

# Anthropocene Dynamics in the Prehistoric Pacific

## Modeling Emergent Socioecological Outcomes of Environmental Change

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**Abstract:** How will human societies evolve in the face of the massive changes humans themselves are driving in the earth systems? Currently, few data exist with which to address this question. I argue that archaeological datasets from islands provide useful models for understanding long-term socioecological responses to large-scale environmental change, by virtue of their longitudinal dimension and their relative insulation from broader biophysical systems. Reviewing how colonizing humans initiated biological and physical change in the insular Pacific, I show that varied adaptations to this dynamism caused diversification in social and subsistence systems. This diversification shows considerable path dependency related to the degree of heterogeneity/homogeneity in the distribution of food resources. This suggests that the extent to which the Anthropocene modifies agroeconomic land surfaces toward or away from patchiness will have profound sociopolitical implications.

**Keywords:** Anthropocene, archaeology, human ecodynamics, model systems, socioecology

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### Introduction: The Transformative Anthropocene

The behavior of our species is driving large-scale and linked change within the earth systems. This change is characterized by several factors that distinguish it from previous types of planetary dynamism. It is extremely rapid, occurring faster than preanthropogenic earth systems reorganization by orders of magnitude; it is experienced along several dimensions; and it is accordingly observable in a series of proxies, including the sedimentological record. This interrelated series of physical, chemical, and biological processes is increasingly considered to constitute a separate geological epoch, the *Anthropocene* (Crutzen and Storer 2000). The intensification and acceleration of processes implied by this term will have massive effects on how humans constitute their societies and how power is both distributed and exercised





within those societies. Beyond recognizing that Anthropocene earth systems processes will be radically socially disruptive, we currently lack meaningful information as to what form this disruption will take, and this represents a significant and problematic lacuna.

The archaeological record of islands provides useful analogues with which to begin to model the effects of anthropogenically induced earth systems change. Accordingly, I examine case studies from the prehistoric Pacific, in an attempt to track—in a longitudinal dimension—emergent social outcomes of large-scale environmental disruption. I do not exhaustively review the archaeology of environmental degradation in the prehistoric Pacific (on which there is an extensive literature; see Kirch 2007); nor do I suggest that Holocene socioecological feedbacks precisely anticipate those of the Anthropocene. Instead, I suggest that the biophysical processes implied by the unifying Anthropocene concept will alter inequality dynamics along semipredictable pathways, and that closer attention to linked biophysical change in the past is the only means to grasp its trajectory into the future.

## **Inextricable Links between Environmental and Social Change**

The spectrum of human behavior is altering the composition of the atmosphere, hydrosphere, biosphere, pedosphere, and geosphere. This changing composition is driving system dynamics, such as mean atmospheric warming, decreasing oceanic pH, and anthropogenically influenced sediment deposition. These dynamics are considered to represent a discrete geological epoch, the Anthropocene (e.g., Crutzen and Storer 2000; Ellis and Haff 2009; Zalasiewicz et al. 2011). Crucially, the earth systems are highly sensitive to variation in neighboring systems, and this sensitivity is reciprocal. For example: the Great Oxygenation Event at ~2.33 BYA involved biosphere activity impinging upon the function of the atmosphere and hydrosphere, but this then substantially reconfigured systemic processes—from ecological to evolutionary scales—within the biosphere (Luo et al. 2016). Similarly, human-mediated impacts on the nonbiological earth systems have concomitant impacts in the biosphere (reduced sum biodiversity; Barnosky et al. 2011; Ceballos et al. 2016; Young et al. 2016) and in biophysical interfaces (e.g., soil–microbiota–root mass interaction; plant transpiration–hydrology relationships; Bolton et al. 2014; Callaway et al. 2004; Lejeune et al. 2015; Perkins et al. 2016).



Critically, recursive earth systems feedback in the Anthropocene will radically alter the material and biological contexts of human behavior, shifting subsistence, demographic, and habitability baselines over decadal and centennial scales. Human social and political organization is frequently premised on predictability in socioecological systems and baseline stability. For example, intensive farming regimes operate according to assumptions regarding nutrient and water availability, and systems of urban settlement in turn are premised upon sustained calorific input. Minor, local, or short-term fluctuations in earth system organization can drive considerable change in human social organization (e.g., d'Alpoim Guedes and Bocinsky 2018; Dugmore et al. 2012; Plunket and Uruñuela 2006). Large-scale earth systems change in the near future will disrupt socioecological organization globally, driving cascade change through subsistence behaviors and consequently reconfiguring settlement ecology and demography. Political economy and methods of wealth acquisition and distribution are closely tied to prevailing patterns of demographic distribution, not least as regards market and labor availability and infrastructure. Changes wrought to earth systems will accordingly drive substantial change in how and in what terms social power is built and exercised.

Much of the voluminous literature on the Anthropocene is concerned with processes of mitigation or management, focusing on trend reversal, alleviation, or the development of sustainable and/or “resilient” socioecological systems (Reyers et al. 2018, with references). It is increasingly clear, however, that strategies ranging from obviation to management are not being adopted or executed at individual or institutional scales (IPCC 2018). Consequently, social scientists and policy makers are obliged to attempt to understand the magnitude and potential implications of these changes. What are the long-term socioecological implications of varied, extensive, and rapid biological and physical change, encompassing but not limited to decreasing environmental predictability? This is especially pressing considering the current emphasis in the social sciences on inequality dynamics as a major determinant of trajectories of social and political change, and the recognition that growing wealth inequality—within and between polities—stresses extant institutions (e.g., Alvaredo et al. 2017; Kohler et al. 2017; Saez 2017). Which mechanisms depress or exacerbate wealth inequality (e.g., Helpman 2018; Piketty 2014; Scheidel 2017), how will intensifying and accelerating Anthropocene processes bear on these mechanisms, and what effects will this have on the coherence of polities and other institutions?

Beyond emphasizing the likelihood of overall disruption, however, this is a challenging proposition. Complex systems have emergent and thereby unpredictable outcomes. Unpicking causal relationships is difficult; the controversy surrounding the extent to which the unrest which ultimately led to the Syrian civil war was partially a socioecological function of decreasing cereal harvests in the face of a climate change–induced multiyear drought is a good example (e.g., Kelley et al. 2015; Selby et al. 2017). Part of the problem lies in (a) a lack of requisite time-depth over which truly substantive institutional evolution (including in decision-making apparatuses and landholding/ownership norms) can be observed and (b) an inability to constrain spatially the relevant environmental variables. Understanding long-term trajectories of socioecological development on the basis of impressionistic surveys of chronologically instantaneous data is clearly inadequate in attempting to build robust predictions about long-term social change in the Anthropocene.

## **Finding Models for Socioecological Responses to System Change**

If we want to know how large-scale anthropogenic environmental change ultimately and reciprocally affects wealth inequality, competition, institutional coherence, and ultimately social power in human communities, what is required is some form of model system. What, in other instances of large-scale anthropogenic environmental change, have been the long-term socioecological implications for social power? This model system must have requisite time-depth, and must be sufficiently circumscribed from other contexts in order to clearly delineate whether or not components within the system, rather than outside it, are driving feedback.

Archaeological data provide a longitudinal dimension in which to observe human behavioral change. Archaeological data are also sensitive to human–environment feedbacks and to equitable versus inequitable distributions of wealth (via certain material cultural proxies) (Kohler and Smith 2018; although cf. Petersen and Drennan 2018). While the temporal resolution of the archaeological record is generally comparatively poor, this record contains the only data relevant to the long-term social outcomes of environmental modification existing in a reciprocal relationship with behavioral plasticity (as regards subsistence and land management practices). Accordingly, the archaeological record



offers the only means of observing and understanding long-term socioecological relationships (Braje 2015; Braje and Erlandson 2013).

The issue of circumscription is more challenging. The archaeology of relatively small or isolated islands, however, provides perhaps the most viable proxy for studying, in microcosm, planetary anthropogenic processes (DiNapoli and Leppard 2018; Fitzpatrick and Erlandson 2018). Peter Vitousek (2002, 2004) demands of a model system not only dynamics that usefully mimic in simpler terms those of the object of study, but also systemic integration. While islands are clearly integrated into larger earth systems (most obviously atmospheric and hydrospheric), their terrestrial biotas are incompletely but substantially insulated (e.g., Fordham and Brook 2010). To the extent that these miniature biospheres interact with physical systems, we can understand these feedbacks as spatially constrained and useful, in model terms, for considering socioecological responses and cumulative outcomes of these to human-induced environmental change.

Consequently, I use case studies from the Pacific—where the best insular multiproxy data exist—to explore these cumulative outcomes and their implications for social organization. In particular, I focus on the relationship between long-term socioecological interactions in the insular Pacific and resulting types of political organization. Surveying the transformations wrought to the Pacific islands by initial human colonization and the multifarious adaptive strategies witnessed in the face of these transformations, I assess how these comparatively circumscribed and different socioecological responses to environmental change drove similarly different, emergent sociopolitical outcomes.

My goal here is to explore whether the archaeological record of islands contains information germane to modeling social processes as we progress further into a world dominated by Anthropocene dynamics, not to contribute to the debate over where or if the start of the “Anthropocene” can be situated (cf. Holdaway et al. 2018). Perspectives on this are largely informed by the particular anthropogenic processes in question. In any case, those human impacts on the wider environment that are conceptualized as constituting the Anthropocene demonstrably differ in both type and degree from deeper-time human ecodynamics. They differ in type in that the large-scale production of anthropogenic compounds have no substantial prehuman precedent (e.g., plastics); and they differ in degree in affecting the majority of the earth’s surface via circulation of anthropogenic chemicals in the atmosphere and hydrosphere, driving novel processes (e.g., CFCs and ozone depletion; CO<sub>2</sub>-induced greenhouse dynamics). The planet-wide



anthropogenic impacts now evident across a range of data sets are to that extent unprecedented.

Yet, as Todd Braje has pointed out, the issue is more complicated (Braje 2015, 2016, 2018; Braje and Erlandson 2013). There are instances throughout the later Quaternary of human-environment feedbacks anticipating, on reduced scales and along fewer dimensions, modern Anthropocene processes. Preindustrial anthropogenic atmospheric signatures are vanishingly rare (although not absent; Koch et al. 2019), but human activity has affected the biosphere, and via biota the hydrosphere, pedosphere, and lithosphere (mechanisms including sediment transport, subaerial erosion, and weathering of exposed regolith [Leppard 2017]). To that extent, by turning to the Holocene archaeology of islands, I do not endorse any particular initiation point for the Anthropocene (considering the different requirements for chronological exactitude in different disciplines, this is always likely to be problematic). Rather, following Braje and Erlandson (2013), I work on the assumption that our species has always substantially modified environments; but that, as these processes of modification become more recent, their operation has accelerated, their scope broadened, and their range diversified.

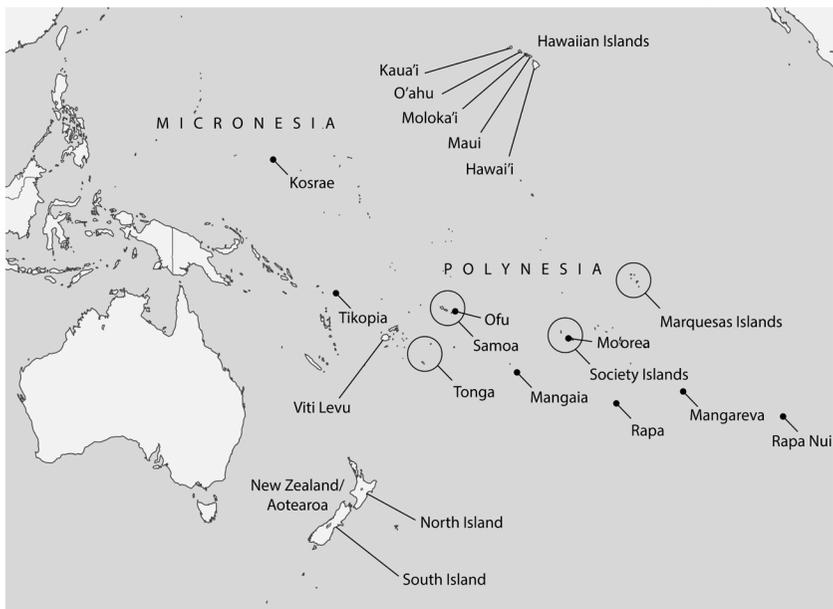
## **Long-Term Socioecological Trends in the Prehistoric Pacific: Human Colonization and Large-Scale Environmental Change**

Islands and other fragmented habitat types are sensitive to external perturbations, and the arrival of domesticated ecosystems represents an extremely strong perturbation. Accordingly, over the Mid- to Late Holocene, islands worldwide have experienced substantial ecosystemic disruption in the aftermath of human colonization (Braje et al. 2017; Leppard 2017, 2018). This is especially the case in the insular Pacific (Figure 1). Remote Oceania (i.e., islands north, east, and south of the Solomons) was, according to recent Bayesian modeling, only colonized after ~3.2 KYA (Rieth and Athens 2017). This Late Holocene colonization is significant for understanding subsequent biological and physical insular systems, in that the colonizing human populations brought with them technologically Neolithic anthropic ecologies. These ecologies comprised domesticated flora and fauna: taro, *Colocasia esculenta* and *Alocasia macrorrhizos*; coconut, *Cocos nucifera*; breadfruit, *Artocarpus altilis*; yam, *Dioscorea* spp.; banana, *Musa* spp.; sweet potato, *Ipomoea batatas*; pigs, *Sus* spp.; dogs, *Canis familiaris*; and chickens, *Gallus*



spp. This suite of taxa recurs so regularly that Patrick Kirch (1982c) has described the process of colonization as involving “transported landscapes.” These invasive ecologies also consisted of commensal, parasitic, and symbiotic taxa, ranging from vertebrates (e.g., the Pacific rat, *Rattus exulans*) to gastrointestinal unicellular biota. Evidence from across Remote Oceania suggests several immediate consequences of colonization, all involving substantial impacts on endemic taxa (frequently to the point of extinction/extirpation) and resulting landscape transformations (Anderson 2009; Kirch 1982b, 1983, 2007; Prebble and Wilmshurst 2009; Steadman 1995). These impacts drove different types of ecological and biophysical dynamics, which tend, however, to exhibit a generalized pattern.

In the aftermath of colonization, there is evidence from across Remote Oceania for partial or total loss of native forest (e.g., Prebble and Dowe 2008), with this forest either replaced by domesticated tree species or successional taxa. Examples include Hawai’i (Athens 2009; Athens et al. 2002; Athens and Ward 1993; Kirch 1982b, 2007), Rapa (Kennett et al. 2006: 350; Prebble et al. 2013), Mo’orea (Lepofksy et al. 1996), Mangaia (Kirch 1996), Mangareva (Kirch 2007; Kirch et al. 2015), Rapa Nui (Flenley and King 1984; Hunt 2007), and New



**Figure 1** ■ Map showing islands mentioned in the text (Drawn by Author).

Zealand/Aotearoa (McWethy et al. 2010, 2014). Endemic forest found itself under ecological pressure from several angles. There are varied reports of increasing charcoal abundance in cores and/or deep excavations correlating with colonization horizons, such as in Tikopia (Kirch 2007: 89–90; Kirch and Yen 1982), Rapa (Kennett et al. 2006: 350), Ofu (Quintus 2018: 3), Mo’orea (Lepofsky et al. 1996: 264), Kosrae (Athens et al. 1996: 842–843), and Mangaia (Kirch 1996), and the most parsimonious explanation of this general trend is that island floras were, at colonization, subject to anthropogenic fires related to horticultural and arboricultural behaviors (e.g., Argiriadis et al. 2018; Spriggs 1981)—either for direct forest clearance or thinning (or promoting grass growth, e.g., on Kaho’olawe [Spriggs 1991: 98–99]), swiddening, or both. Predation by the invasive commensal *Rattus exulans* also drove deforestation (Athens 2009; Campbell and Atkinson 2002; Hunt 2007; Leppard 2018; Wilmshurst et al. 2008) and reconfigurations of nutrient cycling (Swift et al. 2018). The precolonization insular Pacific was particularly rich in endemic bird species, major vectors of marine-terrestrial nutrient transport via their feeding activities that can, in otherwise potentially nutrient-restricted insular ecosystems, support greater autotroph biomass than might otherwise be expected (Sanchez-Pinero and Polis 2000). The extinction of endemic insular avifauna (Steadman 1995) via direct human, domesticate, or commensal predation or by habitat alteration would have had the immediate impact of interrupting the nutrient cycle and lowering biomass thresholds (a supposition supported by modern data that show a relationship between rat introduction and nutrient declines; Mulder et al. 2009), in turn further contributing to deforestation. Jillian Swift and colleagues (2018) highlight both the extent to which anthropogenically induced reconfiguration of nutrient flows can be traced in the insular Pacific (via stable isotope data on commensal introductions), and the ubiquity of this reconfiguration.

We cannot assume that islands that are forested in the ethnographic present did not undergo turnover events during human colonization (cf. Rolett and Diamond 2004). Tikopia is a classic example of a densely forested, intensely managed island environment—yet the agroforest consists of anthropically introduced, not endemic, taxa (Kirch and Yen 1982), with intensively managed tree crops constituting 95 percent of the vegetated surface; the Marquesas provide a comparable example (Huebert and Allen 2016). Kosrae, similarly at present covered by dense forest, underwent a turnover event following colonization, with the palynological record indicating the establishment of anthropic



agroforest by 1550–1350 BP (Athens et al. 1996). Simply because these islands (and others) are presently forested does not preclude the existence of ecosystemically traumatic colonization episodes, involving ecosystem turnover via either replacement or endemic deforestation/invasive reforestation.

Root biomass is a primary constraint on erosion (Gyssels et al. 2005). Destruction of established tropical or subtropical forest exposes soils to exacerbated subaerial erosion, with steepness of slope and precipitation extent further determining erosive potential. Large-scale sediment transport is accordingly and unsurprisingly attested across Remote Oceania in the aftermath of human colonization, for example, in Rapa (Kennett et al. 2006: 348–350), Mo'orea (8,000,000–16,000,000 m<sup>3</sup> of sediment was deposited in the 'Opunohu Valley; Lepofksy et al. 1996: 267), Mangaia (Kirch 1996), Sāmoa (Kirch and Hunt 1993; Quintus 2018: 3; Quintus et al. 2015: 226), and Tikopia (Kirch 1983: 27–28; Kirch and Yen 1982: 147–160). The situation in the Hawaiian archipelago is substantially more complex, and this is perhaps not surprising, considering the size of the islands, the geological and pedological heterogeneity evident between them, and the west-east time lag in colonization. Nonetheless, Stephen Athens and Jerome Ward (1993) find changes in depositional regimes associated, in the Maunawili core, with the *Pritchardia* decline (c. AD 1200).

A simple correlation between human colonization and massive downslope sediment transport is rendered more complex by a consideration of sea level change. During the Mid Holocene Thermal Optimum (~9.0–5.0 KYA), sea levels in the Pacific—and most notably the western Pacific—were approximately (if variably) one meter higher than at present (Dickinson 2004). The gradual drawdown to Late Holocene levels would have altered coastal environments in the insular Pacific as the exposure of fringing reef flat resulted in shoreline progradation. Certainly, some of the instances of shoreline progradation (e.g., on islands with Lapita settlement) are early enough that they could in principle derive from sea level regression; but the gradual stabilization of sea level during the Late Holocene makes it very unlikely that processes of sediment deposition in eastern Polynesia (which, based on radiocarbon assays, postdates eustatic stabilization [Wilmshurst et al. 2011]) could derive from marine regression. In any case, analysis of the relevant sediments on various Pacific islands (including the presence of charcoal) indicates that they are terrigenous (cf. discussion in Kirch and Yen 1982: 186–188).



The ramifications of extensive sediment dynamism in a circumscribed landscape are several (Leppard 2017: 561–562, with references), but they can essentially be understood in terms of effects on sites of sediment loss and sediment deposition. At parent soils, nutrients are lost by leaching or mechanically, while exposure of regolith and bedrock accelerates weathering. Combined biomass and soil loss alters hydrologies, steepening slope and thereby flow rate, exacerbating erosive potential. This process has short-term effects that are, in human subsistence terms, both deleterious but also beneficial. At terrestrial sites of deposition, there are clear potential benefits in turns of nutrient load, although ultimately fluvial transport results in nutrient loss to marine environments. In the case of the insular Pacific, however, as Matthew Spriggs (1981) notes, the progradation of the foreshore via sediment transport may have had substantial beneficial effects in terms of expanding cultivation surfaces with a shallow slope. The effects on marine environments most obviously relate to their degradation and loss via infilling, but increased particulate load in the water column can be deleterious for coral ecologies via inhibition of zooxanthellae photosynthesis (Falkowski et al. 1990; Richmond 1993). Perhaps most significantly, it should be emphasized that all of these processes represent a macroscale change in how the biomass-bearing potential of a landscape is distributed: in general, away from broad distribution, and toward partial distribution in lowlands and coasts. This can be thought of as a shift from greater productive homogeneity toward greater heterogeneity.

It is important to emphasize that these linked, large-scale environmental changes should not be understood as either entirely deleterious or beneficial. Indeed, as well as Spriggs's (1981) recognition that foreshore progradation drove certain short-term benefits in terms of expanding productive surface, deforestation—whether followed by anthropic reforestation or by dryland taro cultivation via rock mulching—was an effective strategy in extracting calorific potential from constrained ecosystems (even as extant nutrient cycles were disrupted by these processes). East Polynesia in particular is carbohydrate poor (Addison 2008), so deforestation followed by the introduction of horticultural regimes represents the only viable method to bring small, isolated islands within the ambit of possible human settlement (Hunt and Lipo 2013). Rather, the interest lies in how different types of subsistence landscape were constructed in the aftermath of colonization-induced environmental perturbation, and the extent to which these different strategies imposed ineluctable pathway-dependent socioecological trajectories over the long term.



## Agroeconomic Strategies in the Face of Environmental Dynamism

Human adaptation to the landscapes of the insular Pacific was not a process that was sensitive only to dynamism in cultural, political, or demographic dimensions. The islands of Remote Oceania were pushed into states of ecosystemic and biophysical flux following the arrival of anthropic ecologies in these highly responsive environments. The archaeological record suggests that the transported landscapes of the Pacific were extremely plastic (e.g., the “loss” of pigs on some smaller islands as a potentially unsustainable calorific competitor for human populations; Clark et al. 2013; Giovas 2006), but this plasticity must be considered as dynamically intertwined with comparably plastic biological, pedological, hydrological, and chemical processes. Intensively managed agroeconomies were built in Remote Oceania in a context of fluctuating forestation, accumulating valley and inshore sedimentation, massive biodiversity loss, and frequently increasing nutrient poverty (although attempts were clearly made to alleviate the latter [Ladefoged et al. 2010]). These agroeconomies, and their diversification along several axes, can accordingly be understood not only as an adaptive means of maximizing productive potential in circumscribed contexts, but also as responses to this dynamism—whether attempts at management, alleviation, or even acceleration of culturally valued landscape processes (cf. Spriggs 1981).

Pacific horticultural strategies can be characterized in several types: (1) swiddening; (2) arboriculture and agroforest management; (3) irrigated and natural wetland corm cultivation; and (4) dryland cultivation (Kirch 1982a, 1994; Quintus and Cochrane 2018). These strategies were not mutually exclusive, although some were spatially exclusive (e.g., swiddening and arboriculture; irrigated corm cultivation and any other type), and clearly preferences were both exercised and changed over time. Here I am interested in understanding how these strategies were adopted concurrent to large-scale environmental change, the extent to which this adoption can be understood as a response to this change, and the implications for social and political organization.

Many terrigenous sediments in valley bottoms and coasts associated with colonization horizons contain charcoal, often indicating anthropogenic burning episodes that seem to be a feature of early Pacific island settlement (Argiriadis et al. 2018). It is unclear whether this represents simple forest clearance, or the establishment of swiddening regimes (e.g., Kirch 1994; Leach 1999, and commentaries); recent work



explicitly connects macrocharcoal with swidden gardening in Micronesia, for example (Levin et al. 2017), although Athens and colleagues (1996) argue for a minimal swiddening period before agroforest establishment on the Micronesian high islands. In any case, considering the general ubiquity of charcoal in terrigenous deposits associated with colonization and forest clearance, some form of swiddening (of whatever duration or extent) seems very likely. Equally clear is that, by Contact, swidden horticulture was extremely rare in Remote Oceania. Rather, a range of arboricultural and horticultural strategies were in use that represent more intensive use of the landscape: crucially, however, they differ in types of spatial organization and labor input.

Multistory agroforest systems represent one such strategy. This involves multicropping tree species (coconut, banana, breadfruit) with low-growth crops: taro, yam, or sweet potato. Seth Quintus and Ethan Cochrane (2018) highlight the predominance of agroforest in various parts of Remote Oceania, most notably the Marquesas and Society Islands, although it is also evident in Micronesia and western Polynesia. Ole Mertz and colleagues (2010) review present agroforest management on Tikopia in detail, and evidence from Sāmoa and the Marquesas suggests an intensively managed agroforest landscape, with substantial investment in landesque capital (especially terracing and ditching) to both expand functional growing surfaces and to restrict erosion (Huebert and Allen 2016; Quintus 2018; Quintus et al. 2015; Quintus and Cochrane 2017). The consensus (cf. Kirch 2007; Kirch and Yen 1982) is that this highly intensive system allows for the maintenance of substantial populations in islands that otherwise are small enough to be dangerously exposed to demographic stochasticity (Leppard 2015; Moore 2001). From the present perspective, it is important to note that the establishment of multicropped agroforest acts: (a) as did its endemic predecessor, as a brake on further erosion of upslope and inland soils, and (b) to distribute the productive potential of the island surface, such that the economically valuable landscape is broader and more homogeneous.

Elsewhere in Remote Oceania other systems of cultivation predominated. In valleys and natural wetlands, corm crops (notably taro) were farmed in water-intensive regimes (Kirch 1994; Quintus and Cochrane 2017). These systems were, in the ethnographic present, highly productive yet clearly substantially circumscribed, viable only in certain types of environments. During initial deforestation, wetland environments of this type would have benefited from an influx of nutrients from upland soil



depletion. Sediment deposition would also have been substantive, and the construction of pondfields might be understood as doubly advantageous, both providing greater surface area for horticulture but also acting as sediment traps to prevent further downslope sediment loss.

Wetland cultivation was not the only means of corm horticulture. Across Polynesia, but expressed to its greatest extent on the leeward coasts of the eastern Hawaiian islands, taro, sweet potato, yam, and breadfruit were cultivated in expansive rainfed systems (Kirch 1994). These field systems—most notably the Kona, Kohala, and Ka'ū field systems on Hawai'i and Kahikinui on Maui—developed in contexts in which relatively reduced rainfall (in the orographic shadow of the interior from the prevailing northeasterlies, although both Kona and Kohala are less arid than other sections of the leeward coast) had not yet fully leached nutrients from exposed soils (Kirch 2007; Ladefoged et al. 2009; Lincoln et al. 2014; Quintus and Lincoln 2018). However, it is also clear that in Polynesian dryland horticulture more generally there were active attempts to curate soil productivity via artificially fostering nutrient loads through mulching (e.g., Vitousek et al. 2014), and this is most clearly evidenced on (deforested) Rapa Nui (Ladefoged et al. 2010). In New Zealand/Aotearoa, dryland cultivation of sweet potato *Ipomea batatas* represented a functional adaptation to latitudinal constraints imposed on a suite of domesticates otherwise less tolerant of temperature gradients—and even rain-fed *Ipomea* is unviable in most of South Island.

Pre-contact Pacific cultivation strategies diversified along several dimensions, with this diversification sensitive to island physiography (size, geology, rainfall), settlement histories, and differing calorific needs of burgeoning populations. This adaptive plasticity must also be contextualized, however, within the extensive environmental changes initiated by the arrival of humans and the Neolithic package. The basic invasive biology of Neolithic colonization, combined with subsequent behavior of the invasive taxa (e.g., fire setting), drove predictable types of biophysical process. Complex responses to this biophysical dynamism had long-term cumulative effects that either mitigated some of these processes (e.g., agroforest establishment, rock mulching), exploited them (e.g., wetland taro cultivation), or exploited niches that remained relatively unscathed (e.g., dryland horticulture on soils suffering less from nutrient depletion). The adoption and evident intensification of these strategies over centennial scales resulted in a myriad of social and political forms (DiNapoli et al. 2018).



## The Socioecological Outcomes of Ecotrauma in the Pacific

Reviewing the varieties of social organization in the Pacific at Contact would be compendious, and would obscure the main point of interest: how can the diversity of Pacific social forms be understood as a function of equally diverse adaptive responses to generalized and large-scale environmental change (a perennial question: Kirch 1984; Goldman 1970; Sahlins 1958)? Remote Oceania provides examples that straddle a spectrum from small-scale societies with limited evidence for social stratification (atoll Micronesia) to massive polities that undertook territorial conquest and oversaw substantially inequitable social systems (Tonga, Hawai'i) (Clark et al. 2008; Earle and Spriggs 2015; Kirch 2010). Is the emergence of leadership of this sort, and the institutional inequality that accompanies it, a consequence of choices made as populations managed changing landscapes?

A link between the diversity in agroeconomic systems and comparable diversity in social and political organization has long been proposed in the Pacific (Kirch 1984, 1994, 2007). In particular, several persuasive explanations orbit a central recognition: the relationship between emergent leadership and horticultural intensification (Kirch 2010). Timothy Earle and Matthew Spriggs (2015) see this process operating in terms of “chokepoints” within the political economy, wherein incipient elites could assert control over resources as they come within their institutional and spatial purview. Quintus and colleagues (2016; Quintus and Cochrane 2018) similarly address resource control, but emphasize that the management of environmental risk drives types of infrastructural and material investment processes that favor elite emergence. Robert DiNapoli and colleagues (2018; DiNapoli and Morrison 2017a) adopt a comparable approach, emphasizing the importance of the calculus resource value versus cost of defense as a determinant of competition over such resources (with, as they note, competition often tacitly understood as generative of emergent leadership). All these approaches differently grasp the overall nature of the dynamic: that heterogeneous, rather than generalized, intensification of systems of production drove divergent social outcomes.

Predictably patchy, highly productive resources such as taro pond-fields involve localized substantial labor investment and maintenance/management costs, increasing (in DiNapoli et al. 2018's terms) their economic “defendability”; predictably *unpatchy* productive resources such as expansive agroforest involve less investment in landesque capital, but their spatial organization also militates against proprietorial



control and oversight (with taro wetland monocropping versus multi-seasonal agroforest polycropping recalling James Scott's [2009, 2017] emphasis on how wetland monocropping in other contexts promotes social hierarchies).

Critically, the degree of intrinsic patchiness of the Pacific landscapes in which these intensive systems of exploitation were developed is a function of initial ecodynamic interactions in the face of anthropogenically induced biophysical change. Socially embedded choices made early in settlement histories accordingly exerted substantial path-dependent effects on subsequent land use and, ultimately, political economy. In contexts where ecodynamic outcomes largely constrained the most deleterious effects of large-scale environmental change, the breadth and diversity of productive landscapes (especially polycropped agroforests) dampened incipient elite emergence. In environments where—presumably as a cumulative outcome of complex, individual-level decisions—early emphasis was placed on wetland and pondfield horticulture (potentially in conjunction with archaeologically elusive swiddening), landscapes evolved rapidly toward a high degree of patchiness. To the extent that dryland corn and tuber horticulture was also unevenly distributed sensitive to nutrient and rainfall gradients, it too tended toward landscape patchiness with emergent outcomes in terms of investment and defendability—an example being the spatial relationship between *pa* construction in New Zealand/Aotearoa and prime sweet potato cultivation (Allen 2016). With burgeoning populations under approximations of *r*-type growth, this divergence along an axis of heterogeneous-homogeneous distribution quickly led to highly divergent social situations. Rapa, with its substantial evidence for sustained conflict, probably represents the extreme end of the spectrum (Anderson and Kennett 2012; DiNapoli et al. 2018). However, the small islands of the Pacific were intrinsically demographically limited from the perspective of carrying capacity, forestalling the development of demographic concentrations allowing the formation of large-scale hierarchical societies.

Hawai'i exemplifies these processes operating when biomass constraints are lifted. Small islands are more sensitive to invasive perturbations; the size and latitude of the Hawaiian Islands permitted demographic accumulations unattained anywhere else in the prehistoric Pacific, while also rendering them resilient and habitat-diverse: despite lowland deforestation, for example, intact forest obtained in the interiors. Accordingly, while traditional wetland and pondfield horticulture in Kaua'i, O'ahu, and Moloka'i seems to have supported population



growth and the formation of stratified chiefly societies, it is the massive dryfield agroeconomies of Hawai'i and Maui that pushed Hawaiian society toward degrees of complexity otherwise unattested in the Pacific (Kirch 2018). The infrastructural specifics of these field systems were minutely finessed, responsive to local environmental specifics, to drive intensive horticultural production over large areas (e.g., Kagawa-Viviani et al. 2018). The scale, intensity, and degree of integration of these systems, and not the wetland systems of the windward coast, seems causally implicated in the emergence of managerial and land-owning class structures incorporated into large, territorially coherent polities (DiNapoli and Morrison 2017b; Kirch 2010; Ladefoged et al. 2008). Hawaiian attempts to preserve, manage, and maintain uniquely productive leeward environments underscores the scale of the transformations witnessed across Remote Oceania, and the consequent social value placed on landscapes that avoided the worst of these transformations.

New Zealand/Aotearoa clearly diverges from the Hawaiian pattern, and this may at first seem problematic, considering that exaggerated resource patchiness and high  $K$  associated with larger size are supposed to be important factors in the pathway toward emergent, large-scale, and territorially coherent polities in Hawai'i and Maui. However, New Zealand/Aotearoa nonetheless has meaningful agroecological differences, not least the necessary reliance on one species, the sweet potato, and the smaller-scale management of this crop when compared to the massive leeward systems of the western Hawaiian Islands. Monocropping may be implicated in a much lower population density for New Zealand/Aotearoa than the Hawaiian Islands at Contact, with estimates for the larger archipelago consistently lower (e.g., Rallu 2007). In any case, the best evidence for intergroup conflict based on resource distribution (i.e.,  $pa$  distribution) reflects the north-south gradient in sweet potato productivity (Allen 2016), with  $pa$  construction becoming less dense along this gradient. Suffice it to say that the unusual size and high latitude of New Zealand/Aotearoa appears to have prompted Māori strategies of landscape management down pathways unanticipated in tropical/subtropical Remote Oceania.

In the Pacific, humans radically altered environments, and this reciprocally impacted those human communities, who responded plastically. The precise nature of this response depended substantially on locally made choices, but resulted in a diversity of socioecological outcomes that we can understand in terms of path dependency. How this diversity was achieved has substantive implications for modeling similar human socioecological processes at much larger scales.



## Scrying the Past: Lessons for the Anthropocene

The Pacific islands are relatively insulated and sensitive biophysical systems. Upon human colonization, these systems were massively disturbed, with colonization driving changes in their biota, in their soil cover, in how moisture was retained and distributed, and even in their total surface area. How populations responded to this series of changes had radical implications for subsequent human ecodynamics: not only in terms of how the landscape was managed, exploited, and owned, but also for the social structures and political regimes that grew out of and reinforced these subsistence behaviors. This should be understood in terms of socioecological path dependency, rather than environmental determinism. Dynamic landscape processes and quotidian, minute human choices made in the context of these processes had cumulative outcomes, nudging Pacific island societies down diversifying socioecological pathways. Along these pathways, various new social strategies became available, just as others were foreclosed upon. The first part of this process parallels, in miniature, how humans are currently driving large-scale earth systems change, while the second part contains information germane to understanding likely socioecological path dependency as this change continues.

Lessons from the specifics of Pacific biophysical change, land use, and resulting social regimes (cf. Kirch 1996: 5300) derive largely from collective responses to ecosystemic flux. Clearly, the type of environmental degradation witnessed in Remote Oceania is constrained to a series of causal processes: invasive biota driving nutrient and land cover change, and responses to this. The important point, however, relates to how resource patchiness was derived from these comparable processes. Ecologists have long recognized how patchiness—and, critically, how environments become more or less patchy—drives complex food web and behavioral change; indeed, this is the foundational assumption for human behavioral ecology (DiNapoli and Morrison 2017a). Comparably, social scientists already recognize that environmental heterogeneity versus homogeneity facilitates certain types of equivalent political landscape (Renfrew and Cherry 1986; Scott 2009). The capacity of “states”—or large scale, urbanizing, integrated societies with class-based institutions and ranking—to function and expand is, in part, related to their capacity to project power horizontally. Even with the prodigious integrative and network capacity of modern states, biogeographic boundaries and ecotones can challenge governmental structures. In the Pacific, evolving resource distribution heterogeneity



had contradictory effects. At small scales, it facilitated resource accumulation, management, and oversight, promoting disparities in social power; but at larger scales, it kept political landscapes fragmented and agonistic. Conversely, evolving or maintained resource distribution homogeneity militates against individuals and lineages accruing uncontested social power by limiting the extent to which oversight and regulatory quantification can be conducted. Under Anthropocene conditions, agricultural surfaces will evolve increasingly rapidly, with this evolution entailing both splintering and expansion under changing anthropogenic macroscale conditions. We should expect institutions reliant on managing and exploiting these surfaces in their current configuration to be stressed or strengthened along different axes. For example, as the increasing frequency of cluster droughts around the Mediterranean littoral drives further fragmentation in an already highly ecologically fragmented environment, we might suppose the capacity of weak central governments to project power horizontally to be challenged by local elites. Conversely, as climate change expands the viable rice-growing surface of China northward and westward (Ye et al. 2015), burgeoning rice yields should bolster governmental institutions, facilitating ongoing large-scale urbanization.

Clearly, the Pacific islands are both generally small and generally remote, and this is not a condition that characterizes most state-level Anthropocene actors. The Hawai'i pathway is accordingly instructive. Concerted attempts to intensively manage extensive leeward "sweet spot" landscapes drove the emergence of aggressive, young polities with which older, spatially fragmented chiefly systems in the western islands and windward coasts could not compete over the long term. We might speculate that in this case intensive and horizontally extensive management of productive niches in otherwise challenging contexts drove logics of territorial expansion at the expense of smaller polities in fragmented but highly productive environments. This has implications for interstate dynamics, most arguably in the Sahel and South-west Asia, if unpredictability in water availability drives up intensity of management of increasingly vital agropastoral "sweet spots" and where patchworks of state-level actors are likely to experience the deleterious effects of climate change with differing degrees of lag.

The implications for wealth distribution are less clear. Intergroup conflict is associated with reduced inequality metrics via the destruction of capital (Piketty 2014; Scheidel 2017). In the Pacific, heterogeneous distribution of intensively managed horticultural resources, in promoting competition over and differential control of these resources, does seem



to limit the scale of wealth differentials; in New Zealand/Aotearoa and Rapa patchily distributed resources exacerbated competition, which eroded or militated against resilient and deep hierarchies. However, it is generally assumed that the Hawaiian chiefly polities were prone to unusually large-scale violence while being substantially inequitable in how social power was distributed. A solution to this problem may involve focusing on the scale and performance of violence in Hawai'i as opposed to other islands with highly patchy distributions: interpolity in a sense that appears unmatched in scale and type.

More generally, in the Pacific and elsewhere, high Gini coefficients often seem associated with polities structured around large demographic agglomerations (Kohler et al. 2017; Kohler and Smith 2018; cf. Petersen and Drennan 2018). These are rare in the prehistoric Pacific, which offers, then, little insight into the feedback between earth systems change, urbanism, and wealth inequality. However, to the extent that this change differentially promotes or erodes urbanism, it can be assumed to have substantial implications for wealth inequality metrics. We might therefore fruitfully speculate about the absence of urbanism in the Pacific and its relationship to environmental variables. Is this an issue of limited island size constraining emergent urbanism, or might it be the case that the types of large-scale environmental cascade change initiated during Pacific colonization foreclosed upon the development of an urban tradition because of increased landscape heterogeneity? Hawai'i itself is just over 10,000 km<sup>2</sup>; other Pacific islands that do not approach Hawai'i in degree of prehistoric political complexity, North Island, Viti Levu, and New Caledonia, are 113,000 km<sup>2</sup>, 10,000 km<sup>2</sup>, and 18,000 km<sup>2</sup>, respectively. In the context of the scholarship on pristine "state" emergence, the absence of any truly urban center in these large spaces is remarkable, and we may be tempted to connect this absence to anthropogenic environmental change precluding nascent urbanism.

## Conclusion

It is important to avoid a simple equivalence between ecological and social resilience, not only because the latter is often understood in terms of value judgments (resilient societies as "good" societies—good for whom? Biodiversity, a driver of ecological resilience, does not self-evidently have a moral value). It is clear, though, that choices made during ongoing and human-induced environmental change in the



Late Holocene Pacific drove radically variable outcomes. Some of these outcomes included more stable social forms with breaks on emergent, institutionalized leadership; some encouraged the development of intergroup competition and formalized hierarchies; some, in conjunction with climatic dynamics, proved unsustainable (Anderson 2001; Leppard 2016). Critically, based on initial socioecological responses to anthropogenic change, the path dependency of individual islands took on a substantial degree of predictability.

All these routes will be taken by global societies as we move further into the Anthropocene. In examining how past choices determined future trajectories—by studying socioecological change in its longitudinal as well as spatial dimension—it will become possible to constrain likely socioecological outcomes. In the Late Holocene Pacific, the essential divergence was between greater homogeneity and greater heterogeneity in the productive landscape, how this impinged on human behavioral ecology, and the outcomes for political economy. As the processes implied by the Anthropocene are more varied in degree and type, we can consequently expect change along many more dimensions. However, if we can begin to model social responses to anthropogenically induced earth systems change from archaeological data sets, unavoidable and radical social change over the coming centuries may at least be anticipated, if not avoided.

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