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Chapter 8

The Human Transformation of Rapa Nui (Easter Island, Pacific Ocean)

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Abstract

Rapa Nui (Easter Island) has become widely known as a case study of human-induced environmental catastrophe resulting in cultural collapse. The island's alleged "ecocide" is offered as a cautionary tale of our own environmental recklessness. The actual archaeological and historical record for the island reveals that while biodiversity loss unfolded, the ancient Polynesians persisted and succeeded. Demographic "collapse" came with epidemics of Old World diseases introduced by European visitors. In this paper, we outline the process of prehistoric landscape transformation that took place on Rapa Nui. This process includes the role of humans using fire to remove forest and convert to land for agricultural use as well as the impact of introduced rats (*Rattus exulans*) as agents that depressed recruitment of native vegetation and contributed to the island's deforestation. For humans, the transformation of the landscape improved productivity. Burning of palms and other trees provided a short-term addition of nutrients to poor soils. Rock mulch and agricultural enclosures solved problems of cultivation and mitigated risk in an uncertain environment. The environmental transformation of Rapa Nui, while a tragedy in terms of biodiversity, was a success for a sustainable Polynesian subsistence economy.

Key Words: Rapa Nui, Easter Island, "ecocide," rats (*Rattus exulans*), invasive species, deforestation, rock mulch, agriculture, sustainability.

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Résumé

Rapa Nui (île de Pâques) est souvent citée comme un exemple de catastrophe écologique résultant d'une gestion insouciante des ressources suivie d'un effondrement culturel. Le terme « écocide » est utilisé pour qualifier cette attitude sociétale « insouciante » à l'égard des ressources environnementales, et suicidaire. Les données archéologiques et historiques de l'île de Pâques montrent que, malgré la perte de la biodiversité et le manque de ressources, les anciens Polynésiens ont persisté et réussi à maintenir une économie de subsistance sur Rapa Nui. L'effondrement démographique est venu avec les épidémies de l'Ancien Monde introduites par les navigateurs européens. Dans ce chapitre, nous décrivons le processus de déforestation et de transformation du paysage à partir des premiers contacts humains sur l'île de Pâques. Ce processus combine deux éléments fondamentaux ; l'utilisation du feu pour dégager des espaces de culture, et l'impact des rats introduits (*Rattus exulans*) jouant un rôle de déprédateurs sur le recrutement de la végétation indigène. Pour la société Pascuane, la transformation du paysage a amélioré la productivité agricole. La combustion des palmiers et des arbres indigènes, a fourni une addition à court terme de nutriments aux sols pauvres. L'utilisation de paillis agricoles et les enceintes de pierres sèches ont apporté des solutions aux problèmes des cultures (*e.g.* manque de précipitation, vent, pauvreté des sols) et atténué les risques climatiques dans un environnement difficile. Alors même que s'opérait la disparition de la biodiversité native, la transformation des paysages de Rapa Nui a été un succès pour une économie de subsistance polynésienne durable.

Mots-clés : Rapa Nui, île de Pâques, écocide, rats (*Rattus exulans*), espèces invasives, déforestation, agriculture, durabilité des ressources.

1. Introduction

Rapa Nui (Easter Island) has become a widely cited example of what happens when human populations grow too large, overexploit their critical resources, and destroy their environment. In his book *Collapse,* Jared Diamond describes an ecological catastrophe induced by the island's prehistoric population that led to their own destruction. Diamond (2005) calls it "ecocide," fueled largely by irrational choices to make and transport giant statues and resulting in the island's ecological devastation and the collapse of the ancient population and culture. He and other researchers (*e.g.* Flenley and Bahn 2002) offer the ecocide story as a warning for today's potential destruction of the global environment. In this paper we offer some perspectives for the island's ecological transformation by humans and the consequences.

Our archaeological research on Rapa Nui has demonstrated a much later settlement for the island than previously recognized, calling into question important aspects of its ecological history (Hunt 2007; Hunt and Lipo 2006). The palaeo-environmental and archaeological evidence reveals a complex history of ecological change for the island, with a variety of impacts that occurred in tandem. This history does not support the notion of "ecocide" where reckless Polynesians overpopulated and overexploited their environment. Here it is essential to disentangle environmental changes on Rapa Nui from a demographic collapse that resulted from European contact. European contact brought Old World diseases and slave trading, among other abuses. Contrary to today's "ecocide" popular narratives, ancient deforestation was *not* the cause of demographic or cultural collapse. Instead, the tragedy of Rapa Nui was not ecocide, but near-genocide following European contact and resulting from it.

Rapa Nui is small (164 km^2) and isolated in the remote southeastern Pacific (Fig. 1). Rapa Nui's nearest neighbors of Pitcairn, Ducie, and Henderson (ca. 2,000 km distance) are small, remote, and relatively impoverished. Voyaging from the central islands of eastern Polynesia under normal conditions would have gone against the prevailing trade winds, making traveling distances even greater, although westerly winds induced by periodic *El Niño* conditions (Larrue 2010; Wright *et al.* 2000) may have enabled Polynesians to voyage downwind to the island (Orliac and Orliac 1988). In any case, Rapa Nui formed a tiny target in the vast, empty southeastern Pacific.

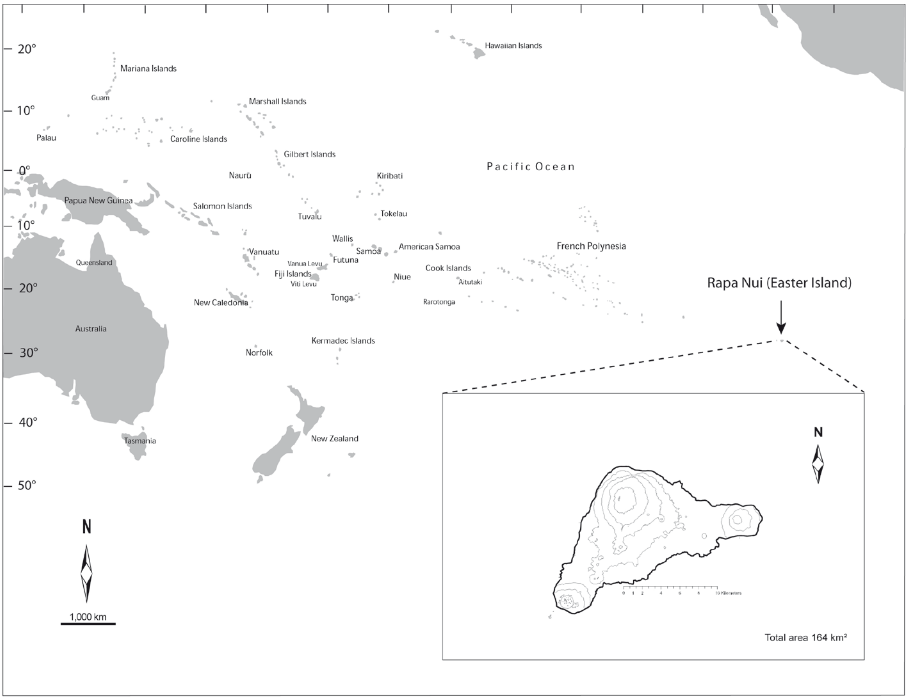

Figure 1. Study site. Rapa Nui (Easter Island), southeastern Pacific Ocean

Rapa Nui is limited in biodiversity, reflecting its young geological age, small size, and great isolation. The island's biodiversity now also reflects its significant losses in recent ecological (*i.e.* human) history. Concerning the island's biology, C. Skottsberg (1956) wrote that:

> ...there is in the Pacific Ocean no island of the size, geology and altitude of Easter Island with such an extremely poor flora … nor is there an island as isolated as this … [T]he conclusion [is] that poverty is a result of isolation – even if man is responsible for disappearance of part of the flora, [it] cannot have been rich.

Only about 48 reported plants are known for Rapa Nui. This list includes 14 Polynesian introductions such as taro, sweet potato, and the other cultigens (*i.e.* human domesticated plants). However, recent lake-core studies of pollen and identifications of wood charcoal from prehistoric earth-ovens expand the inventory of other woody plants that once covered Rapa Nui (Orliac 2000).

The island has few, if any, indigenous terrestrial vertebrates. Two lizard species may be native to the island, but this remains uncertain. The only land birds found on the island today are recent introductions, but archaeological discoveries show that the island once supported 25 species of seabirds and on present evidence perhaps as many as six land bird species (Steadman 2006). A few seabirds survive today, but the original land birds became extinct. Since extensive reefs are lacking, the marine resources are relatively poor, especially when compared to most other islands of the Pacific. Sea mammals, sea turtles, and record of seals are known from Rapa Nui. On present archaeological evidence, the only known animals introduced by Polynesians were rats (*Rattus exulans*) and chickens.

In contrast to much of Polynesia, Rapa Nui presented a challenging environment to Polynesian colonists. The island has no permanent streams. At 27° South, just beyond the tropics, cultivation of Polynesian food crops such as coconut and breadfruit was marginal, if not impossible. Rainfall (ca. 1,250 mm annually) fluctuates seasonally and on longer time scales, creating some unpredictability. Based on historic and some palaeo-ecological data (Mann *et al.* 2008), serious droughts may have occurred periodically. The island also frequently receives strong winds carrying salt spray that can damage Polynesian food crops. Finally, the island has excessively drained, nutrient poor soils marginal for sustained cultivation (Louwagie *et al.* 2006). These conditions meant that Rapa Nui presented constraints on Polynesian agriculture unlike most other islands. In short, droughts, strong winds, poor soil, and no permanent streams posed problems for prehistoric agriculture on Rapa Nui.

2. The ecological parable

Speculations of ecological catastrophe with an ensuing cultural collapse on Rapa Nui began in the 18th Century. From a single day's visit in April 1786, French explorer La Pérouse speculated that at some time in the past the island's inhabitants had carelessly cut down all the trees. La Pérouse (1799: 318–319) wrote that loss of the forest "has exposed their soil to the burning ardor of the sun, and has deprived them of ravines, brooks, and springs. They were ignorant that in these small islands, in the midst of an immense ocean, the coolness of the earth covered with trees can alone detain and condense the clouds, and by that means keep up an almost continual rain upon the mountains, which descends in springs and brooks to the different quarters. The islands which are deprived of this advantage, are reduced to the most dreadful aridity, which, gradually destroying the plants and scrubs, renders them almost uninhabitable. Mr. de Langle as well as myself had no doubt that this people were indebted to the imprudence of their ancestors for their present unfortunate situation."

This idea of the "imprudence of their ancestors" is today promulgated by Jared Diamond (1995:63, 2005) as an urgent warning for our present global environmental problems: "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. Are we about to follow their lead?" Diamond (1995:68) continues:

> 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?"

In sum, Diamond (2005:118) asserts that Rapa Nui is "the clearest example of a society that destroyed itself by overexploiting its own resources" and that the consequences of deforestation "start with starvation, a population crash, and a descent into cannibalism."

In accord with Diamond, some archaeologists (*e.g*. Van Tilburg and Ralston 2005) have argued that carving and especially transport of the giant statues (called "*moai"*) led the islanders to deplete their own natural resources (*e.g*. palm trunks for statue rollers) and then fell into a downward spiral induced by environmental destruction (*e.g*. Kirch 1984, 2000). In other words, people willingly destroyed their island and, in turn, destroyed themselves, thus committing "ecocide."

Did human recklessness, overexploitation, and overpopulation lead to deforestation and ecological catastrophe? Did a collapse of ancient population and culture result from an ecological catastrophe before European contact in A.D. 1722?

3. The ecological evidence

3.1 Early European Visitors

The earliest European visitors recorded few details about Rapa Nui's environment, and the earliest accounts are contradictory. The Dutch expedition led by Jacob Roggeveen in 1722, expecting to relocate a "low and sandy island" sighted earlier by Captain William Dampier, reported:

> 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.

But following their visit to the island, Roggeveen (Ruiz-Tagle 2005:23-24) wrote:

> 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.

3.2 Deforestation

Some of the first clear evidence for the details of deforestation on Rapa Nui came from pollen studies by John Flenley and his colleagues (Flenley *et al.* 1991; Dransfield *et al.* 1984). Sediments cores from the lake floor of Rano Kao provided pollen evidence for an abundance of giant palms similar in size and form to the native of mainland Chile, *Jubaea chilensis* (Photo 1). The pollen evidence shows the classic evidence of deforestation, palms and other woody taxa replaced with grassland. Dating the dramatic vegetation changes, including how fast deforestation proceeded, has been highly problematic (Butler *et al.* 2004). However, careful fieldwork by Daniel Mann (Mann *et al.* 2008) and his colleagues, Andreas Mieth (Mieth and Bork 2004, 2005) and his team from Germany, and French researchers led by Catherine Orliac (2000) and our own excavations (Hunt and Lipo 2006; Hunt 2007) have shown that the forest disappeared over a period of approximately 400 years, from about A.D. 1250 to 1650. The presence of the palm trees in particular are represented by carbonized or otherwise preserved nuts recovered from a variety of contexts. Most of these palm nuts were gnawed by the rats introduced when humans colonized the island. This clear association of radiocarbon-dated palm nuts with humans and rats provides a sound chronology for the forest and its subsequent decline and disappearance (see Hunt 2007). From accounts of what early visitors reported, some native forest may have survived until the late 18th and even 19th centuries.

Photograph 1. Mature *Jubaea chilensis* palms growing in their natural habitat at La Campaña, mainland Chile

Until recent research (Hunt and Lipo 2006, 2008; Wilmshurst *et al.* 2011), most archaeologists believed that Rapa Nui was first colonized as early as ca. A.D. 400, or a few centuries later, about A.D. 700-800 (*e.g.* see Kirch 2000). Yet with the first signs of human impacts on the forest only *after* A.D. 1250, researchers postulated an early, largely if not completely invisible, human presence on the island. This "invisible settlement" would imply that agriculturalists practiced an ecologically sustainable economy, indeed one preserving pristine biodiversity and thus its postulated invisibility. In this unlikely scenario, a small founding population with a remarkably slow population growth had few, if any, visible or measurable ecological impacts. Indeed, Polynesian colonizers on Rapa Nui, in this narrative, would have remained archaeologically and environmentally invisible for many centuries. Thus, some scholars imagined an early period in which islanders sustained agriculture with no ecological or other impacts, but then followed with a period of comparatively severe impacts, including near to total deforestation. The shorter chronology now established for the island (Hunt and Lipo 2006), and for East Polynesia overall (Wilmshurst *et al.* 2011), now reveals that no such invisible to visible transition ever occurred, nor would such a record be tenable in light of what we know about ecology and human colonization generally.

Multiple lines of evidence from archaeological and palaeo-environmental research on Rapa Nui show once Polynesian migrants landed on Rapa Nui, their presence brought immediate impacts to the environment. These impacts are recorded--and visible—in the archaeological and environmental records. Our excavations in the deep, stratified sand dune at Anakena Beach, with multiple radiocarbon dates, provide a chronology beginning about A.D. 1200 (Hunt and Lipo 2006). Our earliest radiocarbon dates come from samples retrieved from the deepest layers of our excavation containing artifacts, charcoal, and bones found directly above the undisturbed clay deposits riddled with the root molds of palms growing when people first arrived. These layers at Anakena also yield the bones from the first introduction of the Polynesian rat, as well as food remains, including sea mammals, birds, and fish (Hunt 2007).

The later dates now established for first colonization fit well with the chronology for initial human impacts and deforestation beginning soon after A.D. 1200. If people arrived centuries before the first signs of regular fires and changes in the vegetation, then one must assume that human and rat population growth was incredibly slow and had no visible presence or impact for 400 to 800 years. Perhaps people could have survived with exceedingly small populations with low growth rates, but it is difficult to argue that rats feeding on nuts from millions of palms would limit their numbers and leave the island's vegetation untouched.

As is the case for Rapa Nui, the careful scrutiny of existing radiocarbon chronologies and "re-dating" of the oldest deposits on other islands across Polynesia have consistently shifted island colonization centuries later than researchers had originally thought. The mistakenly long chronologies in places such as Hawai'i, the Marquesas (French Polynesia), Cook Islands, and New Zealand have now been corrected with better research and more careful use of radiocarbon dating (see Wilmshurst *et al.* 2011). Recent research has shown that the earliest dates for the eastern Pacific are from the Society Islands (French Polynesia), first discovered and settled around A.D. 1050-1100, then the remaining archipelagos of the remote and eastern Pacific (*e.g.* the Cooks, Marquesas, Hawai'i, Rapa Nui, and New Zealand) were colonized rapidly in the 13th Century, between A.D. 1200-1290 (Wilmshurst *et al*. 2008; Wilmshurst *et al*. 2011; Rieth *et al.* 2011). Thus, an approximate A.D. 1200 colonization date for Rapa Nui fits well within the broad pattern for the settlement of eastern and remote Polynesia.

3.3 Hawaiian Research

Archaeological and palaeo-environmental field research from the ʻEwa Plain on southwestern Oʻahu Island provides findings relevant to our understanding of the deforestation of Rapa Nui (Athens *et al*. 2002, Athens 2010). From extensive archaeological excavations and analysis of lake-core sediment pollen and charcoal, J. S. Athens and his colleagues discovered that before arrival of Polynesians, the lowlands of Oʻahu (and other Hawaiian Islands) were covered in a forest of relatively small native palm trees (*Pritchardia* sp. see Photo 2). By ca. A.D. 1200 the Hawaiian palm forests began to disappear rapidly. Over a very short time, perhaps only decades, the forest crashed precipitously, as reflected in lake-core pollen sequences. Whereas many archaeologists blamed Polynesians recklessly using fire to clear land for agriculture, the `Ewa Plain evidence revealed that the palms on the `Ewa Plain and in other lowland portions of the Hawaiian Islands were lost in the absence of local fires. In the same area excavations by Athens and his colleagues (2002) in several limestone sinkholes (excellent sediment traps that capture local environmental changes) showed that also soon after A.D. 1200 the introduced Polynesian rat was exploding in population. At the same time native birds suffered dramatic decline, with several species lost to extinction. In the local lake-core sediments from nearby Ordy Pond (Island of O'ahu), where the palm pollen witnesses the fate of the native forest, charcoal particles from local fires make their first appearance, but only *after* the native forest had nearly completely vanished. Similar evidence of forest loss in the absence of fire emerged from other parts of O'ahu (see Athens 2010). The stunning conclusion: fires had not destroyed the palm forests in the lowlands of O'ahu Island.

Athens' (Athens *et al.* 2002) research on the ʻEwa Plain had also shown that Polynesians had not cleared forest (*i.e*. without fire) for agricultural purposes. By the time Hawaiians settled this dry and relatively marginal part of the island, it had already lost most of its native forest and witnessed major ecological changes. The demise of the forest meant loss of habitat for many birds and other native species. Their rapid extinction resulted.

Research elsewhere in the Hawaiian Islands records a similar pattern. From ʻOhiʻapilo Pond on Molokaʻi (see Denham *et al.* 1999), sediment cores show that pollen from the native palms declined sharply, but charcoal from local fires appears later. The timing was similar; the palms vanished around 800 years ago, but fire was not the cause.

Athens (Athens *et al.* 2002; Athens 2010) hypothesized that the introduced Pacific rat, *Rattus exulans*, was an immediate and serious destructive agent that played a significant role in the rapid loss of the native lowland forest. Rats arrived on the first canoes of colonizers in the Hawaiian Islands and encountered few, if any effective predators or competition from native birds for plant foods. The Pacific rat is an agile climber sometimes described as arboreal. Field ecologists report thousands of rats living in the coconut tree canopies of Pacific atolls where they move on palm frond runways from tree to tree. Unlike birds, rats have teeth and consume hard, thick seed cases, and they destroy the reproductive potential of many of the seeds they consume, governed largely by their size or other dispersal characteristics. As rats devoured the seeds of the next generation of native plants, forest recruitment was depressed. Rats were the first invasive species in the fragile islands of the remote Pacific, and their impact can be devastating.

Photograph 2. *Pritchardia* sp. palms growing at the National Tropical Botanical Garden, Kaua`i Island, Hawaiian Islands

If rats played a significant role in lowland deforestation in the Hawaiian Islands, we can predict patterns in today's vegetation: First, in islands free of rats both now and in the past, native forest should survive despite other potential impacts. This is the case for Nihoa Island in the northwestern Hawaiian chain. This small island is free of rats and probably never had them. Dense stands of the endemic palm, *Pritchardia remota*, persist on Nihoa despite intensive Hawaiian occupation in prehistoric times, the extensive use of fire, and agricultural plots that were cultivated over much of the island.

A second expectation in the Hawaiian Islands is that native forests are more common at higher elevations (above ca. 1,500 meters). This coincides with the range for the Pacific rat, which appears to be limited by adequate fruit-producing trees at higher elevations. The native forests we find today in the higher elevations of Hawaiʻi may owe their survival to the lowland preference of the Pacific rat. The relationship between rats and changes in vegetation is not a simple one. Islands vary by biogeography, ecology, and history, and so will the impacts of invasive species such as rats.

3.4 Rats and Rapa Nui

The palaeo-environmental record for Rapa Nui reveals ancient vegetation once dominated by millions of *Jubaea*[3] palm trees. The pollen record shows that the palms have been established on the island for millennia (dating to at least 37,000 years), and they survived and adapted to significant climate changes and natural catastrophes such as droughts. Other woody plants now extinct or present only in small numbers on Rapa Nui were similar to the kinds of vegetation found on Pacific islands to the west (Orliac 2000). Rapa Nui's native biota reflects a classic case of island biogeography where the forces of evolution in isolation produce a relatively simple community, a small number of plants and animals, and unique adaptations. Together these features make island ecosystems especially vulnerable to alien invasions, as ecologists working in the region know all too well.

Polynesian colonists introduced rats accidentally or intentionally, but the consequences would be the same: rats reached an island with no native predators and an essentially unlimited high-quality food supply provided by millions of palm trees. Under these ideal conditions rats could and did reproduce at staggering rates, capable of doubling their numbers every 47 days. Such rapid rates of reproduction would enable an explosion typical of invasive species, particularly with a vast food supply and few if any predators.

We routinely see these kinds of explosions-- irruptions--when rats enjoy an abundance of resources. At a latitude similar to Rapa Nui, but with a lower abundance of food resources, Kure Atoll (28°24°N) in the northwest Hawaiian Islands supports Polynesian rat densities averaging 45 per acre, with maximum recorded densities reaching 75 (Wirtz 1972). At a minimal estimate of only 45 rats per acre, Rapa Nui would have had a rat population over 1.9 million. At 75 per acre, a reasonable density given the palm nuts and other forest resources, the rat population of Rapa Nui could have reached more than 3.1 million. Such documented population growth rates and rat densities on Pacific islands suggest that Rapa Nui could have easily supported a huge number of rats soon after people first arrived. An initial peak rat population would be sustained until resources diminished and rat numbers fell, following a boom and bust pattern typical of invasive species.

If rats decimated the *Pritchardia* palm forest on the ʻEwa Plain of Oʻahu and by extension the lowlands of the Hawaiian Islands, then this provides a likely ecological parallel for Rapa Nui. The Hawaiian research demonstrates that rats were capable of rapidly transforming large lowland coastal areas. Rats, once introduced to Rapa Nui, would certainly have had a profound impact on the island's forest that was dominated by the nut-bearing *Jubaea* palms. Similar to the impacts on *Pritchardia* palms of Hawaiʻi, rats consumed *Jubaea* palm nuts and seedlings, greatly inhibiting forest recruitment. Indeed, hundreds of palm nuts preserved in caves around the island show the unambiguous signs of rat gnawing and seed destruction. Even if a relatively

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[3] Dransfield *et al*. (1984) proposed a new genus and species (*Paschalococos disperta*) for the now extinct palm of Rapa Nui, while many others (*e.g*. Grau 2001) maintain use of *Jubaea chilensis* or simply *Jubaea* sp. based on similarities with the extant palms on the Chilean mainland. In the absence of any further definitive evidence, we simply use *Jubaea*, while acknowledging that the taxonomy remains to be more fully resolved.

small percentage of all nuts were eaten by rats, the rate of new plant recruitment would be significantly slower as the pool of potential viable nuts for trees succeeding existing ones was reduced. The older established palms and other forest plants provided plenty of food for rats, but ultimately and systematically fewer new seedlings would sprout and survive. Even without imagining the effects of human activity, one can see how eventually the oldest trees would die and the forest would be substantially reduced as younger trees could not sustain replacement. Unlike areas in Hawai'i, where palms grow in areas beyond the habitat of rats--*i.e.*, higher elevations and small off shore islands--no place on Rapa Nui would have provided a refuge for the palms. Lacking effective predators, rat populations would expand to exploit every tree on the island that was capable of producing nuts. Rat population size was probably closely tied to the prevalence of the palms, as we see in many ecological studies. Significantly, *Jubaea* palms, as known from mainland populations, are slow growing and likely would have taken many decades to produce fruit. With rats also eating new seedlings, the impact to palms would have been unmistakable (*e.g*. modern ecological parallels are documented on Lord Howe Island, see Auld *et al.* 2010). Thus it is not a question of whether rats had an impact on Rapa Nui's ecology, but rather a question of their relative role in tandem with the direct actions of the prehistoric islanders.

3.5 Human Cultivation Practices

From a predator-prey perspective, since rats were largely dependent upon palm nuts for food, it is unlikely that they could have caused the palms' extinction entirely on their own. Introduced cultigens and other native plants provided food sources for rats, but by-and-large we can postulate that their populations relied primarily on the abundance of palms. As palm numbers declined over time, so would the rats, though we would expect their diet breadth to increase. Lacking other unrelated effects we might expect that the rats and palms would have potentially reached an equilibrium that would persist today. However, this did not happen: *Jubaea* palms are now extinct on Rapa Nui.

To explain the complete extinction of *Jubaea* palms from Rapa Nui we must also consider the direct role humans played in their demise. Many giant palms were also undoubtedly lost to fire as people cleared land for agriculture. From the perspective of ancient islanders, therefore, *Jubaea* palms provided only marginal economic or subsistence returns on a continuous basis. The palm nuts could not be a major source of food since rat infestations would sharply limit the ability of humans to exploit them. Rats would effectively compete with humans for palm nuts. In addition, the existence of palms provided a habitat ideally suited for Polynesian rats, as they are arboreal, well adapted to living in the palm canopy. Palm trees are also not useful as sources of wood for canoes as their interior is soft and spongy with a brittle bark exterior. Nor are they appropriate for timbers for either statue moving (see Lipo *et al.* 2012) or house construction. While palms could provide some nuts, sap, and "palm hearts," the slow growing tree would not be of great value and remain vulnerable to rat predation. In this way, the palm forests provided little direct return for humans and ultimately supported large rat populations that would potentially also consume crops necessary for human survival.

Lacking substantial near-shore marine resources, people on Rapa Nui were primarily reliant upon cultivated plants. These plants consisted of a suite of cultigens, but the moisture conditions favored the growth of sweet potato and to a lesser extent, taro. Given the nutrient-poor status of the island's soils, we argue that successful cultivation of sweet potatoes *required* removal of the palm forest. Indeed, initially the burned organic material from palm trees could have provided a necessary and temporarily abundant source of nutrients in which to cultivate food crops. Thus, with each tree cut down, more areas became available for sweet potato and taro cultivation, and less habitat was available to *Rattus exulans*. In this way, the decimation of the palm forest was by no means an ecological disaster, at least not for humans. Instead, its incremental loss and ultimately elimination *increased* the productivity of the island for humans. Contrary to the "ecocide" story, environmental carrying capacity was raised, not lowered.

"Slash and burn" cultivation practices are not unusual. Slash and burn strategies increase the productivity of soil by releasing nutrients stored in trees and changing soil pH to make nutrients (such as phosphorous) available for plants. Forms of slash and burn have been used in nearly every forested environment including places such as northern Europe, the Amazon rainforest, Indonesia, and prehistoric North America. The strategy requires populations to move from place to place, as the gain in soil productivity is only temporary, short-term. When populations are able to expand into new unburned areas or rotate fields over long durations, slash and burn strategies can be sustained over the long run. Often groups follow a long-term rotation of land uses return to areas only after trees have regenerated. The timing of the movement from one area depends on the rate at which trees regenerate and the rate nutrients are removed from the soil through plant growth or leaching by rainwater.

On Rapa Nui, neither expansion to new forested areas nor long-term rounds were possible. First, the island is small and it would not take long for the entire island to be burned. Second, the trees simply did not re-grow. With slow growing palm trees and rats eating available nuts and seedlings, the trees were unable to regenerate sufficiently. Consequently, the natural vegetation was converted to agriculturally productive fields with a short burst of nutrients released from burning and then to alternative, longer-term forms of cultivation made possible through rock walled gardens and lithic mulch (Hunt and Lipo 2011; see also Ladefoged *et al.* 2010, Photos 3-4).

Lithic mulch is particularly important on Rapa Nui since the soils of the island are nutrient poor and fundamentally unproductive (Louwagie *et al.* 2006). While volcanic in origin and thus potentially rich in minerals, the soils are highly weathered due to their age. As volcanic soils weather they release abundant nutrient minerals, particularly nitrogen (N), phosphorus (P) and potassium (K) but also calcium (Ca), magnesium (Mg) and sulfur (S). These minerals are essential for plant growth.

Generally, when volcanic ash and rock first weathers into material that is suitable for plant life, it contains adequate N, P, and K. Over time, however, the availability of these minerals declines with leaching and use by plants. Consequently, while young volcanic islands are some of the most biologically productive places on earth, islands with old volcanoes can be biological deserts, even with adequate rainfall. Abundant rain can even exacerbate the situation as the greater the amount of rainfall, the quicker mineral nutrients are 'flushed' from the soil. For this reason, even desert soils can be more productive than volcanic soils simply due to the lack of rain and its leaching effects.

Photograph 3. Prehistoric rock mulch gardens, northwest Rapa Nui

Photograph 4. Prehistoric rock mulch gardens, northwest Rapa Nui, with healthy taro (*Colocasia esculenta*)

In the case of Rapa Nui, millennia of rainfall have depleted the soils of their nutrients. The island, therefore, has been a poor place in which to make a living as a farmer. It was poor long before people arrived in A.D. 1200. It is still a poor place to grow food.

On Rapa Nui then, the loss of trees played little if any role in decreasing the productivity of the island since the soils did not become less fertile overall through deforestation. In fact, it was *only* the action of humans that made it feasible to reliably grow the primary food crop – sweet potatoes – on Rapa Nui. And the way this was done was as ingenious as it was labor intensive.

Lithic mulch increases productivity in three ways. First, the placement of rocks, particularly broken, smaller ones, increases the productivity of the soil by exposing fresh, unweathered surfaces and thus mineral nutrients that are within the rock. Often the rocks are placed not only on the surface, but also directly in the subsurface to directly introduce new sources of minerals into the soil. This form of stone mulching is a hidden, yet vital part of the subsistence practices on prehistoric Rapa Nui. Second, surface rocks protect plants by generating more turbulent airflow over the garden surface. This results in a reduction of the highest daytime temperatures and an increase in the lowest nighttime temperatures (see Hunt and Lipo 2011). The reduction in diurnal temperature swings produces a healthier growing environment for plants than areas with more dramatic day to night temperature differences. In addition, the disrupted airflow also limits the amount of wind that can desiccate foliage.

This effect is similar to the benefits afforded to plants by the walls comprising *manavai* (Photo 5). *Manavai* are relatively small, usually circular, rock lined enclosures that are ethno-historically identified as features for cultivation. *Manavai* were used for propagating staple crops like bananas, taro, sugarcane, as well as paper mulberry, used to make *tapa* or bark cloth. *Manavai* provide a productive and stable environment for plant growth since organic material was added to the area within the rock walls to provide a discrete and cumulative location for dumping household debris, ash, organic material, and other substances that will increase soil nutrients for plant growth. In addition, the enclosing walls of these structures protect plants from winds and, as a result minimize desiccation and thus maximize available water. This provides specific benefits to large leafy plants such as banana that would otherwise suffer in the nearly constant wind of Rapa Nui. In addition, the *manavai* are commonly constructed partially below ground surface, which has the potential to concentrate water as well as reduce diurnal temperature variation.

As we have outlined, the loss of the palm forest actually meant increased productivity of the island for humans. The archaeological record documents this change – forest loss begins soon after A.D. 1200 and takes centuries to complete. The transition from the natural to agricultural environment is relatively slow as cultivators converted land from forest to walled-gardens (*manavai*) and lithic-mulch enhanced fields.

The combined actions of rat preying on native seeds and human clearing land eventually resulted in near-to-complete deforestation. But unlike the scenario described by those who propose "ecocide," we see forest loss creating a habitat most productive for human subsistence. In addition, evidence for statue transport now clearly shows that palms or other trees were not employed as Diamond and others (*e.g*. Van Tilburg and Ralston 2006) have argued (see Lipo *et al.* 2012).

Photograph 5. A stone-wall agricultural enclosure (called "*manavai*"), northwest Rapa Nui

4. Rethinking Rapa Nui's Ecological Catastrophe

By the late 18th Century, when European visits to the island increased, it seems the deforestation of Rapa Nui was complete, or nearly complete. A forest of millions of palm trees and more than 20 other woody trees and shrubs had all but disappeared. Perhaps six species of land birds, several seabirds, and an unknown number of other native species had become extinct. Much of this loss occurred before the final devastating blow of the European introduction of thousands of grazing sheep in the late nineteenth century. Certainly from an ecological and biodiversity perspective, Rapa Nui has experienced an environmental catastrophe.

Once rats arrived on Rapa Nui their numbers exploded and reached a population of millions within just a few years. At this historic instance, rat consumption of palm nuts, other seeds, and seedlings dramatically depressed forest regeneration. Nearly all the plants lost to extinction on Rapa Nui were on the menu as the favorite foods of rats (see Hunt 2007: table 1). The exception is revealing: *Sophora toromiro*, a native woody shrub, was one of the few plants that survived into historic times. Field studies of related plants from New Zealand show that rats damage the seed casings, but in this instance such damage appears to encourage seed germination (Campbell and Atkinson 2002). Rats inadvertently help disperse the plant, rather than destroy its chances for reproduction.

As we have outlined, the evidence for Rapa Nui shows that deforestation took at least 400 years (from about A.D. 1250 to 1650). This means that the number of people grew while forest resources declined over 400 to 500 years. A maximum population for Rapa Nui, growing from an initial colonization of about 50 individuals, was perhaps 3,000 by about A.D. 1350-1370. This maximum population would fluctuate slightly, but probably remained in close balance with the island's resources and the inevitable uncertainties, given the hardships of Rapa Nui presented.

Conclusion

There is no evidence that Rapa Nui population ever grew to a large, unsustainable maximum such as 15,000 or more (Diamond 2005: 90-91) and then crashed from deforestation and resource loss. The large population numbers, 15,000 or even 30,000, often cited for prehistoric Rapa Nui are baseless. They have been posited mainly to dramatize the putative "ecocide" in which populations plummeted. The first and only sign of sustained decline in the population, so vital to the "ecocide" thesis, came from A.D. 1750 to 1800, after the arrival of the first European visitors (see Hunt and Lipo 2009, 2011). On Rapa Nui, like so many other places in the New World and the Pacific, European germs decimated the native population that had only limited immunity to Old World diseases.

Whereas Rapa Nui suffered an ecological catastrophe, there is no evidence that the island represents a case of "ecocide" where a large population crashed from environmental ruin before Europeans arrived. Instead, the actual and documented population collapse began when European contacts inaugurated the real tragedy. As the ethnographer Alfred Metraux (1957:38) described it long ago, what happened on Rapa Nui was "one of the most hideous atrocities committed by white men in the South Seas" and it was "the catastrophe that wiped out Easter Island's civilization." As the idea of "ecocide" has gained currency, the victims of cultural and physical extermination have been turned into the perpetrators of their own demise.

Instead, on Rapa Nui, despite great challenges, Polynesians thrived in isolation for more than 500 years. We believe the real story here is one of human ingenuity and success on a most unlikely island.

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