Human-Environment Relationships in the Pacific Islands around A.D. 1300

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SUMMARY

This paper traces the history of human-environment interactions in the Pacific Islands during the last millennium, focusing on three main periods: the Little Climatic Optimum, the Little Ice Age, and, in greatest detail, the transition around A.D. 1300 between the two.

The Little Climatic Optimum (approximately A.D. 750–1300) was marked by warm, rising temperatures, rising sea level and probably increasing aridity. The latter condition was linked to development of water-conservatory strategies (agricultural terracing being the most common) requiring cooperation between human groups which facilitated formation of large nucleated settlements and increased sociopolitical complexity.

The transition period (approximately A.D. 1270–1475) involved rapid temperature and sea-level fall, perhaps a short-lived precipitation increase. Temperature fall stressed crops and reef organisms, sea-level fall lowered water tables and exposed reef surfaces reducing their potential as food resources for coastal dwellers. Increased precipitation washed away exposed infrastructure. Consequently food resource bases on many islands diminished abruptly across the transition.

The Little Ice Age (approximately A.D. 1300–1800) was marked by cooler temperatures and lower sea levels. The lingering effects of the earlier transition

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largely determined human lifestyles during this period. Conflict resulted from resource depletion. Unprotected coastal settlements were abandoned in favour of fortified inland, often upland, settlements.

Climate change is suggested to have been a important determinant of human cultural change during the last millennium in the Pacific Islands.

KEYWORDS

Pacific Island, human settlement/environment interaction, climate change

INTRODUCTION

Most tropical Pacific Island groups had been settled by humans before A.D. 1100 (Figure 1). There is considerable debate about the extent and precise nature of early human impacts on island environments, some authors favouring the idea that settlement by early humans brought about abrupt, severe and enduring changes,[2] others highlighting the uncertainties in the evidence for human impact, and emphasising non-human causes of environmental change.[3]

By the beginning of the last millennium (A.D. 1000), human communities on most Pacific Islands appear to have had few sustained impacts on their environments, probably because population densities were low relative to the resilience of island ecosystems, and perhaps because people were also more transient (settlements were less permanent) than at later times. Although divisions of culture history within the last millennium have been recognised on many islands and island groups throughout the Pacific,[4] most authors have assumed that the primary causes of change were linked to human activities and have thus sought local or regional (typically archipelagic) rather than Pacific-wide explanations for these. Yet many of these changes (from one division to another of culture history) appear to have been abrupt and, in some places, accompanied by environmental change. It has been claimed that such environmental changes were also the outcome of human activities. Supporting evidence commonly goes little beyond the belief that post-settlement environmental change in the Pacific Islands was caused (largely) by human impact and that, in consequence, any abrupt change within this period must have been caused by human impacts reaching a level which produced a rapid and irreversible response in the environment. In the light of recent work documenting abrupt climate changes[5] such inferences can be challenged.

Evidence has been compiled in recent years to allow recognition of an 'A.D. 1300 event' during which temperatures and sea level fell rapidly in much of the Pacific and which had widespread effects on island environments and societies.[6] Hitherto such evidence was interpreted almost exclusively in terms of human impact.

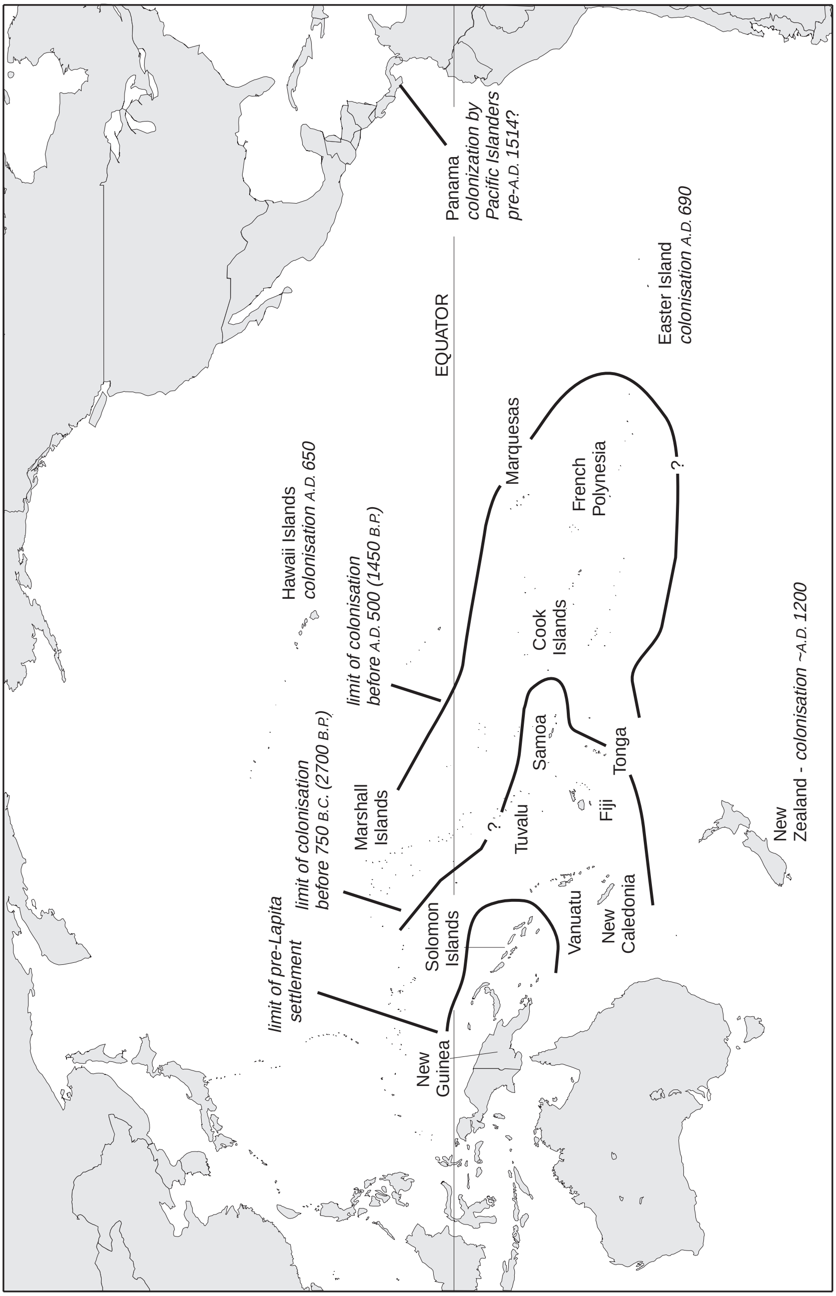

FIGURE 1. Map of the Pacific Islands showing the main islands and island groups named in the text. Isolines indicating the earliest-known time of initial human settlement in various places are also shown (from various sources).

An influential example comes from Easter Island (Rapanui) where the Ahu Moai Phase, during which the islanders carved, transported and erected giant statues (*moai*) along the coast, was succeeded by about A.D. 1500 by the Huri Ahu Phase, during which many statues were pulled down and destroyed: a conspicuous manifestation of the conflict, widely attributed to overpopulation and deforestation, which raged in Easter Island society during this period.[7] The main problem with citing overpopulation and deforestation as causes of this societal breakdown is that there is no independent evidence for them; even key elements of the suggested scenarios have been cogently challenged recently.[8] It is more plausible to suppose that the collapse of the Easter Island social order at this time was driven largely by an abrupt reduction in the food resource base associated with rapid climate change around A.D. 1300 for which palaeoenvironmental evidence in the south and east Pacific is widespread.[9]

One reason why Pacific-wide explanations of last-millennium cultural changes have not been sought is that none have appeared available to most investigators. Recently this situation has begun to change as more has become known about natural (non-human) changes during the last millennium in the Pacific Islands. Now there is a sea-level curve which broadly traces temperature change both as known directly and as inferred from other sources.[10] There is also evidence that rapid cooling and sea-level fall around A.D. 1300 coincided with a rise in El Niño frequency which may have been responsible for a short-lived increase in precipitation in the Pacific at the time (see Figure 2).[11]

This paper advances the view that most major pre-European (effectively pre-1850) cultural transformations to have occurred on Pacific Island groups during the last millennium can be explained by natural, climate-linked changes rather than human impact. With this in mind, a chronology based on the last-millennium sea-level history shown in Figure 2 is used here. Within the time frame of interest (A.D. 1100–1500), three divisions can be recognised: the Little Climatic Optimum (Medieval Warm Period), the Little Ice Age, well-known from other parts of the world, and the less widely-acknowledged transition between the two.[12] Each of these divisions is discussed in turn below with reference to the climate, sea level, and cultures of the Pacific Islands, with particular attention being given to the transition period.

PRELUDE: THE LITTLE CLIMATIC OPTIMUM

Lasting in the Pacific Islands from around A.D. 750 to A.D. 1300, the Little Climatic Optimum was a time during which temperatures and sea levels rose gradually (see Figure 2). Palaeoenvironmental evidence for the occurrence of the Little Climatic Optimum along the continental borders of the Pacific is abundant.

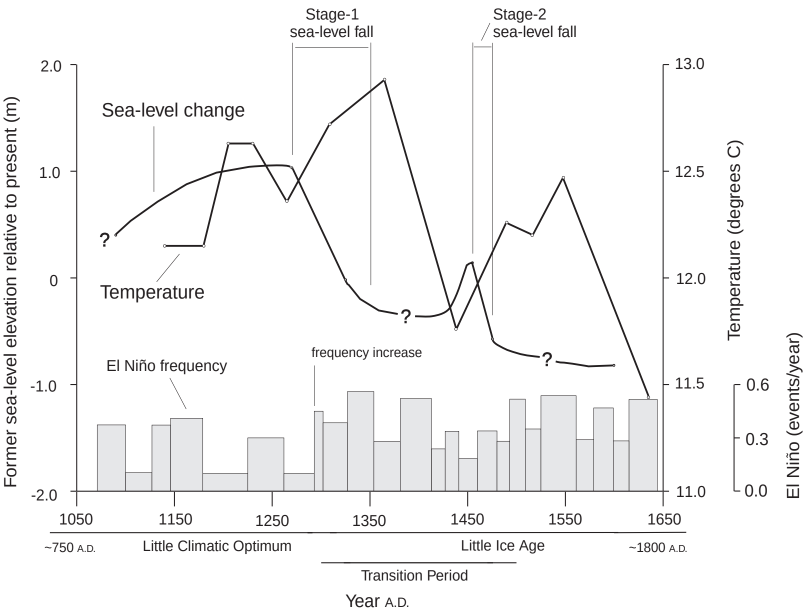

FIGURE 2. Sea-level change A.D. 1100–1600 from Pacific Island data.[13] Also shown are temperature changes from oxygen-isotope analysis of a New Zealand stalagmite [14] and a reconstruction of El Niño frequency.[15]

It includes a period of warming 1250–650 B.P. in Pacific Antarctica,[16] a comparable situation marked by population increase and progressive land degradation in parts of Mexico,[17] wider tree rings A.D. 900–1300 in the southern Canadian Rockies,[18] a warm period in eastern China A.D. 1200–1300 when citrus and the perennial herb *Boehmeria nivea* reached their northernmost limits in recorded history,[19] and a similar situation in Tasmania revealed by dendrochronological studies of the long-lived *Lagarostrobos franklinii* (Huon Pine).[20] There have been no comparable palaeoclimatic studies in the Pacific Islands although reconstruction of palaeosea levels – an acceptable proxy of temperature change over such time periods – shows that sea level rose slowly throughout the Little Climatic Optimum.[21]

In most Pacific Island groups around the start of the Little Climatic Optimum, most settlements appear to have been small, (near-) coastal and undefended.[22] Larger, nucleated settlements (a measure of increased sociopolitical complexity) had not yet developed in many places. Marine and littoral resources continued to dominate island diets. Conflict between human groups appears not to have been common; weapons of war were not manufactured in large quantities until many centuries later.

Towards the end of the Little Climatic Optimum, most Pacific Island settlements were still located along the coast but many were larger and more structured than they had been at the beginning of the period. The best examples come from the denser archipelagoes of the southwest Pacific where there was sufficient room for scattered settlements to develop and later to coalesce; examples are likely to occur on Totoya,[23] Kabara and Lakeba islands [24] in Fiji. Many island communities had constructed and operated elaborate agricultural terrace systems for growing a variety of root crops.

It is likely the Pacific Islands became increasingly arid as the Little Climatic Optimum progressed, perhaps as a consequence of both rising temperatures and progressively reduced forest cover. One outcome of this for their human occupants was to realise the need to make maximum use of available water. To this end on many islands, a range of artificial structures – canals, aqueducts, and, most commonly, agricultural terraces – were constructed.[25] Undertaking such enterprises required co-operation between small groups, and could have led to the amalgamation of smaller settlements into larger ones, and a consequent increase in sociopolitical complexity.[26] This suggestion does not negate anthropological explanations of early last-millennium increases in sociopolitical complexity throughout the Pacific Islands, it merely suggests that this process began only when contemporary aridity started to affect human livelihoods, which would also have been affected by other, more localised factors such as population growth.

AROUND A.D. 1300: THE TRANSITION PERIOD

Overview

It is unfortunate that so little attention has focused on the transition between the Little Climatic Optimum and Little Ice Age because it is the most rapid climate change to have occurred within the last millennium and is considered to have played a major role in the shaping of many more recent societies in the Pacific Islands.[27]

The evidence for a short and rapid cooling around A.D. 1300 is well marked around the Pacific Rim where it also appears to have had a major influence on human communities.[28] Palaeoenvironmental evidence of cooling occurs in the southern Andes A.D. 1270–1340,[29] in western Canada [30] and southern Alaska [31] and in New Zealand.[32] Examples of abrupt cultural transformations around the Pacific Rim at this time are known from Peru,[33] from southern Alaska [34] and from coastal Australia.[35]

In the tropical Pacific Islands it has been suggested that the transition period between the Little Climatic Optimum and the Little Ice Age lasted only some 100 years [36] yet recent analysis of sea-level change around A.D. 1300 suggest that in much of this region it was of longer duration and may have involved two distinct steps (see Figure 2).[37] Assuming that sea-level fall was driven by a multi-stage temperature fall (totalling a net 1.5°C in New Zealand – Figure 2), the most plausible reconstructions of sea level, shown by broken lines in Figure 2, involve a 75-cm sea-level fall A.D. 1270–1325 (680–625 cal yr B.P.) followed by a 40-cm fall A.D. 1455–1475 (495–475 cal yr B.P.): rates of 14 mm/yr and 20 mm/yr respectively.

There is some evidence that the transition period in the Pacific Basin was marked by increased precipitation levels, far greater than were experienced during either the Little Climatic Optimum or Little Ice Age.[38] Examples from the Pacific Rim include the evidence for increased ice accumulation at Quelccaya in the Peruvian Andes [39] and the regional increases in effective precipitation in Mexico [40] and western Canada.[41] An abrupt peak occurs at this time in some proxy records of precipitation from California and coastal China.[42] For the Pacific Islands there are poorly-dated indications of increased precipitation in the Marquesas and Galapagos islands.[43] Increased precipitation around A.D. 1300 may represent an increase in cyclonic storms, particularly tropical cyclones (hurricanes or typhoons) in the tropical Pacific, and is likely to be linked to the increased El Niño frequency (see Figure 2).[44]

This account examines in detail the environmental and societal changes which occurred in three Pacific Island environments (upland, lowland-coastal, reef-lagoonal) during the transition period and which are likely to be connected to the cooling, sea-level fall and precipitation increase which characterised it.

Upland environments

The impact of falling temperatures during the transition period would have placed stress on some crops, particularly those that were already close to their lower limits of temperature tolerance. Falling sea level during the transition period would have caused water tables to fall, reducing the groundwater available to shallow-rooting plants in upland areas. Some examples are discussed in the following section.

An increase in precipitation in the Pacific Islands across the transition would have had the greatest impacts on upland environments. Particularly in steepland areas, many of which had been rendered suitable for agriculture only by being terraced, massive soil erosion and landsliding would have resulted from the unusually large amounts of rainfall over prolonged periods. Artificial structures, designed to optimise the use of lesser amounts of water, would have been destroyed as their capacity was exceeded, and the consequence could have been the almost total destruction of upland agricultural production on some islands.

Among the direct records of the environmental effects of increased precipitation on Pacific Islands around A.D. 1300 is the 'catastrophic forest destruction' in Japan,[45] and the situation in New Zealand where ‘gales damaged forests and coastlines [and] heavy rainfalls produced major floods which devastated the vegetation and soils’.[46] Contemporaneous and subsequent societal changes, discussed in a later section, provide additional support for the environmental effects of increased precipitation.

Lowland-coastal environments

In the centuries leading up to the transition, most Pacific Island settlements were located along island coasts or a little inland, typically along flat well-drained alluvial plains. While many crops growing in such areas were less likely to have been close to their lower temperature tolerance limits, some undoubtedly were. Although not exclusively a lowland crop, a good example is sweet potato (or *kumara*: *Ipomoea batatas*), a crop which arrived in New Zealand with the first settlers probably around A.D. 1150. The warm temperatures of the Little Climatic Optimum allowed sweet potato to be grown successfully in most parts of New Zealand up until around A.D. 1350 when temperatures fell abruptly.[47] Thereafter, despite the development of techniques for its long-term post-harvest storage, sweet potato declined in importance as a food for the Maori people.

Lowland crops being grown on coastal plains could have been severely affected by water-table fall associated with sea-level fall at this time. Dryland crops may have failed regularly. Wetland agriculture in these areas may occasionally (seasonally and/or interannually) have suffered from a surfeit rather than a lack of water associated with increased precipitation. Flooding of lowland areas and their soils may have led to falls in agricultural yields, forcing people to depend more on what they could gather from the forest than on what they could plant themselves.

On some islands, opportunities for wetland agriculture increased as a result of sea-level fall around this time, with the transformation of what had formerly been tidal inlets into brackish lagoons and freshwater lakes. Examples are known from Tikopia in Solomon Islands,[48] from Kosrae in Micronesia,[49] and from Mo’orea in French Polynesia.[50] On some of these and other islands, new land, particularly along the reef fringes of coastal lagoons, emerged and/or became available for human colonisation at this time as a result of sea-level fall. Examples are known from Kapingamarangi in the Marshall Islands [51] and from Aitutaki in the Cook Islands.[52]

Assuming that the precipitation increase at this time was associated with an increased frequency of cyclonic storms, this would have seen an increase in storm surges affecting island shorelines. Repeated storms may have led to the abandonment of coastal settlements. Although difficult to date precisely, this is observed around this time throughout the Pacific Islands, from the Fiji archipelago,[53] through New Zealand [54] and French Polynesia [55] to the Pitcairn Group.[56]

An increase in storminess and lowland flooding could also be implicated in the development of pit-storage techniques for the long-term preservation of root crops on tropical islands like Tikopia in Solomon Islands around A.D. 1300 (650 B.P.).[57]

Reef-lagoonal environments

Although cooling around A.D. 1300 may have increased stress on reef ecosystems, most reef organisms would – like today – have probably been living well above their lower temperature tolerance limits, so would have been little affected by cooling, at least compared to other sources of stress.

Most important of these would have been the fall of sea level. It is reasonable to assume that during the Little Climatic Optimum most tropical Pacific Islanders depended on the protein food they could extract from offshore reefs and surrounding waters. Much of that food – crab, octopus, turtle, a variety of shellfish, and the numerous species of fish that frequent inshore and lagoonal waters – flourishes in such places because of the existence of a veneer of living coral at the surface of nearshore reefs. For example, the standing stocks of fishes on coral reefs may be 15 times the stock in the more productive parts of the open ocean but this figure falls sharply as the numbers of reef organisms decrease.[58] Another useful measure is the gross primary production of biomass in grams of carbon per square metre per day, which may reach $20gCm^{-2}d^{-1}$ for high density coral communities but falls to $5–1gCm^{-2}d^{-1}$ for algal pavements and reefs which have been stripped of most living coral or invaded by predators such as *Acanthaster planci* (Crown-of-Thorns starfish).[59]

Given such considerations, the effect of a sea-level fall of perhaps 1m during the transition between the Little Climatic Optimum and the Little Ice Age (see Figure 2) may have proved devastating. The upper surface of fringing reefs would have been exposed, killing off all the sedentary organisms thereon, and displacing many others. Through exposure of reef surfaces, sea-level fall in reefal areas would also have created barriers to water flow which would have increased organic mortality in deeper areas because of reductions in water movement and nutrient flows.

The effects of sea-level fall on reefs A.D. 1270–1475 (see Figure 2) would have been comparable to those observed during the much shorter-duration sea-level falls which affect many Pacific Island reefs during El Niño events.[60] Some periods of prolonged exposure of reefs associated with 20th-century El Niño events have destabilised reef ecosystems to such an extent that predators such as *Acanthaster* can gain access to vast areas of reef which normally resist such infestations (Figure 3). When particular conditions prevail, infestations of *Acanthaster* and bioeroders can become chronic, leading to comprehensive reef degradation.[61]

FIGURE 3. People living on Avea Island in northeast Fiji depend greatly for food on the island's 20–50 m broad fringing reef, shown here exposed during an unusually low tide in July 1999. Were this to be exposed for decades, as during the Transition Period, rather than hours the effects on the island's inhabitants would be severe and enduring.

The increase in precipitation inferred to have affected the tropical Pacific during the transition period would have introduced massive amounts of terrigenous sediment into lagoons, resulting in heightened turbidity levels. The increase in freshwater concentrations in nearshore areas would have reduced their salinity. Turbidity and salinity changes would have led to increased mortality of corals and associated organisms. If, as appears likely,[62] the precipitation increase in the tropical Pacific around A.D. 1300 was the result of increased tropical-cyclone (hurricane) frequency and eastward penetration, then the effect of physical damage to reefs from large waves, well-documented in the twentieth century,[63] is also a factor to consider.

It is difficult to disentangle nearshore environmental changes of this kind from others which happened in the past, particularly in view of the subsequent re-establishment of fringing reefs around most tropical Pacific islands. Perhaps the clearest expression of the reduction in reef resources comes from observations of increased dependency by humans on offshore (deep water) rather than nearshore fishing, as has been documented for Kapingamarangi (Table 1),[64] and from reductions in the amounts of lagoon-harvested materials traded between islands. An example of the latter is the export of pearl shell for making fishhooks from Aitutaki to Ma'uke and Mangaia islands in the southern Cook Islands;[65]

Time (years BP)	Cod/groper catch	Parrotfish catch
100–0	23.26%	20.93%
300–100	19.75%	18.81%
700–300	15.99%	17.27%
?1000–700	7.69%	23.08%

TABLE 1. Changes in the percentage catch of parrotfish and cod/groper on Kapingamarangi, Micronesia, over the last millennium.[66] Parrotfish are abundant and generally easy to catch using nets in shallow water near coral thickets. Cod and groper are more difficult to catch, and can only be caught in deeper water usually from boats. The conclusion of Leach and Ward that the change in relative catch around 700 B.P. 'must indicate a dramatic improvement in fishing skills' [67] is not borne out by the material culture and may rather be one expression of the damage to reef-lagoonal environments which accompanied the rapid sea-level fall around this time and forced the inhabitants of Kapingamarangi to sail offshore to obtain the quantity of food which had hitherto been available inshore.

Aitutaki pearlshell disappeared from Mangaia about A.D. 1300,[68] perhaps because it no longer grew in the Aitutaki lagoon in exportable quantities because of sea-level fall.

Societal outcomes of climate change

Near the end of the transition period, a situation may have prevailed on many Pacific Islands where upland agricultural systems had been destroyed, with much topsoil lost downslope. Lowland-coastal agricultural potential had fallen dramatically, leading people to increase their dependence on foods which could be gathered from the forest. Large, nucleated coastal settlements were abandoned in favour of smaller fortified (upland) inland sites. Reef resources had been reduced. It is no surprise that the dramatic fall in the food resource base which these changes entailed on many Pacific Islands led to conflict, a situation that prevailed on many until their first permanent colonisation by European administrators and missionaries around 150 years ago.

This conflict was manifested by the appearance for the first time of weapons of war on many islands. Examples include Easter Island where obsidian spearheads (*mataa*) began to be manufactured only from A.D. 1300, the same time as people began to inhabit more easily defensible sites such as caves and rock shelters.[69] A similar situation is marked by the poorly-dated start of the Vuda

FIGURE 4. All major mountain tops on Totoya Island in southeast Fiji were occupied around 600 years ago following the abandonment of coastal settlements. Oral traditions recall firebombs being lobbed from one mountain top to the other, a manifestation of the conflict associated with the island's Little Ice Age history. In 1840, the people of Totoya had 'the reputation of being more ferocious and savage than any other [island]; they are said to be constantly at war, and are obliged to reside on the highest and most inaccessible peaks, to prevent surprise and massacre'.[70]

Phase in Fiji, a time during which coastal settlements were abandoned for hilltops, and warfare became endemic (Figure 4).[71] The establishment of fortified, commonly inland, settlements (*pa*) in defensive locations throughout New Zealand by the early 15th century [72] may also have been partly a response to the reduction in the food resource base associated with climate and sea-level changes during the transition.

AFTERMATH: THE LITTLE ICE AGE

The Little Ice Age was a time in the Pacific lasting from about A.D. 1300–1800 when the climate was cooler and drier than today. Evidence for the Little Ice Age has been gathered from most parts of the world [73] and is especially well marked around the continental borders of the Pacific Ocean. Excellent palaeoenvironmental records of the Little Ice Age have been obtained from the South Pole and from Quelccaya in the Peruvian Andes,[74] and from San Joaquin Marsh in California.[75]

Isolation and conflict characterised many Pacific Island societies for much of the (early) Little Ice Age. Isolation within islands was reinforced by isolation on islands within archipelagoes and even farther afield as the meteorological conditions which had facilitated successful long-distance voyaging during the Little Climatic Optimum were replaced by those which militated against it. These included increased storminess and cloudiness, and more variable wind systems.[76] Evidence for sharply decreased inter-island contact around A.D. 1300 exists within the Marquesas[77] and the southern Cook Islands,[78] and more generally within the central eastern Pacific.[79]

Conflict is indicated by the continued manufacture of weapons of war, and the spread of practices like cannibalism and headhunting which can be envisaged as responses to consistently high levels of competition for a pool of food resources significantly diminished from that available during the Little Climatic Optimum. In many island groups, settlements continued to be located in defensible locations, often enhanced by the building of walls and excavation of ditches.

CONCLUSIONS

Independent recognition, as far as available data permit, of the existence of a rapid cooling and sea-level fall, perhaps accompanied by precipitation increase, around A.D. 1300 has important implications for the understanding of subsequent environmental and cultural change in the Pacific Islands. It should remove any notion that the environment was merely a passive backdrop to human endeavours within this period. It provides a reason for re-examining the causes of environmental and cultural changes both on particular islands and within the region as a whole. This paper is only a start to what it is hoped will be a thorough and unbiased investigation of human-environment relationships during the last millennium in the Pacific Islands. There are many difficulties which remain.

It is difficult to pinpoint the times at which particular changes in human lifestyles took place, yet the outline of the climatic model proposed here requires to be tested with such information. For example, the start of the Vuda Phase of Fiji history, when people abandoned their exposed coastal settlements in favour of fortified hilltops, has been dated to around A.D. 1100 yet it appears equally plausible to suppose that this date is perhaps 100–200 years too early, and that it was the 'A.D. 1300 event' which actually prompted this profound lifestyle change. The use of proxies for cultural change – such as the age of a change in lowland sediment type as an indicator of upland terrace development, for example – is fraught with difficulties, not least of which is the assumption that the proxy is valid for the event with which it is believed to coincide. Finally all these sources of potential error and inaccuracy are compounded by the widespread use of radiocarbon dates, which are not as precise as they were once believed to be, and which are even more uncertain in the time around A.D. 1300 because of the existence of a radiocarbon plateau.[80]

Notwithstanding these caveats, it is considered that a valid model for environmental change and cultural transformation within the last millennium for the Pacific Islands is outlined here. It is a model rooted firmly in available observations of environmental change, and has support, albeit necessarily incomplete or imprecise in some instances, from the known record of human culture change.

It is likely that this climate model could be successfully extended to other parts of the world. Data for an 'A.D.-1300 event' from the continental Pacific Rim have been presented by Nunn [81] and include evidence for abrupt climate change, sea-level fall and cultural transformation around this time. Were it to be demonstrated conclusively that this event had in fact had triggered the major changes in human cultural development during the last millennium, that would set the stage for a re-evaluation of ideas about environmental determinism which have fallen out of favour in recent decades.

NOTES

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[1] corresponding author
[2] Kirch 1982, Kirch et al. 1992, Spriggs 1985, 1997.
[3] Brookfield and Overton 1988, Grant 1994, Hunter-Anderson 1998, Nunn 1994a, 1999.
[4] E.g. Anderson 1991, Bahn 1993, Best 1984.
[5] Berger and Labeyrie 1987, Adams et al. 1999.
[6] Allen J. 1997, Nunn 1994b, 1999, 2000.
[7] McCoy 1979; Bahn and Flenley 1992.
[8] Hunter-Anderson, 1998.
[9] McCall 1994; Nunn 1994a, 1999, 2000.
[10] Nunn 1998.
[11] Anderson 1992, Nunn 1999, 2000.
[12] Grove 1988, Hughes and Diaz 1994, Nunn 1994a, 1999.
[13] Nunn 2000.
[14] Wilson et al. 1979.
[15] After Anderson 1992.
[16] Baroni and Orombelli 1994.
[17] Lauer 1993.
[18] Luckman 1994.
[19] Zhang 1994.

[20] Cook et al. 1992.
[21] Nunn 1998.
[22] E.g. Green 1980, Bahn 1993, McGlone et al. 1994, Walter 1996.
[23] Clark et al. 1999, Nunn 1999.
[24] Best 1984.
[25] E.g. Earle 1980, Spriggs 1981.
[26] Kirch 1984, 1997, Spriggs 1986, Nunn 1999.
[27] Nunn 2000.
[28] Nunn 1999.
[29] Villalba 1990.
[30] Luckman 1993.
[31] Wiles and Calkin 1994.
[32] Wilson et al. 1979.
[33] Wells 1990.
[34] Mills 1994.
[35] Hiscock and Kershaw 1992.
[36] Nunn 1994a.
[37] Nunn 2000.
[38] Nunn 1999.
[39] Thompson and Mosley-Thompson 1987.
[40] Metcalfe 1987, O'Hara 1993.
[41] Luckman 1993.
[42] Huntington 1913, Yao 1943, 1944, Schove 1949.
[43] Decker 1970, Sanchez and Kutzbach 1974.
[44] Anderson 1992.
[45] Yasuda 1976: 56.
[46] Grant 1994: 166–167. Approximately 52% of the vegetation on the Ruahine and Pouakai Ranges in New Zealand was destroyed at this time by gales and erosion (Grant 1989).
[47] Grant 1994.
[48] Kirch and Yen 1982.
[49] Athens 1995.
[50] Parkes 1997.
[51] Leach and Ward 1981.
[52] Allen M. 1997.
[53] Shaw 1967, Best 1984, Nunn 1999.
[54] Grant 1994.
[55] Orliac 1997.
[56] Weisler 1996.
[57] Allen M. 1997.
[58] Salvat 1992, Wilkinson and Buddemeier 1994.
[59] Kinsey 1991.
[60] Glynn 1988, Glynn and de Weerdt 1991. From mid-March until the end of May 1983, the mean sea level dropped by 20–25 cm below normal in the Society Islands 'causing extensive death to corals, algae and reef biota close to the surface' (Payri and Bourdelin 1997: 46).
[61] Glynn 1997, Maragos 1997. On Cocos Island in the far eastern Pacific, 90–95% of coral reefs were damaged during the 1982–1983 El Niño event, and subsequent predation by

Acanthaster and bioeroders is causing further degradation (Glynn 1997). The *Acanthaster* infestation at Malakal in Belau (Palau) has persisted – against all expectations – for two decades (Maragos 1997).
[62] Nunn 1999.
[63] Harmelin-Vivien and Laboute 1986.
[64] Leach and Ward 1981.
[65] Walter 1996.
[66] After Leach and Ward, 1981.
[67] Leach and Ward 1981: 100.
[68] Kirch 1997.
[69] Bahn and Flenley 1992.
[70] Wilkes 1845: 145.
[71] Shaw 1967, Rechtman 1995.
[72] Anderson 1991.
[73] Grove 1988.
[74] Mosley-Thompson 1992.
[75] Davis 1992.
[76] Bridgman 1983.
[77] Suggs 1961.
[78] Walter 1996.
[79] Through analyses of legends, Fornander (1969) concluded that the prolonged period of inter-island travelling in East Polynesia ceased abruptly at the end of the 14th century.
[80] It is now known that the atmospheric $^{14}C/^{12}C$ ratio is not constant, as thought once, but fluctuated through time. Using measurements of the $^{14}C/^{12}C$ ratio from wood of known ages, all 'conventional' radiocarbon ages can now be calibrated. Calibrated ages are expressed as ranges, of length varying according to the degree of fluctuation. The radiocarbon plateau around A.D. 1300 represents a high degree of fluctuation, meaning that calibrated age ranges are uncommonly long. Taking for example, Shaw's (1967) earlier date for the beginning of the Vuda Phase (700±300 B.P.) in Fiji, this is calibrated to a calendar age somewhere between A.D. 950 and A.D. 1550, a manifestly unsatisfactory situation for those interested in linking palaeogeographic and cultural transformations.
[81] Nunn 1999.

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