and persistence of a large population until forest resources declined.

5.1. Rethinking Rapa Nui's ecological catastrophe

By early historic times the deforestation of Rapa Nui was complete, or nearly complete. A dense forest of palm trees and more than 20 other woody tree and shrub species had mostly disappeared. Perhaps as many as six land birds, several

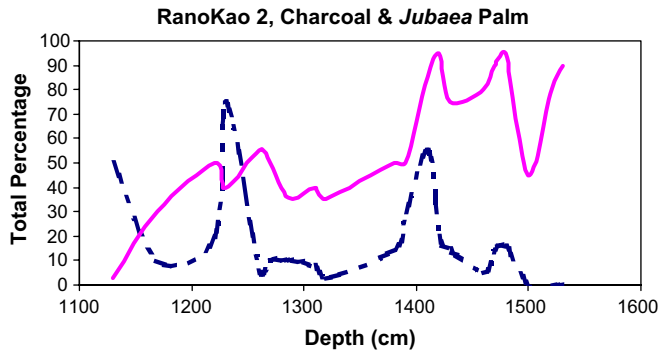


Fig. 13. Pollen (solid line) and charcoal particles (dashed lines) from Rano Kao (Core Kao-2). Data from Butler and Flenley (2001).

seabirds, and an unknown number of other native fauna were lost to extinction (Steadman et al., 1994). It seems likely that most of the biotic loss occurred before the final disastrous effects of thousands of grazing sheep in historic times (Fischer, 2005; Rainbird, 2002). Certainly from an ecological and biodiversity perspective, Rapa Nui experienced an environmental catastrophe. Flenley et al. (1991) suggested that the Pacific rat might have played a significant role. Nevertheless, many accounts and their popular derivations have gravitated to a narrative of human recklessness, over-exploitation, and over-population leading to demographic and cultural collapse (e.g., Diamond, 2005). These scholars speculate about the human motives in *cutting down the last tree*. However, the ecological impact—indeed the ultimate ecological catastrophe—undoubtedly was not as simple as the popular story implies.

Once rats arrived on Rapa Nui, probably in the first canoe(s) of Polynesian colonization, their numbers could irrupt and reach a population well over a million within just a few years. At this historic instance, rat predation of palm nuts, other seeds, bark, seedlings, etc., effectively halted the regeneration of Rapa Nui's forest. The *Jubaea* palm and other forest plants would have comprised the primary food for rats. Moreover, rat predation of *Jubaea* nuts probably effectively removed this resource from human consumption,⁵ suggesting that the palms never provided a primary food source to prehistoric people.

As shown in Table 1, the majority of extinct plants from Rapa Nui were highly vulnerable to impacts by rat predation. Most yielded relatively large edible fruits/seeds, lacked toxicity, and faced destruction rather than dispersal by rodent predation. Perhaps significantly, *Sophora toromiro* was one of the few native plants that survived into historic times. Field studies from New Zealand show that rats do not appear to

affect juvenile recruitment of a member of the same genus, *Sophora microphylla*. Indeed, through damage to the seed casings, rats may aid in the germination of these seeds (Campbell and Atkinson, 2002, p. 29). Does the survival of *S. toromiro* on Rapa Nui into historic times reflect its tolerance or even symbiotic relationship with rats? Research in field ecology may help to resolve this question.

Researchers who have adhered to a longer chronology for Rapa Nui must assume a remarkably slow human population growth rate (e.g., 1.0%) over several centuries in which Polynesian colonists (and their introduced rats) had virtually no impact on the island's ecology, assuring that they would remain archaeologically and ecologically invisible. A shorter chronology notwithstanding (Hunt and Lipo, 2006), a scenario of slow growth is unlikely among populations that likely succeeded as "supertramps" expanding their numbers over the vast Pacific in remarkably short bursts of time (Clark and Terrell, 1978; Diamond and Keegan, 1984; Kennett et al., 2006b). Birdsell's (1957) analysis of historically documented cases of small human colonizing events to remote, unoccupied islands has shown that growth rates exceeding 3.0% can occur for short periods of time. Indeed, rapid population growth would be critical to successful human colonization of remote islands. With even small numbers of initial colonists at a 3.0% growth rate, populations would rise dramatically and reach more than 2000 (a density of over 10 people per km² on Rapa Nui) in just over a century. Rapid population growth is consistent with late colonization as well as the timing of deforestation. Direct human impacts from felling and fire, as population grew, would lag behind the initial, but continuing, impact of rats. With the usual precision of palaeo-environmental research, the relative chronological impacts of rats and humans might appear to be one-and-the-same.

In cases such as the 'Ewa Plain, the records for decline of the forest and advent of local fires show a separation of centuries, reflecting the work of rats in advance of people settling this part of the island (Athens et al., 2002). In other sequences, the discernible demise of the forest and the rise of local fire are not separated by centuries, but perhaps only decades. Rapa Nui is likely a case of the latter, where early impacts may be separated by a short period of time, but not by proximity. The effects of rats could have persisted as human populations grew and brought increasing impacts with felling and the use of fire. Testing the role of rats as a major factor in the process of ecological change on Rapa Nui will require extraordinarily well documented palaeo-environmental records to distinguish timing, causes, and consequences. Such demanding research may reveal a more complex, synergy of forces in the ecological transformations of the island.

If rats could have played a major role in Rapa Nui's deforestation, how about other Pacific islands? The palaeo-environmental record from the Hawaiian Islands reveals that vast lowland areas were largely deforested over a short duration, in some cases (e.g., 'Ewa, O'ahu Island) prior to the direct human impacts of fire and felling. Rolett and Diamond (2004) have recently considered environmental correlates with pre-European deforestation on Pacific Islands. For Rapa Nui

⁵ *Rattus exulans* is an agile climber and, like *R. rattus*, consumes seeds and other reproductive parts while still high in trees. McCartney (1970, p. 1062) documented *R. exulans* nesting in the crowns of coconut trees, using palm fronds for "interconnecting arboreal runway systems," with only a portion of the population occupying habitats on the ground. This may be an appropriate analog for the *Jubaea* palms of Rapa Nui. If so, rats would have effectively won the competition for *Jubaea* nuts, making the nuts' contribution to the human diet minimal, even when the forest was at its peak.

Rolett and Diamond (2004, p. 445) correctly point to “extreme environmental fragility” as a major factor in the island’s deforestation. Rapa Nui’s extreme fragility is in part explained by the environmental factors they consider, including latitude, size, elevation, and precipitation. However, island biogeography may better explain the pattern Rolett and Diamond (2004) interpret for the Pacific by way of comparison. The persistence of forests west of the Andesite line, dividing continental and oceanic islands, may be less a function of dust fall or other environmental factors they propose. Instead, lower rates of deforestation in the southwestern Pacific may be explained by (1) generally lower human population densities controlled by the density-dependent nature of malaria infection over much of Melanesia; (2) on average larger islands with higher elevations provide forest refugia; and perhaps especially (3) a complex co-evolutionary history of diverse plants and animals, including native rodents and their predators. The co-evolution of plants and rodents, among other relationships, and the presence of predators in complex ecosystems, imply a minimal impact would result from the human dispersal of *Rattus exulans* to the continental islands of the western Pacific, or even the comparative biotic complexity of oceanic high islands of the central Pacific (e.g., Samoa, Tahiti). Biogeography also explains how island elevation, area, and isolation (distance) are auto-correlated, as continental islands are on average larger, higher, and less remote. Islands generally decrease in size (and elevation), as distances increase moving from west to east, from continental islands to the truly oceanic islands of the Pacific Plate. Remote, predominantly small, oceanic islands have biota dictated by biogeographic factors with lower taxonomic diversity at the family and generic levels, but commonly with higher rates of speciation. As a consequence, biogeography anticipates the environmental fragility of Rapa Nui and other small, remote oceanic islands, particularly to the impacts of an invasive species such as the rat.

The available palaeo-environmental record for Rapa Nui shows that deforestation occurred over about 400 years (ca. 1250–1650 AD), with remnants of forest lasting into historic times. This means that the human population increased even as forest resources declined with direct and indirect ecological impacts over 400–500 years. A maximum population, perhaps 3000–4000, could have been reached by about 1350–1370 AD (Fig. 14), following an early growth rate of 3.0% (Birdsell, 1957) and assuming growth stabilized at a relatively low number given the unpredictable and limited environmental carrying capacity of Rapa Nui. A maximum population would fluctuate slightly, but probably remained in close balance with the limitations of environmental uncertainty, particularly given the effects of rainfall shortages and damaging salt-laden winds on Polynesian cultigens (Hunt and Lipo, 2001).

Erosion of primary soils—although perhaps never very fertile (Ladefoged et al., 2005; Louwagie et al., 2006)—may have brought problems for cultivation (see Mieth and Bork, 2004, 2005). The effects of drought, wind, and soil erosion could have intensified as forest cover declined over 400–500 years. Perhaps as a consequence, even early Rapa Nui agriculture comprised managed soils and field systems using

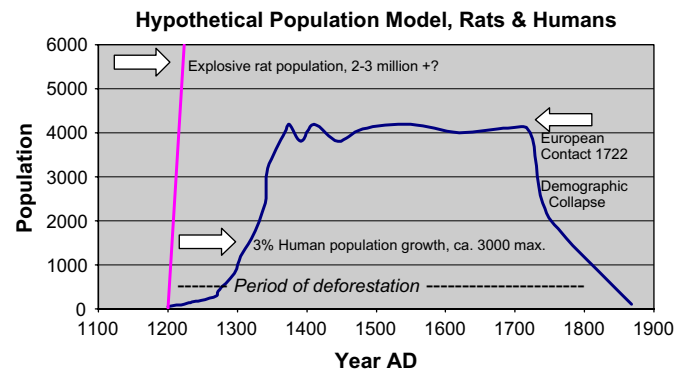


Fig. 14. A hypothetical model for (a) rat population irruption and ecological impacts, and (b) human population growth (3.0%, after Birdsell 1957), deforestation, and demographic collapse following European contacts. The model distinguishes “ecocide” from historic genocide.

stone mulch and enclosures (*manavai*) (e.g., Ayala-Bradford et al., 2005; Bork et al., 2004; Stevenson et al., 1999; Wozniak, 1999). As Stevenson et al. (1999, p. 811) hypothesize; stone mulch agricultural systems may date to as early as the 14th century.

Contrary to common claims, there exists no reliable evidence that the Rapa Nui population ever grew to a large, unsustainable maximum such as 15,000 or more (Diamond, 2005, p. 91), and then crashed as a consequence of deforestation (Peiser, 2005; Rainbird, 2002). Certainly, many dimensions of the island’s supposedly turbulent prehistory rest on little, if any, reliable evidence. The large population numbers (e.g., 6000–30,000) (Diamond, 2005, p. 90) often cited for prehistoric Rapa Nui are little more than speculation. Nonetheless, arguing a large pre-contact population (e.g., 15,000) in reference to reduced historic numbers (e.g., in 1864), some 200 years earlier, is critical to notions of “ecocide” (Diamond, 2005).

Despite repeated claims, Rapa Nui does not appear to represent a case of “ecocide.” The documented population collapse for Rapa Nui occurred as a consequence of European contacts, with Old World diseases and slave-trading (Peiser, 2005; Rainbird, 2002). As VanTilburg (1994, p. 164, *emphasis added*) noted, the scary parables and metaphors for disaster represent “a projection of Western values which emphasizes the self-destruction of the Rapa Nui culture over the *actual, near-annihilation* of it by contact with the West.” Indeed, early ethnographer Alfred Metraux described the historic genocide as “one of the most hideous atrocities committed by white men in the South Seas” and as “the catastrophe that wiped out Easter Island’s civilization” (Metraux, 1957, p. 38). Today the idea of “ecocide” enjoys popular acceptance, but an actual *genocide* decimated the native Rapa Nui population and its culture (Peiser, 2005; Rainbird, 2002). Unfortunately, the victims of cultural and physical extermination have been turned into the perpetrators of their own demise.

The model of “ecocide” was constructed in part on the foundations of faith in a long chronology, speculation about prehistoric population size, and a remarkable, but still somewhat coarse-grained palaeo-environmental record for the

island. Recent field research, including comparative case studies in places such as the Hawaiian Islands, have changed some perspectives and allowed us to raise questions about Rapa Nui's historical ecology. In this review I have examined archaeological, palaeo-environmental, and contemporary ecological evidence to suggest that the Pacific rat may have played a major role in Rapa Nui's ecological catastrophe. The fact that rats alone are capable of widespread forest destruction compels us to evaluate their contribution to the transformation of Rapa Nui, as well as in other island ecosystems. While I argue that the role of rats has often been underestimated, direct human actions of felling and use of fire likely have played a significant role as well. Additional research will be essential to disentangle the contributing factors. The environmental catastrophe of Rapa Nui is likely a complex history, one that has been masked by speculations about the intentions of people cutting down the last tree. Indeed, the "last tree" may simply have died. Rats may have simply eaten the last seeds. Perhaps the lessons of Rapa Nui tell of the effects of invasive species, invasional meltdowns, and the synergy of effects that ensue as people and their portmanteau biota reach evolutionary isolates in the remote islands of the Pacific.

As biological invasions and extinctions continue at unprecedented rates, deciphering ecological histories and the consequences of biological invasions has gained urgent significance. It is increasingly evident that invasions and extinctions predate and precondition modern ecosystems. Research in archaeology and palaeo-ecology is providing evidence of ecological impacts that may have few, if any, modern analogs. Lacking modern analogs, the dramatic ecological transformation of Rapa Nui is that much more difficult to imagine, but all the more important to fully comprehend.

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