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Rehearsing the Anthropocene in microcosm

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REHEARSING THE ANTHROPOCENE IN MICROCOSM

The palaeoenvironmental impacts of the Pacific rat (*Rattus exulans*) and other non-human species during island Neolithization

*Thomas P. Leppard*

Introduction: Anthropocene as present singular or past plural?

The Paris Agreement on climate change—signed on 22nd April 2016 by over 170 states and other entities—binds, in section 2(a), its ratifying parties to ‘*pursue efforts to limit the temperature increase to 1.5°C above pre-industrial levels*’ (already perhaps a vain hope; Huntingford and Mercado 2016). Yet, at the time of writing, only 22 countries have ratified the Agreement. Many of these ratifying parties are Pacific and Indian Ocean island nations facing existential threat in the face of climate-change-induced sea level rise. The plight of low-lying islands exemplifies and underscores the massive changes being wrought to the physical systems of the planet by the series of processes implied by the term ‘Anthropocene’ (Crutzen and Stoermer 2000). The relationship between islands, their environments, and the capacity of our species to radically alter the physical organization of the planet’s surface, peculiarly exemplary as it may be in the present, might, however, have a deeper antiquity. This chapter will consider what nuances a perspective offered by island archaeology may bring to our understanding of the Anthropocene. It also argues that—because of their singular environmental organization— islands have, throughout the late Quaternary, been unusually exposed to anthropogenic biophysical change in a manner which has salutary effects for a broader understanding of human ecodynamics.

The intention is not to critique the notion that our species is having effects on the organization of the planet that are unprecedented in scale or rapidity; this much is well documented (e.g., Barnosky *et al.* 2011; Corlett 2015; Helmus *et al.* 2014; Lewis and Maslin 2015; Waters *et al.* 2014, 2016; Young *et al.* 2016). Rather, two claims are made. First, that the Anthropocene should be understood not as a process driven solely by modern humans, but as a project in which many species working—unintentionally—in concert are implicated. Second, that, following Braje (2015, 2016; Braje and Erlandson 2013a, 2013b), the Anthropocene is not fully
unprecedented (also Ruddiman 2013). Rather, it comprises a series of related processes that have been rehearsed in microcosm across the world’s islands throughout the later Quaternary, rehearsals which may have been local but, collectively, represent the anthropogenic construction of island ecosystems on a global scale.

The Anthropocene is the subject of competing definitions, as scholars variously view the object of study through lenses provided by biology, atmospheric chemistry, geology, and so on (Braje 2015). Averaging these definitions, we could loosely characterize the Anthropocene as that period in which humans have affected not only their immediate biological environments but broader biophysical and physical systems, up to and including the organization of the geosphere (i.e., the combined lithosphere, pedosphere, hydrosphere, and atmosphere) alongside the biosphere (e.g., Waters et al. 2016; Young et al. 2016). Implicit in this approach is the assumption that prior Late Quaternary human interactions were (a) largely limited to direct biotic impacts (introduction/extinction) and (b) that these impacts did not pattern consequentially at a global scale. This fails to reflect both how transformative anthropic ecosystems can be (especially those ecologies which were assembled during Holocene processes of domestication; cf. Smith 2012; Zeder 2015 arguments), and how these transformations can affect the nature of not only biotic systems, but also the biophysical interface between these and physical systems.

To illustrate this series of biotic and biophysical transformations, the spread of the Near Oceanian Neolithic ‘package’ throughout Remote Oceania (Figure 3.1)—from a range of possible examples (Diamond and Bellwood 2003)—is considered, focusing to the point of exclusivity (as a means of highlighting the specifics of much broader processes) on the effects of the invasive Pacific Rat, *Rattus exulans* (Figure 3.2). While humans imposed trauma directly and indirectly on remote islands, so did co-traveler species such as *R. exulans*; the full range of impacts of humanity’s Neolithic co-conspirators has only rarely, however, been fully considered. The trauma associated with invasive and introduced Neolithic taxa was not limited

![Figure 3.1 Map of the Pacific Ocean showing most islands, island groups, and toponyms mentioned in the text.](image-url)
to biota but, mediated via biotic impacts, reverberated throughout biophysical systems (in particular pedological and hydrological organization) in a manner which parallels, on a reduced spatial scale, Anthropocene-type dynamics. The aim is to show that the difference between the Anthropocene and the Holocene is one best comprehended in terms of scale, rather than type, and that Anthropocene dynamics have been enacted in miniature as growing anthropic ecosystems collided with endemic types of organization during the Holocene. It is also underscored that the anthropic ecosystems which now dominate the planet are emergent outcomes of multi-species efforts.

**Neolithic packages as multi-component ecosystems**

Before turning to the data on how and in what terms bundles of species (intentionally or unintentionally corralled by humans) can drive biophysical change, it is important to be quite clear what these bundles—what Neolithic packages—are. We need to focus, not so much on their composition, but rather on how the interrelationships of their constituents have made these Holocene multi-species alliances such potent forces for change when arriving in new environments.

**Co-evolutionary trajectories in Neolithic packages**

It has become relatively commonplace to speak of Neolithic ‘packages’—bundles of functionally related species that, from centers of incipient domestication, were carried or transmitted across the planet (Çilingiroğlu 2005). Frequently, these multi-species agglomerations are conceived only in terms of those taxa which most consistently held the attention of human agropastoralists; species used as food, or for ‘secondary products’ (Sherratt 1981). Neolithic packages should be thought of more broadly, however, as sets of domesticates, commensals, parasites, and even diseases which traveled together and between which ecological webs formed (Boivin et al. 2016).

The co-opting of these diverse sets of species into anthropogenic ecologies—‘domestication’—implies a series of complex and interrelated processes, including artificial selection by humans for desirable traits in those species in which they have maintained keen interest (Zeder 2012, 2015; Fuller et al. 2010). Such selection, of course, has pleiotropic effects (e.g., paedomorphic traits in dogs; Morey 2010), but there are other unintentional or emergent aspects to domestication. We can assume that natural selection is also implicated in trajectories from ‘wild’ to ‘domesticated’ species; i.e., not all gene flow can be or is regulated artificially. (In general, we might imagine a spectrum occupied by those species more or less explicitly involved with trajectories of domestication; at one extreme, for those taxa in which humans have maintained intense interest in terms of morphology and behavior (e.g., *Bos*), artificial selection is the prime determinant of gene-flow; on the other extreme, for taxa in which humans have no such interest (e.g., *Mus*), natural selection the major determinant; and for species in between (e.g., *Felis catus*), both types of selection are important.) Other niches have been intentionally and inadvertently created in the construction of anthropic ecologies (Laland and O’Brien 2010, 2011; Rowley-Conwy and Layton 2011; Smith 2007, 2012), niches which have been occupied by taxa placed under peculiarly anthropogenic selective pressure which is nonetheless not artificial *sensu stricto*; most obviously commensal species, but also parasites, pests, and diseases, recognizing that these categories elide into one another at their fringes.

In the transition to domesticated ecosystems, the structure of these ecosystems (and of their interstitial forms) has exerted profound evolutionary pressure on passenger taxa. Throughout the Holocene, the emergence of agropastoral lifestyles across the planet has been a process of co-evolution, involving degrees of both artificial and natural selection within the adaptive
landscapes formed by emergent Neolithic societies. How have these evolutionary trajectories been constrained by and within these landscapes? Are there macro-evolutionary trends, moving these species in general or parallel adaptive directions within evolutionary space (McGhee 2007: 6–30)?

Humans are rapacious generalists. The history of the incrementally greater range of Homo across the planet can be understood in part as a function of changes in cognitive architecture allowing for greater behavioral plasticity, opening vistas onto diverse and mutable adaptations (Gamble 2013; Grove 2015; Rowley-Conwy and Layton 2011). These adaptations have allowed hominins to cross latitudinal or biogeographic barriers, culminating in the capacity of modern humans to reach (if not to colonize) the most isolated habitats on the planet. For the vast majority of the history of the genus, however, hominins existed within naturally assembled trophic structures. Such hunter-gatherer lifestyles are subject to spatial restrictions, especially in higher, seasonal latitudes, exposed to the unavoidable trophic logic of carrying capacity.

The feedback dynamics of domestication in the aftermath of the Last Glacial Maximum—reliance breeding reliance—drove the emergence of subsistence systems which have certain advantages over hunter-gatherer lifestyles in terms of reliably supporting large, sedentary populations in confined spaces. The essential element is multi-component generalism, allowing a plasticity in precisely how subsistence strategies are constructed which is hard to rival. The ability to tailor agropastoral subsistence to suit the demands of a given niche—to develop bespoke anthropic ecologies—has facilitated the expansion of agropastoralists into some of the least promising environments on the planet. The co-evolution of non-human domesticates and commensals alongside humans, then, as components of Neolithic ‘packages’, might be understood as overall selection towards increased or exacerbated generalism in these species. Ecological generalism in this sense is simply an increased capacity to tolerate variability—in temperature, seasonality, or prey-abundance—or other types of heterogeneity in environmental organization. Selection towards greater tolerance of variability is of course evident in those species exploited primarily for nutrition; for example, *Hordeum vulgare* or *Capra hircus* in the Old World, or *Zea mays* in the New World (recognizing of course that the association with humans of some of these species is pre-Neolithic; Morey 2010). We can assume that other taxonomic elements of Neolithic packages have also experienced selective pressure towards generalism, however, from companion and commensal species (e.g., *Canis familiaris*, *Mus musculus*) to pests and pathogens.

The repeated construction by humans of Neolithic niches to which these species are pre-adapted, and their ability to tolerate wide variability in these and other, less anthropogenic types of ecosystem, render these sets of companion species especially competitive. Previously insulated environments—and, in particular, remote islands—when exposed to these dynamic, interrelated, and anthropic ecological systems have suffered appalling consequences. To understand why and in what terms, we first need to consider the nature of isolated (specifically insular) biotas.¹

**Fragility in island ecosystems**

A key issue in resolving degree of impact of these bundles of species involves extent of ecological insulation. Main centers of domestication in both the Old and New Worlds were continental, or, in the case of the gradual assembly of the Near Oceanian Neolithic package, were located on large quasi-continental islands.² Parts of the planet with substantial ecogeographic barriers separating them from these centers were insulated from the new Neolithic ecosystems and from the selective pressures they exerted. This isolation rendered islands peculiarly exposed to rapid and extensive ecological transformation in the wake of Neolithic colonization.
Rehearsing the Anthropocene in microcosm

It is productive, in both archaeological and ecogeographic terms, to think of islands less as intrinsically isolated and more as fragments of habitat surrounded by radically, qualitatively different habitat (Terrell 1999). Insular dynamics can be found across the planet (e.g., forest fragments, or taiga fading into tundra; MacArthur and Wilson 1967; now Losos and Ricklefs 2010), but ‘true’ islands have the distinction that they are distributed across an intervening habitat type which is uniquely, aggressively hostile to most terrestrial taxa. Variables which structure ecological dynamics on islands include the size and organization of these habitat patches, and the degree to which they are separated from similar patches by intervening sea, as well as latitude, geology, and corresponding pedology and hydrology. These factors conspire to make island biotas remarkable in several respects.

Intervening inhospitable patches of habitat act as a filter for invasive species, and the greater the distance between terrestrial fragments, the more efficacious the filter, all other factors being equal (see Losos and Ricklefs 2010; Whittaker and Fernández-Palacios 2007). Essentially, ocean gaps limit gene flow; both preventing initial colonization by taxa, and then—after colonization—limiting gene flow between colonists and ancestral populations. The former effect results in highly skewed, disequilibrium island biotas, with taxa better adapted for overwater dispersal better represented at the expense of less well-adapted taxa. What makes a taxon a good overwater adapter varies (capacity for flight, low metabolic needs, and tolerance of brine all stand out), but in general this results in islands tending to be depauperate of mammals, of taxa with high energetic demands, of K-selected taxa, and so on (recognizing that these categories, for good reason, often overlap one another). The second effect means that even if a colonist is successful, gene flow between it and its source population is likely to be circumscribed. This can operate on extant founder-effects as an engine of allopatric speciation, driving insular endemism.

It is not only distance between habitat fragments that imposes structure on island biotas (and interlocked biophysical systems). There is a relationship between habitat size, degree of qualitative difference of surrounding habitat, and complexity of trophic structure; the positive correlation between size and trophic complexity is especially relevant to the current discussion (Brose et al. 2004). Islands, as habitats which tend to be small and highly distinct from neighboring patches, accordingly have reduced foodweb complexity; i.e., possess fewer trophic levels. Islands are, in short, hostile to higher-tier taxa, the very taxa which struggle most—because of morphology and energetic requirements—to colonize in the first instance.

The effects combine to produce island biotas that tend to be skewed in contrast to ‘mainland’ equivalents. Most famously, islands tend to be highly endemic and species-poor; that is, comparatively rich in endemic taxa, but comparatively poor in total taxa. Exaggerated endemism often subsequently drives increased overall levels of specialization and the emergence of rare localized niches. Specialization, and the paucity of higher-tier taxa, means that many anti-predator adaptations are lost. The odd gravitation of smaller taxa towards gigantism, and bigger taxa towards dwarfism/nanism, may in part be explained by this, but the phenomenon of anti-predator adaptation loss is evident more broadly at the behavioral level (insular ecological naïvete). This renders island biotas relatively fragile. Various aspects of the physical organization of environments are dependent on biotas, most notably soil composition and dynamics (in terms of nutrient cycling or slope stability) as well as hydrology. Accordingly, these biophysical systems—kept stable in part by their biological components—are, on islands, intrinsically more fragile than their continental equivalents.

What are the implications for the arrival of Neolithic packages in previously insulated ecologies? We can explore this in detail with respect to a given element of a given package multiple times over, but the overall implications are clear. The arrival of continental species—species which are the outcomes of overt selection towards generalism and tolerance
of variability—should be enormously disruptive. Island ecologies structured around endemics should be dangerously exposed to out-competition of their endemics by invasive Neolithic species, which should have concomitant effects on trophic neighbors. Precisely how pervasive these impacts might be, however, as well as their qualitative variety, are hard to grasp in the absence of specifics. More generally, it is not clear whether these impacts should be limited to the biosphere, or include the organization of systems which interface between the biosphere and the geosphere (i.e., the pedosphere and the hydrosphere); if the latter, are there implications for how we understand the qualitatively distinct aspect of current human impacts on biophysical systems? Consequently, it is instructive to consider now in detail one particular example of inadvertent introduction of an invasive species as part of a wider multispecies package; in this case, the prehistoric introduction of the Pacific Rat, *Rattus exulans*, to Remote Oceania.

**Palaeoenvironmental transformations in the Pacific Islands**

‘In your case,’ said O’Brien, ‘the worst thing in the world happens to be rats.’

*George Orwell*, *Nineteen Eighty-Four* (1949)

**The Pacific Rat (Rattus exulans) and human colonization**

Beginning at around 3000 BP, Austronesian-speaking groups living in the eastern extremities of Near Oceania spread into the wider Pacific in episodic, long-distance bursts, first into the Marianas and large central Pacific groups of Vanuatu, New Caledonia, Fiji, and Sāmoa, then into central Polynesia, and finally reaching Hawai‘i, Rapa Nui/Easter Island, and Aotearoa/New Zealand during the first millennium BP (Sheppard et al. 2015; Wilmshurst et al. 2011). These colonists brought a suite of Southeast Asian domesticates to previously uninhabited islands, notably taro (*Colocasia esculenta*), breadfruit (*Artocarpus altilis*), coconut (*Cocos nucifera*), banana (*Musa* spp.), and yam (*Dioscorea* spp.). The introduction of these species and the development of polycropping, combined with deliberate landscape modification by human colonists, transformed the biological organization of Remote Oceania (e.g., Kirch 2002). It would be inaccurate, however, to understand these transformations as solely mediated by humans.

The sheer scale of the human achievement that is the colonization of the Pacific is intrinsically impressive. Perhaps more impressive is that the journey from the Solomon Islands to Rapa Nui—a distance of some 9,000 km—was also completed by the Pacific or Polynesian Rat, *Rattus exulans* (Figure 3.2) (Anderson 2009). Smaller than *R. rattus* or *norvegicus*, the Pacific Rat (or *kiore* in Māori) nonetheless occupies a parallel niche as an omnivorous generalist, polyestrous, nocturnal, with short gestation and weaning cycles. Various types of data (including recent genetic work; Mattisoo-Smith and Robbins 2009) indicate that *R. exulans*, having originated in Southeast Asia, accompanied human colonists throughout Remote Oceania (Barnes et al. 2006). It is disputed as to whether the rat was introduced accidentally as an unwilling stowaway, or as a food source (see Allen 2015; Mattisoo-Smith et al. 1998). What is clear is that it spread to the most isolated corners of the Polynesian triangle coincident with their colonization by humans, and in so doing drove exaggerated and rapid environmental change. Our immediate concern here, then, is establishing through what pathways rats drove this change. These pathways range from the direct and unsurprising (predation) to more esoteric means of impact.
The Pacific rat: direct impacts on fauna

The most immediate context in which *R. exulans* is implicated in rapid environmental change associated with human colonization is in the extirpation and extinction of various species endemic to Remote Oceania. These extinctions span a wide range of taxa.

The best-known example is the eradication of large swathes of the Pacific endemic avifauna during colonization, with some 2,000 species of bird being lost (Steadman 1995). Steadman and Martin (2003) emphasize both the scale of this loss and also the various factors that conspired to drive it; introduced mammalian carnivores, however, are implicated in predation on ground-nesting avifauna, especially on eggs and juveniles (Atkinson 1985; Medway 2001). In the absence of evolved anti-predator defenses, ground-nesting endemics would have provided an initial calorific glut for invasive rats, driving up numbers and thereby exerting even greater pressure on avifauna. Combined with human predation, such pressure meant localized extirpation was swift (e.g., Kirch 2007), probably following at a decadal scale post-colonization. The capacity of *Rattus* spp. to drive local extirpations is underscored when considering instances in which rat predation has not been accompanied by human predation, or has been actively resisted via extermination programs.

Direct predation on native faunas was not limited to avifauna. It is challenging to bridge the evidential gap between the disappearance of taxa from the stratigraphic/sub-fossil records of islands and the introduction of rats, but modern proxies can illuminate the sort of ancient behaviors which would have driven such extinctions. Hadfield and Safler (2009; see also Hadfield et al. 1993) record substantial modern predation on the endemic Hawai’ian land snail *Partulina redfieldi* by *Rattus* spp., with this predation indicated by characteristic shell trauma. The association with *R. exulans* as opposed to *R. rattus* is not in this case demonstrated, but similar patterns...
of trauma are also evident in the archaeological record of New Zealand. Discounting erroneously old radiocarbon dates, younger dates reported in association with more persuasive evidence for rat predation on another snail, *Placostylus ambagiosus* (Brook 2000) are coincident with newer, more robust dates for the colonization horizon which are themselves associated with rat-gnawed seeds (Wilmshurst *et al.* 2008). This suggests parallel prey selection in the constituent species of *Rattus*, and that types of population depression (i.e., severe depression caused by rats taking both juveniles and adults; Hadfield *et al.* 1993: 616–618) caused by modern rat predation may have occurred during *R. exulans* colonization events. To land snails (and invertebrates more broadly; St Clair 2011) we can also add vertebrate fauna. The relationship between presence/absence of kiore and variability in lizard populations has been demonstrated (Towns 1991), and there is reliable evidence for direct predation (rather than competition) on lizards, although not on the *tuatara* (Newman and McFadden 1990). This ecological relationship can also be retrojected to colonization by *R. exulans*.

**The Pacific rat: direct impacts on flora**

*Rattus exulans* is omnivorous, and its direct impacts upon arrival were felt by flora as well as fauna. In a landmark study, Athens *et al.* (2002) suggested a correlation between the appearance of Pacific rat in the ‘Ewa plain of western O‘ahu (as evidenced by radiometrically dated *R. exulans* bones) and the disappearance of endemic Hawai‘ian lowland forest, dominated by *Pritchardia* spp. Crucially, the retreat of endemic flora occurs prior to radiometrically visible human presence in the area, suggesting no direct anthropic impact, yet is contemporaneous with the apparent localized extirpation of endemic avifauna (Athens 2009) (Figure 3.3). Athens interprets these data as suggestive with regard to the relationship between arrival of the Pacific rat and the collapse of native lowland forest (indeed, as Athens points out [2009: 1498], the only remnant stands of *Pritchardia* in Hawai‘i in which that genus dominates come from Huelo and Nihoa, both of which remain free of *R. exulans*).

Further compelling evidence of the capacity of invasive rats to drive deforestation comes from Rapa Nui. Hunt (2007) notes that the island—which is presently deforested—was, according to the palynological and anthracological data, covered by *Jubaea* palm forest prior to human colonization at ~750 BP (Wilmshurst *et al.* 2011). The process of deforestation has often (and especially in the popular literature) been attributed to anthropogenic degradation, most conspicuously by Diamond (2005). Yet the presence in the archaeological record of *Jubaea* endocarps which have signs of rat-gnawing, the retreat of *Jubaea* forest prior to evidence for localized burning, and the substantial amount of *R. exulans* skeletal material found in post-colonization deposits all suggest an explosive rat population preying on endemic taxa at the most vulnerable point in the reproductive cycle of those taxa (Hunt 2007). Wilmshurst *et al.* (2008) present similar evidence for rat-gnawing of endemic flora in New Zealand, again tightly correlated in radiocarbon terms with retreat (although not mass extinction) of this flora. Kirch (2007) highlights that broadly parallel types of process occurred with variation across Remote Oceania.

Summing the data, there is broad evidence that the extirpation of endemic flora—and in particular palm species—was not unique to the corners of the Polynesian triangle, but rather was the norm (Prebble and Dowe 2008). Meyer and Butaud (2009) query whether *Rattus* can drive localized extinction in the absence of other factors, but research on modern rat populations and their relationship with endemic palms suggests that predation can substantially disrupt recruitment to the extent that conservation can only be guaranteed by controlling rat numbers (Auld *et al.* 2010; Campbell and Atkinson 2002). Campbell and Atkinson (2002) in particular highlight
the varied ways in which *kiore* predation can affect floral life-cycles, not only via endocarp consumption but also via eating flowers and saplings.

In short, there is compelling evidence from a series of proxies (archaeological, zooarchaeological, and palynological) that the arrival of *R. exulans* in Remote Oceania was closely associated in both time and space with the local or complete eradication of endemic flora and fauna, often prior to evidence for significant human occupation of a given environment and with suggestive signs of direct effects (such as endocarp gnawing). Modern data track how rats (both *R. exulans* as well as *R. rattus* and *norvegicus*) can drive these processes of eradication, achieving very high population densities by exploiting a range of food sources and thereby causing demographic collapses in native biotas (Russell *et al.* 2009). These effects move beyond these biotas, however, and drive changes in the abiotic systems with which they are interlinked.

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**Figure 3.3** The pollen diagram from Ordy Pond, ‘Ewa Plain, O’ahu, from data first published in Athens *et al.* 2002, demonstrating profound floral change after \(\sim 950\) cal BP. Two pollen sums were used in calculating percentages for the curves; for all types except the sedges, the curves are based on a sum excluding sedge pollen from the total, while the sedge curve (not depicted here) is based on total pollen and spores (Athens 2009: fig. 2a–b). *Prosopis pallida* is a late, Euro-American introduction. Note that, in the interests of clarity, not all taxa from the original diagram are here reproduced. Modified after Athens 2009: fig. 2a–b; reproduced by permission.
The Pacific rat: indirect impacts

Introductions of non-native taxa, followed by the extirpation or extinction of native taxa, are recognized as common outcomes of the collision of Neolithic lifeways with previously insulated ecosystems. These collisions, however, have effects beyond driving down overall biodiversity; they promote changes in the structure of ecologies and in the organization of interwoven biophysical systems. Tracking these changes in Remote Oceania involves understanding the pathways by which deforestation occurs. Again, the Pacific rat is exemplary (Drake and Hunt 2009).

In the ‘Ewa Plain, Athens (2009) charted a radiometric lag between eradication of the *Pritchardia* ecosystem and the subsequent establishment of introduced species. Conversely, in Rapa Nui, the degradation of native forest was followed by grassland succession (rather than the establishment of complex, multi-storey agroforest as on, e.g., Tikopia; Kirch 2007). The eradication of endemic lowland forest and its replacement by introduced species (e.g., *Cocos nucifera*, *Artocarpus altilis*, *Musa* spp.) in a regime of mixed arboriculture, dryland horticulture, or wetland horticulture resulted in physical reorganization. Along what pathways did these related types of process occur? Recent work from the Mangareva/Gambier Islands (Kirch et al. 2015) highlights the complex nature of the relevant ecological interactions, with both direct impacts (via predation on endemic flora) but also indirect (predation on native birds disrupting nutrient cycling) likely combining to impact native forest. In this as in other examples across Remote Oceania, arrival of *R. exulans* and deforestation seem to be associated; direct predation no doubt played a vital role, but rat impacts on forest organization should be conceived of more broadly. Kirch (2007), in reviewing the noted strong correlation between human colonization, the radiometrically dated Pacific rat, and deforestation, suggests that the eradication of endemic avifauna and consequent nutrient poverty should be understood as a driving factor in forest destruction. Because of the temporal distance, the ecological specificities of rat invasion, seabird extirpation, and deforestation are hard to grasp. Research on modern ecologies subject to rat invasion, however, is instructive, especially in terms of the types of change that rat invasion promotes in the pedosphere and the effects of these changes for community dynamics.

We can proceed from the reasonable assumption that *R. exulans* played a substantial role in eradicating endemic avifauna, and seabirds in particular (Steadman and Martin 2003). Seabirds play a key ecological role in their transfer of marine nutrients to terrestrial environments, driving up island nutrient levels (especially of phosphorous and nitrogen) and consequently the capacity of islands to sustain more biomass than might be expected based on raw area and latitude (Sanchez-Pinero and Polis 2000). Their extirpation should, then, theoretically alter island soil chemistries. This is borne out by recent studies which indicate that presence of *kiore* on small islands off New Zealand’s North Island radically disrupts nutrient flow. Mulder et al. (2009) observed changes in soil chemistry as a function of depression of seabird numbers; in particular, islands with fewer seabird burrows (because of rat predation) experienced reduction in overall phosphorous and nitrogen levels, as well as their soil pH being affected. Parallel disequilibria in leaf chemistry (with lower percentages of nitrogen on invaded islands than rat-free islands, with the inverse for potassium) reflect the imbalanced soil chemistry via processes of nutrient uptake. In general, Mulder et al. suggest, seabird presence/absence is a strong predictor of soil pH and nitrogen content. This is especially relevant when considering that Polynesian arboriculture and horticulture may have patterned spatially to take advantage of variably organized nutrient distribution; the apparent relationship between phosphorous values and intensive cultivation in the Kohala field system on the Big Island of Hawai’i is a good example (Vitousek et al. 2004), and there are hints of parallel patterning on a smaller scale on Rapa Nui (Ladefoged et al. 2010).
Impacts are not only limited to the direct input and vegetative uptake of nutrients from seabird guano, but also include intermediaries. Fukami et al. (2006) demonstrate variability between the soil microfaunas of rat-free versus rat-invaded islands, as well as variability in rate of litter decomposition and overall moisture content. The role of rats as not only seed consumers but also—depending on seed morphology—seed dispersers can drive heterogeneity in soils at a larger scale (Shiels 2011 and Shiels and Drake 2011; also Traveset and Richardson 2006 on mutualism disruption). While the relevant ecological relationships are complex, in general (a) there is a relationship between rat invasion and dynamic changes in soil chemistry and also biology, and (b) this has implications for plant biomass. Again, operating on the gross assumption that higher autotroph biomass permits bigger populations of heterotrophs, from the perspective of soil biochemistry rat invasions should push tropical insular carrying capacity down, notwithstanding the calorific potential of the rats themselves.

As a function of both direct predation but also post-colonization changes in soil chemistry, the retreat of native forest drove changes in macro-scale soil organization. Destruction of primary forest—whether succeeded by secondary forest or not—leads to radical changes in soil organization, not only in consequent nutrient cycling but also in overall cohesion. In the absence of root-bonding, soil horizons can become very dynamic when exposed to waterflow, experiencing sheet erosion and gullying and exposing the regolith to weathering (see Mieth et al. 2002 for these processes on Rapa Nui). These processes have a number of consequences, the most conspicuous of which is the transfer of sediment and its accumulation downslope (exemplified in Mangareva). Sediment transport in turn drives downslope changes, depending on degree of consolidation (i.e., A-horizon formation), including alluviation and silting, altered frequency and severity of flooding events, and disruption of inshore—especially lagoonal, in the lower latitudes—environments (and their biota) via silting. Dynamism of this sort also renders soils exposed to further changes in nutrient composition by rendering them more susceptible to rainwater leeching. These large-scale changes in pedology ultimately affect neighboring physical systems. Hydrological organization is in part dependent on moisture retention within soils and the deposition of sediment in stream beds. In terms of lithology, erosion of the regolith ultimately exposes underlying bedrock to weathering processes, with this weathering driving geochemical changes in local soils and sediments.

To continue to list the wave of changes deriving from biotic impacts would be to labor the point; panning out from our tight geographic focus, what are the broader lessons implied? Invasive fauna are understood to have effects on islands such that they stimulate trophic cascades. Reviewing the impacts of the Pacific rat during its colonization of Remote Oceania, it is evident that its effects are best conceived of as achieved through multiple pathways and as driving biophysical cascades. Not only were island biotas reorganized, but the systems that interface with these biotas, including local soils and local hydrologies. Rats, moreover, were only one component of a Neolithic package which contained several species likely to have had as severe impacts for local biotas as rats (particularly pigs and dogs, even if these proved easier for human populations to control and eradicate in the face of trophic crunches; Kirch 2007). Do other instances of island colonization by bundles of taxa associated with Neolithic life ways parallel the types of biophysical scenarios witnessed in Remote Oceania?

**Rehearsing the Anthropocene: a drama for several players**

While Remote Oceania is probably exemplary in terms of sheer degree of disruption driven by the arrival of an alien Neolithic, this process—with similar and dissimilar species involved—has
occurred repeatedly; in the Mediterranean and Caribbean during the early to middle Holocene, and in the more remote islands of the world’s oceans (especially in the higher latitudes) during Euro-Asian expansion in the late Holocene.

We have already encountered rats in the form of *Rattus exulans*, but it is unsurprising that *R. norvegicus* and *R. rattus* have also had catastrophic effects on insular biota elsewhere. Striking examples of the impacts of these and of other murids come from remote Indian and Southern Ocean islands which remained isolated from the Euro-Asian agropastoral lifestyle the longest (Angel et al. 2009; Bolton et al. 2014). Even island environments with a long exposure to murids—and continued co-presence of rats and endemic birdlife—witness the continuing capacity of *Rattus* spp. to exert predation pressure which drives ecological organization (Ruffino et al. 2009). While murids are well understood to have promoted large-scale environmental change (Harris 2009; Simberloff 2009), this should nonetheless not be taken to suggest that only commensals drive generally deleterious changes. The introduction of the domestic goat (*Capra hircus*) to first the Mediterranean islands, and then subsequently islands worldwide, has had catastrophic impacts, primarily regarding goat browsing behaviors and their capacity to out-compete endemic herbivores (e.g., Leppard and Pilar Birch 2016). In particular, the ability of goats to tolerate plant morphologies and biochemistries which make them unattractive to other herbivores (e.g., Hernández-Orduno et al. 2012) has had catastrophic effects for endemic floras, with by now predictable cascade-type outcomes (Chynoweth et al. 2015; Hata et al. 2014). Examples could be multiplied, including domestic rabbits, *Oryctolagus cuniculus* (e.g., Chapuis et al. 1994) and cats, *Felis catus* (e.g., Bonnaud et al. 2011). This is before turning to the direct and indirect impacts of humans themselves, clearly significant but beyond the purview of this chapter.

What do these examples have in common? In each instance, human colonization and introduction of a Neolithic *modus vivendi* equates, in ecological terms, to the invasion of a suite of co-adapted generalist species occupying a variety of trophic positions. These species exerted direct and indirect pressure on disequilibrial, specialized, and predator naïve taxa which—tending to be insular endemics—lacked the security of a broad metapopulation. This pressure was brought to bear while human colonists, as well as their accompanying species, built Neolithic niches to which these invasive species were already adapted. Through a combination of processes (being eaten; being out-competed; having mutualisms disrupted; pathogen introduction), populations of endemics underwent overall degradation (i.e., population decline) and spatially specific degradation (i.e., range fragmentation). In doing so, they became more exposed to the stochastic effects which bear more heavily on smaller populations, resulting in extirpation or extinction. Localized or generalized extinction had concomitant effects on systems predicated on endemic stability; for example, the chemical composition of soils and, by extension, plant biomass dependent on certain chemical configurations in these soils. These changes cascaded through environments, not only in biotic terms but driving broader biophysical change, change observable in a number of palaeoenvironmental proxies.

How can we characterize these changes, and what do they have to do with the Anthropocene? Recognizing that in each case the ecological specifics were unique, we can nonetheless identify significant trends. First, the outcome of these colonization events is catastrophic localized losses in biodiversity (i.e., in genetic variability), and reduction in sum global biodiversity. Moreover, biases in how this diversity is lost make the process semi-predictable. Second, as total environments provide the context for natural selection to operate on phenotypes, so radical changes in the organization of these environments can disrupt evolutionary trends. Surviving pre-colonization taxa should evolve under conditions of anthropogenic selective landscapes. Because the organization of these landscapes will often be similar, we might assume that parallelism in
the resulting evolutionary trends should promote convergence. Third, as should be evident from the foregoing, these predictable effects are not limited to biotic organization, but extend to aspects of pedological and hydrological organization. There are broader implications here for the subaerial life histories of oceanic islands; if the trajectories of these histories are broadly knowable (Whittaker and Fernández-Palacios 2007), to what degree does destruction of primary forest and resulting sediment transport accelerate erosion (in the oceanic tropics, from ‘high’ islands to atolls) in predictable and non-local ways? Finally, these changes have been (a) global and (b) occurring throughout the Holocene. These effects are not area limited, nor restricted to the later Holocene.

These are Anthropocene dynamics—physical as well as biological, global not local, predictable not specific—enacted in miniature as growing anthropic ecosystems collided with endemic types of environmental organization. These anthropic ecosystems, corralled by humans both intentionally and unintentionally, were multi-species conglomerates comprising bundles of taxa which had been under selective pressure towards adaptability and tolerance of variation during the ongoing process of ‘domestication’. Changes in island biophysical systems deriving from the introduction of these species were not affected by any single member (although clearly human direct impacts were exaggerated); rather, multiple species—humans, domesticates, and commensals—exerted pressure on endemic biota from different angles and along different ecological pathways. The result was, from the first expansion of Old and New World Neolithic packages to insulated environments, miniaturized biophysical transformations that foreshadow the various aspects of the Anthropocene.

Conclusions: the islands of the day before

The purpose of this chapter is not to suggest that there is nothing new under the sun. Certain types of biophysical impact—ocean acidification, for example, affecting the chemical pathways of organisms which rely on calcium carbonate, or atmospheric warming on a global scale—are almost certainly uniquely outcomes of industrial and post-industrial types of human social organization. Yet if we adopt a broader definition of the Anthropocene, one that involves humans driving a variety of complex processes that affect the biotic and abiotic organization of the planet, then we will have to be willing to admit that these processes have been driven not only by our, but by other, associated species which have benefited from the spread and multiplication of modern humans. This has been the case not only in deep time, but into the present. The annual CH$_4$ production of cattle, for example—the vast majority of which claiming descent from the ancestral domesticated population of *Bos primigenius* in Southwest Asia (Bollongino et al. 2012)—is a major contributor to sum atmospheric greenhouse gas totals (Ripple et al. 2014). While unwitting villains, our Neolithic co-species are perhaps guilty by association in the Anthropocene plot (cf. Ruddiman 2013).

In nuancing our approach to take into account data of greater antiquity, we will also be forced to recognize that understanding the Anthropocene, in part, involves understanding encroachment and isolation—the breakdown of biogeographic barriers, and the implicit reduction in genetic diversity. It is surely instructive that, as agropastoral modes of living have expanded, the environmental outcomes for islands have been broadly similar; we might then best understand human (Neolithic) niche-construction as an intrinsically homogenizing process. This almost certainly has implications, not only for scholars concerned with impending socioecological scenarios, but also for those of us interested in the ecological and subsistence parameters which have constrained and directed the evolution of human societies, arguably towards structural convergence, since the Last Glacial Maximum. 4 This view of the
Anthropocene also necessitates framing it in terms of accelerating incremental intensification throughout the Holocene, rather than looking for its genesis at a series of distinct horizons; that is, considering whether we can extend the tail of the ‘great acceleration’ back into the deep Holocene (Steffen et al. 2015).

Finally, and bleakly, an archaeological and intrinsically longue durée perspective on human eco-dynamics on islands offers a parable for future directions within and beyond the Anthropocene. Modern humans, excelling at maximizing return and benefit at evolutionarily relevant time-scales and genetic distances, have repeatedly disrupted previously isolated biophysical systems in a manner which is hard to characterize as other than deleterious. Despite our species’ capacity to model long-term dynamics and—crucially—to act to mitigate negative effects (contra Diamond 2005), the emergent outcomes of our anthropic ecosystems have by definition driven unpredictable effects. The indigenous population of Rapa Nui was resilient, and demonstrably survived the eradication of the Jubaea forest. From the perspective of the intrinsic value of genetic diversity, however, we should insist on noting that the fate of the forest was sealed, not by the felling of the last palm, but by the consumption of its relatives and its own seeds by seemingly harmless Neolithic co-travelers. Whether or not the policy and will exist to mitigate present and future change in the planet’s systems, our historic willingness to spread apparently innocuous anthropic ecologies has created emergent ecological, physical, and evolutionary scenarios which will be difficult to model as we progress further into the Anthropocene.

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Notes

1 Examples of modern humans crossing biogeographic barriers and driving profound environmental change at the continental scale come from the later Pleistocene; most notably, the colonization of Sahul/Australia at ~47 kya and the Americas at ~15 kya. Clearly, these were hunter-gatherer colonization events, thereby involving only limited suites of commensal species, yet the effects on environmental organization were nonetheless substantial (direct impacts in the form of the extinction of endemic faunas are the most conspicuous). The subsequent, catastrophic late Holocene introduction of Afro-Eurasian biota during European colonization from 500 BP is indicative of how invasion by bundles of species associated with agropastoral regimes can further transform already radically altered anthropic environments.

2 In general, it is an unhelpful yet established distinction to think in terms of continental versus insular. The Americas and Afro-Eurasia are as much islands—bodies of land surrounded by water—as are Pitcairn or Iceland. Interest lies in spatial scales of contiguous, qualitatively comparable habitat-space; as Terrell recognized (1999: 240–241) when he emphasized that ‘island archaeology’ is the archaeology of a certain type of environmental patchiness.

3 ‘Neolithic’ is used throughout broadly and indulgently to connote pre-industrial communities with an agropastoral means of subsistence, rather than connoting more refined temporal specificities or cultural affiliations.

4 In general, the relationship between social organization, convergence, and directed change requires substantial further attention, but this is neither the time nor the place.
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