Journal of Pacific Archaeology – Vol. 7 · No. 2 · 2016

– ARTICLE –

Between Deterministic and Random Process in Prehistoric Pacific Island Abandonment

Thomas P. Leppard[1]

ABSTRACT

The cause or causes of prehistoric island depopulation in the Pacific remains a subject of debate. Explanations have tended to focus either on the inherent environmental limitations of the 'Mystery Islands,' or the unviability of small populations. It is argued in this paper that these factors are functionally related (low carrying capacity drives exaggerated demographic stochasticity), but that this recognition cannot account for why some small, otherwise fragile islands were not depopulated. It is suggested that we should recognize a causal role for both less, as well as more, deterministic processes. Late Holocene climate change and the spatial aspects of pathogen transfer through the Pacific are highlighted as types of process which may have rendered already liminal populations ultimately unfeasible.

Keywords: Demography; historical ecology; colonization; pathogens; climate change

INTRODUCTION: THE MYSTERY ISLANDS OF THE PACIFIC

Several islands in the Pacific were, when first encountered by Europeans, uninhabited, yet exhibited evidence of previous habitation (Bellwood 1978; Kirch 1988). The cause or causes of the depopulation (either via abandonment or localized extinction) of the so-called 'Mystery Islands' (Kirch 1988) remains a subject of debate. Explanations have tended to cluster around physiographic and environmental conditions, citing ecological fragility, reduced carrying capacity (K), and resource depletion as causal factors (Anderson 2001), or conversely focusing on small population size as a driver of exacerbated demographic stochasticity (Terrell 1986). This paper builds on these explanations in noting that small K and exaggerated demographic stochasticity are functionally related, but that this in and of itself cannot fully explain physiographic and geographic patterning of the Mystery Islands. Rapa Nui, amongst other examples, as a small and subtropical island at a latitude which precludes reef-formation has a comparatively low carrying capacity, but nonetheless did not experience extinction or abandonment (although it is probably instructive that the island does seem to have witnessed pronounced demographic fluctuations).

It is suggested that, in attempting to account for the Mystery Island phenomenon, we should consider the interrelationship between more, as well as less, deterministic factors. Certain types of human ecodynamic process are arguably more deterministic in that they seem to operate along reasonably predictable trajectories dependent on initial conditions. Examples include very rapid, r-phase population growth in the immediate aftermath of island colonization (following the gradient of Neolithic Demographic Transition models; e.g., Bocquet-Appel 2011), and unsustainable exploitation of endemic biotas to the point of localized extinction, accompanied by associated ecological reorganization. These types of factors may have explanatory potential when considered in conjunction with less deterministic, more stochastic (but not necessarily truly random) factors, either emerging as a function of wider deterministic structure (i.e., demographic stochasticity developing in small populations during post-colonization boom-bust cycles; cf. Goldberg *et al.* 2016; Timpson *et al.* 2014) or as stochastic variables in their own right. Examples of the latter might include short- to medium-term climate change, or the introduction of alien pathogens.

Accordingly, in this paper, late Holocene climate change and the introduction of virulent Eurasian pathogens into the insular Pacific are highlighted – in the context of the few radiometric dates available for Mystery Island settlement – as types of non-deterministic factors which may potentially have posed severe problems for populations hovering close to thresholds of demographic viability, with this fragility having emerged as a function of predictable post-colonization ecodynamic scenarios. It is in particular suggested that the 'Mystery Islands' were especially exposed to pathogen transmission, being not so remote as to reduce pathogen transmission to zero, but not connected enough to the wider Pacific metapopula-

---

[1] McDonald Institute for Archaeological Research, University of Cambridge, Downing Street, Cambridge CB2 3ER

Corresponding author: thomas.leppard@googlemail.com

Submitted 1/1/16, accepted 22/4/16

tion to allow ready access to bigger, more stable demographic units. In concluding, it is emphasized that multicausal explanations of this sort are in general most likely to approximate actual processes.

GEOGRAPHIC AND ENVIRONMENTAL PATTERNING IN THE MYSTERY ISLANDS

Those islands normally described as the Mystery Islands are: Necker and Nihoa, in the Hawaiian chain; Pitcairn and Henderson, in far eastern Polynesia; Kiritimati, Howland, Washington, Fanning, Malden, Palmerston, and Suwarrow, lying close to the equator; Norfolk; and Raoul, in the Kermadecs. Patterning in the distribution and ecological and physiographic organization of these islands has long been noted (Anderson 2001, 2002; Diamond 1985; Kirch 1988). With the exception of Kiritimati, they are generally small (it is hard to know what this means in practical terms, of course – how small is too small? – although they are probably smaller than the mean prehistorically inhabited Pacific island); they also tend to exist in smaller or less dense archipelagoes, such as the Kermadecs, the Pitcairn group, or the northeastern Hawaiian chain (in contrast to, for example, Sāmoa or the Tuamotus). These islands also cluster into two physiographic general types: 'high', relatively young islands in the subtropical latitudes of the southern and northern Pacific (i.e., Necker, Nihoa, Pitcairn, Henderson, Norfolk, and Raoul), and low-lying corraline islands in the central Pacific (i.e., Kiritimati, Howland, Washington, Fanning, Malden, Palmerston, and Suwarrow). These factors conspire to drive down net productivity in both categories of island. The low-lying islands tending to be drier, as they do not benefit from orogenic rainfall; it is also possible that variable rainfall across the tropical and subtropical Pacific promotes exaggerated drought frequency on both the high as well as the low islands (Anderson 2002). The high islands in the subtropics, lying outside of the equatorial zone of optimal coral growth, are deprived of the maritime resources associated with coral ecologies, but also lack the seasonally-driven bounty of the mid-latitude seas.

PREVIOUS EXPLANATIONS OF THE MYSTERY ISLAND PHENOMENON

Previous explanations for the Mystery Island phenomenon have focused on initial environmental impoverishment or post-colonization resource depletion (Anderson 2001; Diamond 1985; Kirch 1988), demographic stochasticity (Terrell 1986), or decaying inter-island contact (Weisler 1994, 1995, 1998). Anderson's recent synthesis is arguably the most substantially developed, and the one most firmly grounded in the archaeological and environmental data. He notes that the majority of the Mystery Islands exhibit latitudinal patterning, lying outside the belt of optimal coral growth (i.e., in seas which drop below 23 degrees Celsius on a seasonal basis), but remaining too equatorial to experience the maritime abundances of temperate seas, the complex seasonal trophic structures built on plankton blooms. Highlighting evidence for both (a) substantial exploitation of avifauna and certain classes of high-value (in Human Behavioral Ecology terms) maritime fauna on these islands, and (b), using settlement size as a proxy for human population size, he largely rejects explanations based on exaggerated demographic stochasticity in early colonizing populations, and suggests instead that the Mystery Islands may represent examples of what might be termed ecodemographic bottlenecks. In these bottlenecks, burgeoning populations based on energetically efficient gathering strategies – often focused on naïve endemic biotas – became inherently unfeasible as these strategies broke down because of resource depletion and extinction of prey species, with islanders unable to replace such strategies with mixed intensive horticultural and reef or pelagic fishing (these islands being either too small, too dry, or existing in an oddly inverse 'Goldilocks' zone; too cool for coral; too warm for seasonal abundances).

This is, in essence, an argument about relative resilience as a function of island latitude, size, and ecological heterogeneity. Some islands were resilient to human colonization – driving catastrophic ecological change – in the short- to medium-term; some were much less resilient in these terms, with colonizing populations accordingly following common trajectories towards ecodemographic crunches (see Anderson 2001, 2002; Weisler 1995 for a detailed consideration of these interrelated processes on Henderson). Problematically, other islands in the Pacific aside from the Mystery Islands were also probably less resilient in environmental terms – such as Rapa Nui, the Chathams, or the northern Marianas – and yet remained permanently settled or were not settled at all. As Anderson (2001:14) has pointed out, if we are to build useful explanations of the Mystery Island phenomenon, modes of explanation will need to be able to account for not only abandonment in some parts of the Pacific, but also continuity of settlement in others; that is, to explain why some excellent candidates for Mystery Island status did not experience human abandonment or localized extinction.

Before moving to a synthetic model, we need to consider the relationship between the liminal types of environmental configuration that Anderson highlights and types of demographic dynamics that might be driven by human subsistence strategies in such environments. It is suggested that environmental and demographic fragility are functionally related, in that certain types of island physiographic configuration probably exposed colonizing populations to exaggerated growth and subsequent contraction. Based on previous modeling (Leppard 2015), which suggests that demographic growth can have consequences for cultural contact and genetic flow between separated populations, it is argued that populations on islands with low K were ultimately vulnerable to the pronounced stochasticity that small populations experience. This argument is essentially built around a framework in which stochastic vulnerability arises from deterministic conditions; even if *K* and trajectories of growth are not known, they can be modeled with varying degrees of confidence across a set of islands sharing ecophysiographic characteristics.

In explaining why the Mystery Islands, and not others, were depopulated, we then turn to other, qualitatively dissimilar types of stochastic processes with implications for already fragile demographic structures. Focusing on the – admittedly sparse – radiometric data from the Mystery Islands suggests that abandonment and/or localized extinction processes occurred relatively late in the Pacific cultural sequence. Accordingly, the spatial aspects of (a) disease transfer in the Pacific from 1000 BP to present (and especially implications of pathogen transfer for small populations), and (b) the onset of less ameliorative climatic conditions during the last six hundred years BP are considered as potentially relevant factors.

METAPOPULATION DYNAMICS AND DEMOGRAPHIC STOCHASTICITY

Small populations of organisms, including humans, are more exposed to various types of stochastic processes than are larger populations (Bocquet-Appel 1985; Lande 1993; Melbourne and Hastings 2008), lying closer to thresholds of localized unviability (Hanski *et al.* 1996). The effects of demographic stochasticity in terms of the viability of very small colonizing populations has been considered before in the context of the pre-contact Pacific (MacArthur *et al.* 1976). Exploring the possibility of modeling strategies to mitigatef demographic stochasticity, it has recently been suggested that the concept of the metapopulation has explanatory potential when it comes to dealing with how populations act to promote stability (Leppard 2015). Metapopulations (i.e., populations of populations) tend to experience lower rates of localized extinction of their constituent units the more well-connected they are in terms of gene-flow; in essence, well-connected metapopulations with high rates of gene-flow form true populations (Hanski 1998). To that end, for small, geographically distinct or isolated populations, there exist strong imperatives to maintain meaningful links with neighboring populations to allow for exogamy, and these links should have social, material, and thereby archaeologically observable effects (cf. Bocquet-Appel 1985). Conversely, as individual populations grow, the imperative to mitigate demographic fragility by maintaining exogamous practices should diminish, and endogamy should become increasingly viable. Again, this should be archaeologically observable; there is little room here to discuss specific examples, but the Lapita expansion into western Remote Oceania, and the subsequent overall breakdown in cultural homogeneity, may be explicable in these terms (Leppard 2015).

This model, depending on the extent to which it approximates reality, has implications for the human colonization of remote Oceania. There is general agreement that initial colonizing propagules in Polynesia were small, but that, following colonization, these populations probably experienced variations on *r*-type growth moving towards *K* (e.g., Kirch 1990: 321–326, 2010: 128–140). If overall connectivity should in fact decrease as populations – moving towards the carrying capacity of their environment – become less dependent on the wider metapopulation for stability (cf. Hunt 1987: 326–9), then the potential security afforded by this connection to the wider metapopulation is lost. Thus far, we have only considered population growth, not decline. The data (Anderson 2001; Steadman and Olson 1985) do seem to indicate overexploitation of endemic faunas to the extent that we might then expect demographic crashes accompanying the depletion of island food resources. These crashes – potentially socially traumatic, possibly hard to access archaeologically – would drive populations down towards totals which lay closer to thresholds of viability.

This in general suggests that, on smaller or less ecologically robust islands, demographic crashes should (a) follow hard on the heels of anthropogenic environmental trauma, and (b) that this should occur after the social links which allow for exogamy have broken down, stranding smaller and thereby more fragile populations in a state of relative (but presumably not absolute) isolation from the overall metapopulation. In this way, then, we can reintroduce demographic stochasticity into the causal chain, *not* at the point of colonization, but rather following population crashes later in settlement histories. In so doing, we may link anthropogenic environmental deterministic explanations and demographic-stochastic explanations as functionally related.[1]

SPATIAL AND TEMPORAL ORGANIZATION OF DEPOPULATION: PATHOGENIC AND CLIMATIC FACTORS

Unifying environmentally- and demographically-driven explanations does not, however, account for why some islands which we may also reasonably suppose to have ex-

---

[1] This implicitly endorses what may be considered the general consensus view of post-colonization Polynesian voyaging; that return voyaging, or maintenance of long-distance contact, was normal in central Polynesia, becomingly increasingly rare towards the corners of the Polynesian triangle and as the last millennium BP progressed. This is not a universally held position, and it may be the case that return voyaging was the vanishing exception, rather than the norm. There is little room to explore this topic or the associated literature here, but the nature and extent of inter-island contact in central Polynesia clearly has profound implications in the context of pathogen transmission.

perienced ecodemographic overshoot did not similarly experience extinction or abandonment. As such this does not address the problem explicit in Anderson's challenge: why this subset of islands, but not others which resemble them in ecological and physiographic terms, which we might expect to have been equally exposed to demographic fragility driven by such ecological and physiographic organization? An unsatisfactory but potentially accurate answer relates to historical contingency. It may be that essentially random processes imposed unstructured sorting on small, dry, or otherwise depauperate Pacific islands which had experienced demographic crashes and relative social isolation, and that – if we were to re-run the human seeding of the Pacific a large number of times – at each iteration a different subset of islands would succumb to the mathematics of small numbers.

One potential route away from resorting to random process may involve thinking about the spatial and temporal organization of island depopulation in terms of factors which exhibit stochastic dynamics but are explicable probabilistically, rather than being truly random. Likely candidates for this sort of factor are large-scale processes which (a) effect the organization of human populations, (b) whose effects on populations vary depending on the spatial structure of these populations, and (c) which occur on timescales or at tempos which makes them substantially unpredictable at a decadal scale. Disease events and medium-term climatic change arguably fall into this category. What, then, do temporal and spatial patterning in island abandonment or localized extinction suggest in terms of processes of this sort?

In terms of temporal patterning, the data are few but nonetheless potentially suggestive. Radiometric dates for abandonment or extinction contexts are nearly impossible to achieve. We are forced to use the latest available dates for each island; these are few and far between for the islands in question, and reporting standards vary quite substantially. It is nonetheless interesting, however, that dates from Henderson, Norfolk, Raoul, and Nihoa indicate the persistence of human settlement into the second half of the last millennium. From Henderson, the latest viable date is ~390 bp (495 ± 105 BP; Diamond 1985); this agrees with a rather curiously reported date from the excavation at HEN-20 (Weisler 1994). On Norfolk, the latest date is perhaps ~450 bp (Anderson 2001); from Raoul, ~454 bp (518 ± 64 BP; Anderson 1980); and from Nihoa – recognizing that the relevant sample is poorly provenanced – the latest possible date is ~314 bp (514 ± 200 BP; Kirch 1988). At a gross scale, it appears that the Mystery Island phenomenon is a comparatively late one.

Spatial structure is equally protean; form is hinted at, but hard to define. Remoteness is extremely difficult to quantify in terms which are useful in the context of specifying human responses to it (e.g., Boomert and Bright 2007; Fitzpatrick *et al.* 2007), but, that said, we might tentatively speculate that the Mystery Islands exhibit patterning in their *relative* isolation. They are, compared to most of the groups between the Solomons and Fiji, remote, but not as distant as Rapa Nui or New Zealand (excepting, of course, Necker and Nihoa, although these are remote in their local context, the Hawaiian chain). The Kermadecs, Norfolk, the Pitcairn group, Palmerston, Howland, Kiritimati, and Suwarrow are all either isolates, or in comparatively small isolated archipelagoes, separated from the main Pacific groups by hundreds (although not thousands) of kilometers of ocean (e.g., Irwin 1992: 174–204); there might be, in this observation, a hint of geographic structure. What types of Pacific-wide events may, then, conceivably have been occurring within this timeframe that might be expected to have differential impacts on small, depauperate, and relatively (but not absolutely) remote islands spread across the basin?

For the continental Americas, knowing the approximate date of introduction of some of the pathogens which evolved in Holocene Eurasia (subsequent to the effective separation of Amerindian and Eurasian populations) is very suggestive in the context of the massive demographic trauma experienced by indigenous Americans from 500–200 BP (Crosby 1976; Nunn and Qian 2010). The picture in the Pacific is less distinct. It is not clear, for example, when some of the more virulent Eurasian mainland diseases were introduced to the Pacific. Possibilities for introduction include (a) having spread eastwards with the first colonists, (b) having only arrived with the first Europeans between 450 and 150 BP, or (c) periodically pulsing across the basin in the intervening millennia (genetic evidence for limited Polynesian-Amerindian contact in South America, and the absence of smallpox, measles etc. from the Americas until 500 BP, perhaps suggests one of the latter scenarios). If various Pacific islands did, however, experience catastrophic demographic crashes in the centuries following initial Eurasian forays into the basin (Kirch and Rallu 2007), a type of general – rather than context-specific – explanation is preferable. Bearing in mind the high virulence of the poxviruses, morbilliviruses, and influenzas in immunologically inexperienced populations (e.g., Anderson and May 1992; Eichner and Dietz 2003: 11–18), the spread of introduced pathogens through inter-connected small populations in a manner usually modeled as stochastic sounds like the type of process that could account for variation in survival of such populations.

The relevance of this observation for the Mystery Islands lies in recognizing that we are probably dealing with small, remote populations which were nonetheless not *absolutely* socially isolated. Various Old World viruses (and some bacterial infections, such as bubonic plague/*Yersinia pestis*) are highly infectious, moving with epidemic ease across previously unexposed populations. The only effective defenses are absolute insulation from the pathogen, previous exposure, or robust demographic units capable of absorbing high mortality rates. It may be that the Mystery Islands, post initial population crash, would neither be totally insulated (like Hawai'i or New Zealand, which experienced the effects of Eurasian pathogens comparatively later; we would expect, then, the abandonment of Necker and Nihoa to be correspondingly late), nor robust enough demographically to absorb exacerbated mortality. By being simultaneously small, depauperate, remote, but not remote enough to be insulated, islands like Kiritmati and Raoul may have been fatally exposed to transmission of highly infectious pathogens via sporadic long-distance contacts and, lacking large enough populations to provide long-term viability, experienced demographic depression below absolute or culturally-constructed viability thresholds.

A second factor that may be relevant, if episodes of abandonment or extinction date approximately to 700–300 BP, is dynamism in the Holocene climate system. Nunn *et al.* (2007) have explored the effects of the 'AD 1300' event for the settlement histories and sociospatial organization of several Pacific islands (although cf. Fitzpatrick 2010). While their case studies do not include the Mystery Islands, they argue that overall cooling in the Pacific basin (along with associated decreased rainfall and potentially sea-level drawdown) from around 650 BP drove both the breakdown of inter-island contacts and associated broad social organization changes in Polynesia. While there are numerous potential avenues via which to explain decreasing long-distance contact, it is nonetheless clear that medium-scale climatic variability has exercised profound influence over the parameters of human behavior in the Pacific (Anderson *et al.* 2006), and Nunn *et al.* remind us that decreased rainfall would have stressed established – and potentially brittle – subsistence strategies. In the small and depauperate islands whose populations were eventually to succumb to extinction or abandonment, environmental stresses of this sort would have been all the more exaggerated.

DISCUSSION

It is likely that the most effective means of explaining the Mystery Islands phenomenon (certainly in the Pacific; potentially elsewhere, such as Barbados and also in the Mediterranean) involves recognizing that multiple types of process operating at a range of scales specified the final, archaeologically visible result. We can, to some extent, generalize about more deterministic and less deterministic aspects of these processes. In the abstract, because of the organization of island ecologies, the naivety of their biotas, and the rapaciousness of colonizing modern humans, we can predict to a considerable degree likely ecological outcomes of colonization on small Pacific islands. What happens next in historical ecological terms is, however, parameterized by physiographic and cultural variables, not least degree of environmental resilience and speed of subsistence adaptation. In islands with reduced carrying capacity (either because of small size, dryness, or absence of marine resources), we might expect initial population boom to be followed by ecodemographic bust, driving populations back down into ranges in which stochastic perturbations could have had exaggerated structuring effects, and thereby towards thresholds of tolerance.

This provides the initial deterministic set of conditions driving demographic fragility, upon which other types of stochastic (or historically contingent) processes can operate, whether the introduction of unknown pathogens – the spread of which would display spatial structure – or climatic wobbles. In the face of these contingent circumstances (disease and climate have been outlined here, not exhaustively, but more in terms of the types of processes we might expect), it is likely that the Mystery Island communities were peculiarly exposed: already hovering close to the boundaries of survivability and increasingly isolated from bigger, more robust demographic units, but proximate enough to suffer the consequences of biological events like the introduction of Eurasian pathogens. This is to reiterate, and to some extent build upon, Anderson's (2002) observation: that anthropogenically-driven environmental change was clearly vital in specifying subsequent historical ecological trajectories, but that variability in climatic conditions over the medium term (and in particular spatial and temporal variability in rainfall) was probably a more significant determinant for the viability of small, liminal populations. Climate – as well as the spatial aspects of disease transmission – have only been dealt with perfunctorily here, but that these (along with other factors, such as demographic structure and environmental degradation, for which we have more robust data) can be modeled grossly should provide reasons for optimism in teasing apart the fabric of prehistoric demographic and settlement histories. Recognizing that we can, to some extent, predict the breaks of the island game is likely to have more general applicability, not only in the Pacific but also beyond.

Acknowledgments

I would like to thank: Atholl Anderson, John Cherry, Scott Fitzpatrick, and Elizabeth Murphy for their helpful comments on an early version of this paper; Helen Dawson for our ongoing discussions regarding island abandonment; and the two anonymous reviewers for insightful and constructive criticism. I would also like to thank the editorial staff at JPA, and in particular Ethan Cochrane, for a deep and critical reading of the submitted text which highlighted initial weaknesses of style and argumentation. Research for this paper was supported by a postdoctoral fellowship at Rutgers' Center for Cultural Analysis, the support of which I gratefully acknowledge.

References

Anderson, A.J. 1980. The archaeology of Raoul Island (Kermadecs) and its place in the settlement history of Polynesia. *Archaeology and Physical Anthropology in Oceania* 15:131–41.

Anderson, A.J. 2001. No meat on that beautiful shore: The prehistoric abandonment of subtropical Polynesian islands. *International Journal of Osteoarchaeology* 11:14–23.

Anderson, A.J. 2002. Faunal collapse, landscape change and settlement history in Remote Oceania. *World Archaeology* 33:375–90.

Anderson, A.J., J. Chappell, M.K. Gagan, and R. Grove. 2006. Prehistoric maritime migration in the Pacific islands: a hypothesis of ENSO forcing. *The Holocene* 16:1–6

Anderson, R.M. and R.M. May. 1992. *Infectious Diseases of Humans: Dynamics and Control*. Oxford: Oxford University Press.

Bellwood, P. 1978. *The Polynesians: Prehistory of an Island People*. London: Thames and Hudson.

Bocquet-Appel, J.-P. 1985. Small populations: Demography and palaeoanthropological inferences. *Journal of Human Evolution* 14:683–91.

Bocquet-Appel, J.-P. 2011. When the world's population took off: The springboard of the Neolithic demographic transition. *Science* 333:560–1.

Boomert, A. and A.J. Bright. 2007. Island archaeology: in search of a new horizon. *Island Studies Journal* 2:3–26.

Crosby, A.W. 1976. Virgin soil epidemics as a factor in the aboriginal depopulation in America. *The William and Mary Quarterly* 33:289–99.

Diamond, J. 1985. Why did the Polynesians abandon their mystery islands? *Nature* 317:764.

Eichner, M. and K. Dietz. 2003. Transmission potential of smallpox: Estimates based on detailed data from an outbreak. *American Journal of Epidemiology* 158:110–17.

Fitzpatrick, S.M. 2010. A critique of the 'AD 1300 event', with particular reference to Palau. *Journal of Pacific Archaeology* 1:168–73.

Fitzpatrick, S.M., J. Erlandson, A. Anderson, and P.V. Kirch. 2007. Straw boats and the proverbial sea: a response to 'Island archaeology: in search of a new horizon.' *Island Studies Journal* 2:229–38.

Goldberg, A., A.M. Mychajliw, and E.A. Hadly. 2016. Post-invasion demography of prehistoric humans in South America. *Nature* 532:232–5.

Hanski, I. 1998. Metapopulation dynamics. *Nature* 369:1–49.

Hanski, I., A. Moilanen, and M. Gyllenbern. 1996. Minimum viable population size. *American Naturalist* 147:527–41.

Hunt, T.L. 1987. Patterns of human interaction and evolutionary divergence in the Fiji islands. *The Journal of the Polynesian Society* 96:299–334.

Irwin, G. 1992. *The Prehistoric Exploration and Colonisation of the Pacific*. Cambridge: Cambridge University Press.

Kirch, P.V. 1988. Polynesia's Mystery Islands. *Archaeology* May-June:26–31.

Kirch, P.V. 1990. The evolution of sociopolitical complexity in Prehistoric Hawaii: An assessment of the archaeological evidence. *Journal of World Prehistory* 4:311–45.

Kirch, P.V. 2010. *How Chiefs Became Kings: Divine Kingship and the Rise of Archaic States in Ancient Hawai'i*. Berkeley: University of California Press.

Kirch, P.V. and J.-L. Rallu (eds.). 2007. *The Growth and Collapse of Pacific Island Societies: Archaeological and Demographic Perspectives.* Honolulu: University of Hawai'i Press.

Lande, R. 1993. Risks of population extinction from demographic and environmental stochasticity and random catastrophe. *The American Naturalist* 142:911–27.

Leppard, T.P. 2015. Adaptive responses to demographic fragility: Mitigating stochastic effects in early island colonization. *Human Ecology* 43:721–34.

McArthur, N., I.W. Saunders, and R.L. Tweedie. 1976. Small Population Isolates: A Micro-Simulation Study. *Journal of the Polynesian Society* 85:307–326.

Melbourne, B.A. and A. Hastings. 2008. Extinction risk depends strongly on factors contributing to stochasticity. *Nature* 454:100–3.

Nunn, P.D., R. Hunter-Anderson, M.T. Carson, F. Thomas, S. Ulm, M.J. Rowland. 2007. Times of plenty, times of less: Last-millennium societal disruption in the Pacific basin. *Human Ecology* 35:385–401.

Nunn, N. and N. Qian. 2010. The Columbian exchange: A history of disease, food, and ideas. *Journal of Economic Perspectives* 24:163–88.

Steadman, D.W. and S.L. Olson. 1985. Bird remains from an archaeological site on Henderson Island, South pacific: Man-caused extinctions on an "uninhabited" island. *Proceedings of the National Academy of Sciences* 82:6191–5.

Terrell, J.E. 1986. *Prehistory in the Pacific Islands.* Cambridge: Cambridge University Press.

Timpson, A., S. Colledge, E, Crema, K. Edinborough, T. Kerig, K. Manning, M.G. Thomas, and S. Shennan. 2014. Reconstructing regional population fluctuations in the European Neolithic using radiocarbon dates: A new case-study using an improved method. *Journal of Archaeological Science* 52:549–57.

Weisler, M.I. 1994. The settlement of marginal Polynesia: New evidence from Henderson Island. *Journal of Field Archaeology* 21:83–102.

Weisler, M.I. 1995. Henderson Island prehistory: Colonization and extinction on a remote Pacific island. *Biological Journal of the Linnean Society* 56:377–404.

Weisler, M.I. 1998. Issues in the colonization and settlement of Polynesian Islands. In: Vargas Casanova, P. (ed.), *Easter Island and East Polynesian Prehistory*, Santiago: Universidad de Chile, pp. 73–86.