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New Ideas about Late Holocene Climate Variability in the Central Pacific

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Pacific archaeologists, geographers, and other social scientists have long used a model of Late Holocene climate change based largely on other regions of the world. In high-latitude regions, two major climate periods have been recognized: the Medieval Warm Period, dated to ca. AD 900–1200, and the Little Ice Age, dated to ca. AD 1550–1900. However, new evidence from long-lived Pacific corals, along with more general climate modelling, suggests that while the rest of the world was experiencing the Medieval Warm Period, conditions in the tropical Pacific were cool and possibly dry. Similarly, during the Little Ice Age the central Pacific was comparatively warm and wet and stormy conditions more common. A significant body of new evidence points to substantial climate variability in the central Pacific over the past millennium. Changing background climate, El Niño–Southern Oscillation variability, and the potential for regional variation are here considered with an eye to understanding the potential influence of climate on prehistoric human populations in the central Pacific region.

For the past 50-odd years, Pacific archaeologists, geographers, and other social scientists have been using a model of Late Holocene climate change based largely on climate variability known from other regions of the world (e.g., Fagan 2000; Grove 1988; Lamb 1965). Until recently, there was little reason to suspect that conditions in the central Pacific diverged from those of the Northern Hemisphere, where two major climate periods are recognized: the Medieval Warm Period (MWP, also known as the Little Climatic Optimum), dated to ca. AD 900–1200, and the Little Ice Age (LIA), when temperatures were up to 1.2°C cooler (relative to the long-term average), dated to ca. AD 1550–1900 (following Jones, Osborn, and Briffa 2001, 665). Increasingly, however, there is evidence to suggest global variability in the timing, duration, and character of these two periods (Jones et al. 1998; Jones, Osborn, and Briffa 2001; Jones and Mann 2004). In the central Pacific, both observational studies and climate modelling now suggest that the MWP was relatively cool and the LIA relatively warm, the inverse of Northern Hemisphere conditions. Further, other parameters of climate may have been variable within the Central Pacific region. While not promoting an environmental determinist perspective, I argue that it is necessary to evaluate the potential influences of climate variability, at a variety of scales, on Pacific peoples and the biota and landscapes with which they interact; the newly available paleoclimate records will greatly facilitate our efforts to do so.

Climate Variability and Cultural Change in Polynesian Prehistory

The question of how climate variability has shaped human societies has been much debated (e.g., Betancourt and Van Devender 1981; Dean et al. 1985; Lamb 1977; Upman 1984), and climatic explanations have often been rejected as overly deterministic. However, with growing recognition of the impact that climate has on our own lives (e.g., Barnett 2001; Gillespie and Burns 2000; Watson, Zinyowera, and Moss 1998), climatic explanations of prehistoric cultural change appear to be gaining increasing acceptability. A number of recent analyses by both anthropologists and natural scientists have explored the relationships between periods of significant social and economic change and dimensions of climate (e.g., deMenocal 2001; Fagan 2000; Hodell et al. 2004; Hoegh-Guldberg et al. 2000; Jones et al. 1999; Kennett and Kennett 2000; Richerson et al. 2001). These kinds of studies have been most successful in temperate regions, where high-resolution paleoclimate records are comparatively plentiful.

Perhaps not surprisingly, early interest in the role of climate in cultural change in the Pacific also derives from a temperate locality. The two South Pacific islands that constitute New Zealand (fig. 1) were settled by tropical Polynesian colonists (people today known as Maori) at least 700 years ago (see Higham and Jones 2004). More than 50 years ago, Raeside (1948) suggested that changes in South Island vegetation, soils, and sedimentation rates indicated slightly warmer temperatures (possibly by 2°C) in the relatively recent past, conditions which he linked to the Northern Hemisphere MWP. Lockerbie (1950) subsequently drew on this evidence to explain an apparent geographic contraction in Maori gardens over time, suggesting that areas of the country that are today too cold for productive cultivation of traditional crops had been more suitable on the Polynesians' arrival (see also Cumberland 1962; Green 1963; Yen 1961). Subsequently, climate became an integral part of Leach and Leach's (1979) explanations of cultural change at Palliser Bay, at the southern end of the North Island, where they argued that the onset of the LIA, coupled with human activities, led to significant erosion, deterioration of both terrestrial and marine resources, and eventually abandonment of the coast by local Maori except for the occasional gathering of seafood.

More recently, climate variability in the Late Holocene (the past one to two millennia [following Williams and Wigley (1983)]) has been invoked to explain a variety of cultural phenomena in tropical Pacific localities. Climate-based models of cultural change can be roughly divided into two groups, those which consider climatic variability as a general condi-

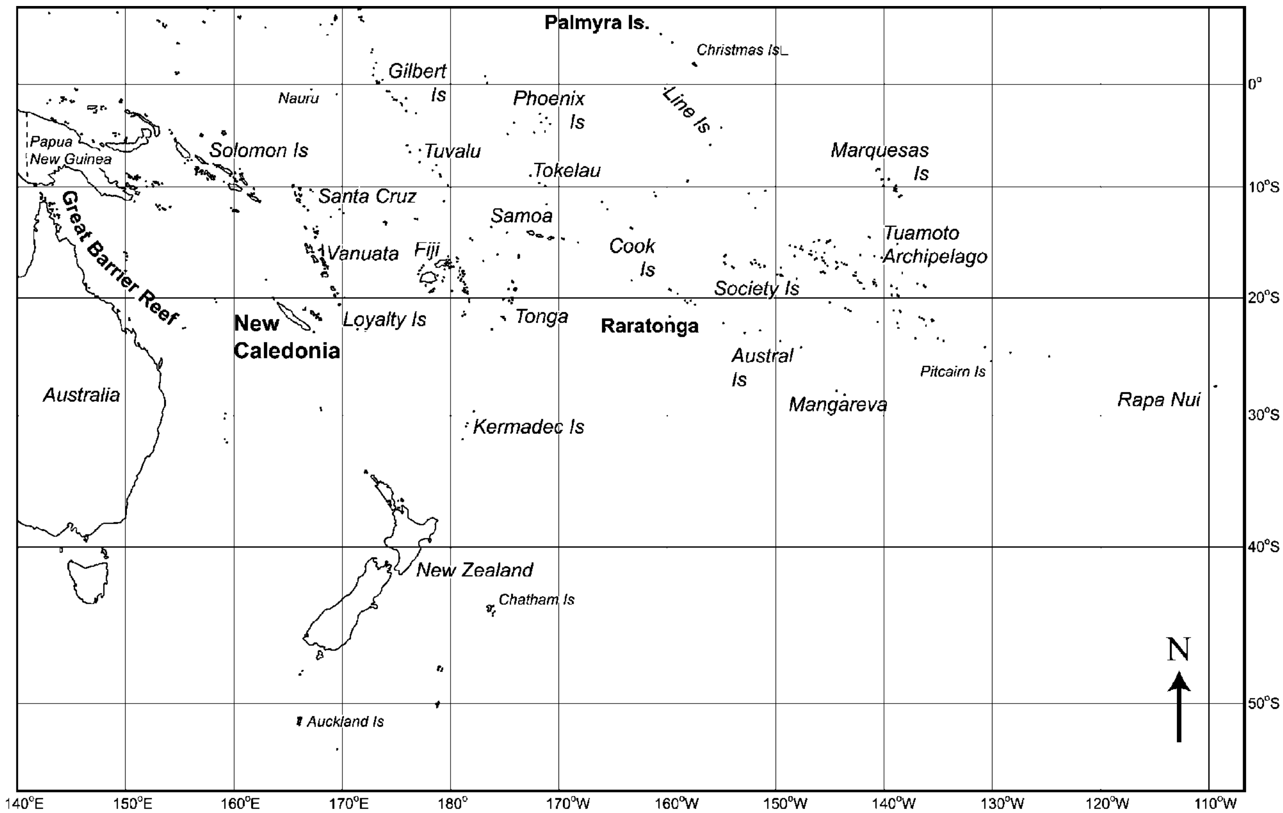

Figure 1. The Pacific, with localities that are discussed at length indicated in boldface.

tion and those which attempt to correlate specific climate parameters with environmental and/or cultural change. As an example of the former, climate variability has been suggested to have promoted cultural elaboration in central East Polynesia (Graves and Ladefoged 1995), Rapa Nui, and Hawai'i (Hunt and Lipo 2001). More specific parameters of climate variability have also been explored. Bridgman (1983), for example, argued that increased storminess associated with the LIA led to a decline in long-distance voyaging, an idea that has been further considered by a number of archaeologists working in the East Polynesian region. Others have suggested that the near-complete deforestation of Rapa Nui stemmed from increasing aridity rather than human impacts (Hunter-Anderson 1998; McCall 1994; Orliac 2000; but see Bahn and Flenley 1992 and Diamond 2005). Similarly, Nunn (2000*a*) posits that the appearance of storage mechanisms on Tikopia Island, the abandonment of pearl-shell fishhooks on Aitutaki in the southern Cook Islands, and declines in terrestrial productivity on Rapa Nui relate to the onset of cooler temperatures during the LIA. One of the most in-depth analyses of the relationship between climate variability and changing patterns of settlement and subsistence has been that of Julie Field (2003, 2004) on Viti Levu Island in Fiji.

Recognition of climate change or lack thereof has also played a role in our understanding of Pacific colonization. In the southern Cook Islands, for example, ideas about the timing of human settlement hinge on our ability to differentiate climate-induced vegetation disturbances from those related to human activities. For at least 1,000 years, the ~1,200-km expanse of open ocean between West Polynesia (Samoa and Tonga) and the southern Cook Islands impeded human settlement of more eastern islands and altogether excluded several other species (see Thorne 1963, 314). Some argue that marked vegetation changes seen in local pollen cores, first at around 450 BC and again at around AD 350, may reflect the arrival of Polynesian explorers and/or colonists (Kirch and Ellison 1994; Kirch et al. 1992); others (Spriggs and Anderson 1993) point out that the archipelago's earliest archaeological sites are no older than ca. 1,000 years, suggesting that earlier vegetation changes may relate to climate variability. Precise information on past climate conditions has been lacking, and the issue remains unresolved. Most recently, Anderson et al. (2006) have considered another climate-related aspect of the colonization process, suggesting that pulses of voyaging and settlement correlate with periods of intensified El Niño activity and the anomalous westerly winds which prevail under such conditions (see also Finney 1985).

Old Ideas about Late Holocene Climate Change in the Pacific

Until quite recently, paleoclimate data from Pacific island localities, particularly data relevant to the Late Holocene, were limited (Allen 2005; Nunn 1999, 278). Proxy data sources that have proven useful in temperate regions (e.g., speleothems, varved lake sediments, tree ring sequences, ice cores) are rare or absent in the tropics, and long historical documentary records are comparatively scarce. Nevertheless, the potential impact of climate change has been recognized by a number of prehistorians, as outlined above. In recent years, the geographer Patrick Nunn (1991, 1998, 1999, 2000*a*, 2003; Nunn and Britton 2001) has drawn on a wide range of paleoclimate proxies in an effort to refine ideas about Late Holocene climate in the Pacific and evaluate its effects on the region's human populations. Evidence from the continental margins has been particularly important in this effort, augmented by oxygen isotope analysis of a New Zealand stalagmite (after Wilson, Hendy, and Reynolds 1979) and Nunn's own sea-level studies from Pacific island localities (1998, 2000*b*), data he has used as proxy indicators of temperature change. Nile River flow data (from Anderson 1992), which suggest changes in El Niño–Southern Oscillation (ENSO) frequency around AD 1300, have also been incorporated into Nunn's climatic framework. Drawing on these varied records, Nunn (2000*a*, 716) has identified the MWP as a warm, dry period (relative to today) with persistent trades, extending from about AD 750 to 1250, and the LIA as a cool, dry period with increased storminess between AD 1350 and 1850. Nunn (2000*a*; Nunn and Britton 2001) has also been particularly interested in the MWP/LIA transition. He suggests that initially there was a significant but short-lived increase in precipitation, followed by an abrupt shift to the cooler conditions of the LIA. Specifically, he argues that this transition was so rapid (less than a century) that it precipitated a series of environmental and social "catastrophes." He links an array of geomorphic and biotic changes to this "AD 1300 event" (Nunn 1999, 2000*a*) and suggests that it led to significant disruptions in human settlement, subsistence, and voyaging, as well as increases in competition and warfare, throughout the Pacific, including parts of Micronesia and the Hawaiian Islands.

Nunn's (2003; Nunn and Britton 2001) explicitly environmental determinist approach to explaining so many aspects of cultural change in the Pacific has met with some scepticism. That argument, however, is not the main concern here. Rather, the intent of this paper is to draw attention to some relatively new evidence for paleoclimate conditions in the Pacific, along with new ideas about global variability in climate over the past millennium. These new data suggest that the model of Late Holocene climate change initially developed in New Zealand, based on Northern Hemisphere patterns, extended to the Pacific islands by Nunn (1991, 1999, 2000*a*, 2003; Nunn and Britton 2001), and used in the past by a large number of Pacific scholars (myself included), is inappropriate for the central Pacific.

New Paleoclimate Evidence for Late Holocene Conditions in the Central Pacific

As outlined above, past reconstructions of paleoclimate conditions in the central Pacific have been developed largely on the basis of evidence from areas outside the region. Recent research, however, shows that teleconnections between the Pacific and other regions have varied over time: agreement is sometimes strong and sometimes not, for reasons that are not always well understood. Fortunately, paleoclimate proxy records are now available from several Pacific island localities. Most important among these are those from long-lived corals, which are allowing for sometimes continuous and generally high-resolution (often monthly) reconstructions (e.g., Cobb et al. 2003*a*; Hendy et al. 2002; Linsley, Wellington, and Schrag 2000; McCulloch et al. 1996; Tudhope et al. 2001; Urban, Cole, and Overpeck 2000; Woodroffe, Beech, and Gagan 2003). Modern and fossil coral studies have been spurred by interest in the ENSO system, the quasi-periodic cycle of alternating warming (El Niño) and cooling (La Niña) phases which stems from ocean-atmosphere coupling in the equatorial Pacific. While debate continues as to the specific mechanisms responsible for climate variability at millennial, centennial, and decadal time scales, it is now generally agreed that the tropical Pacific has played an important role in global climate change (e.g., Cobb et al. 2003*a*; Deser, Phillips, and Hurrell 2004; Kiladis and Diaz 1989; Labeyrie et al. 2003; Loubere et al. 2003; Trenberth et al. 1998). Key for archaeologists working in Remote Oceania (the region east of the Solomon Islands, after Green 1991), where human occupation dates to approximately the past 3,000 years, is the growing number of Late Holocene paleoclimate records. While some of these are of limited relevance to Pacific prehistory in that they predate human arrival or relate only to the past few centuries (see Gagan et al. 2000), the emerging finds are intriguing and, along with more general models of paleoclimate process, are relevant to our understanding of human ecodynamics in the tropical Pacific.

Paleoclimate studies involving long-lived corals utilize geochemical characteristics of the coral skeleton. Similarly to trees, with their annual growth rings, corals produce incremental bands that vary in density over an annual cycle, mainly in response to temperature and light, and allow for estimation of a coral's age. Further, changing patterns of sea surface temperature and salinity are recorded in the coral's aragonite skeleton through the ratio of two stable oxygen isotopes, the rare ^{18}O and the more common ^{16}O, expressed as $\delta^{18}O$. *Porites* corals in particular have been favoured because of their dense skeletons and rapid growth rate (8–20 mm/year) (Tudhope et al. 2001). While analysts generally have been able to dem-

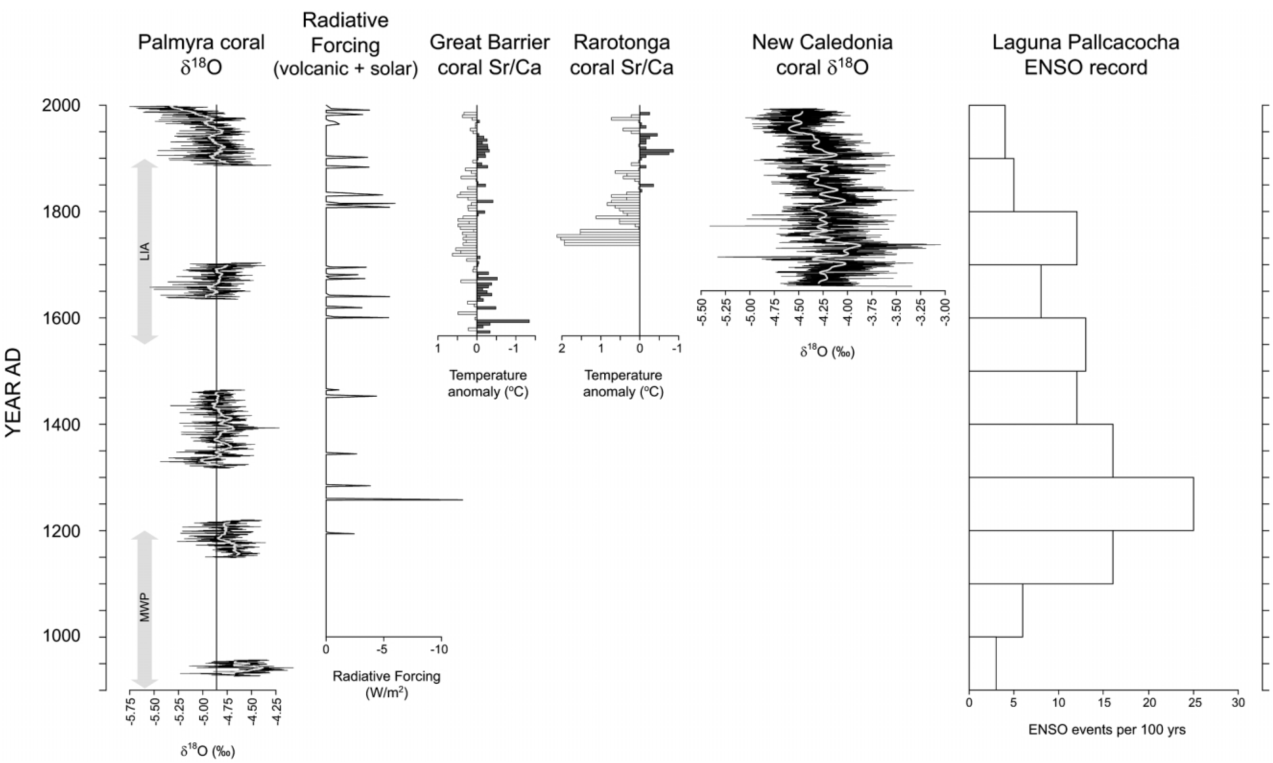

Figure 2. Summary of proxy records relevant to Pacific climate in the Late Holocene. *Palmyra coral* $\delta^{18}O$*:* record of monthly resolved coral δ^{18}O (*thin black horizontal lines*) shown with ten-year running average (*thick white horizontal lines*) relative to the average of the Palmyra modern coral δ^{18}O for the period AD 1886 to 1975 (*grey vertical line*) from Cobb et al. (2003*a*, fig. 5). The dating error for all five coral sequences is ± 10 yrs. or less. *Radiative forcing:* data from Mann et al. (2005, fig. 1*a*), shown as W/m^{-2}. *Great Barrier Reef, Rarotonga coral Sr/Ca:* reconstructions of sea surface temperature anomalies based on coral Sr/Ca records from Hendy et al. (2002, fig. 2) and Linsley, Wellington, and Schrag (2000). Hendy et al. resampled the records to equivalent five-year averages and normalized the series to the common period of AD 1860 to 1985. *New Caledonia coral* δ^{18}O: reconstruction of interannual (*thin black horizontal line*) and interdecadal (*thick white horizontal line*) coral δ^{18}O record from Amédée Lighthouse from Corrège et al. (2001, 3478, fig. 2). *Laguna Pallcacocha ENSO record:* reconstruction of number of ENSO events in 100-year nonoverlapping windows, based on data from Moy et al. (2000*b*).

onstrate close correspondences between modern instrument records and temperatures reconstructed from coral δ^{18}O, coral trace-element compositions, especially strontium/calcium (Sr/Ca) ratios but also uranium/calcium (U/Ca) ratios, measure temperature variation alone and are considered by some (e.g., Hendy et al. 2002; Corrège et al. 2001, 3477–78; Linsley, Wellington, and Schrag 2000; Stephans et al. 2004) to be better indicators of past sea surface temperature. For example, Hendy et al. (2002, 151), comparing of δ^{18}O, Sr/Ca, and instrumental sea surface temperature from multiple sites, argue that the δ^{18}O signal in the southwestern Pacific is sea-surface-salinity-dominated. Others (e.g., Cobb et al. 2003*a*; Kilbourne et al. 2004) have found the reverse, highlighting both the possibility of regional variation in the strength of sea-surface-temperature–δ^{18}O relations (see above references for discussions of potential confounding factors) and the advantages of measuring both trace elements and δ^{18}O.

Among the more lengthy Late Holocene Pacific climate reconstructions is one from Palmyra in the equatorial Line Islands. Here monthly-resolved records of 30- to 150-year intervals are available for a period of 1,100 years (Cobb et al. 2003*a*, 2003*b*). Although this study relies on δ^{18}O alone, the authors demonstrate strong correlations with the regional twentieth-century instrument records. Within this 1,100-year period, five time intervals were examined (fig. 2), three represented by multiple overlapping fossil coral records which were spliced together, a procedure that increases the number of independent observations of a climatic state at a given time interval. Additional coral proxy records come from the Australian Great Barrier Reef, Rarotonga in the southern Cook Islands, and New Caledonia (see fig. 2). At the Great Barrier Reef site, Hendy et al. (2002) utilized multiple measures (Sr/Ca, U/Ca, and $\delta^{18}O$) to reconstruct sea surface temperature and salinity over a 420-year period from AD 1565 to 1985. The 271-year Rarotongan record, in contrast, relies primarily on Sr/Ca, but comparisons were also made with $\delta^{18}O$ values from the same corals for calibration purposes. The authors suggest that variability in coral Sr/Ca explains significantly more of the variance in sea surface temperatures than coral $\delta^{18}O$ (Linsley, Wellington, and Schrag 2000, 1146). A 335-year record from New Caledonia, like the Palmyra reconstruction, is based on $\delta^{18}O$ (Quinn, Taylor, and Crowby 1998; Quinn et al. 1993), although trace elements analysed for the period between AD 1701 and 1761 indicated that $\delta^{18}O$ values were overestimating temperature declines by 0.4°C (Corrège et al. 2001, 3478). These paleoclimate proxy records, along with some more general ideas about global climate variability, are reviewed below in terms of centennial-scale background climate (e.g., evidence for the MWP and LIA), interannual ENSO variability, and the AD 1300 "event" posited by Nunn (2000*a*).

Medieval Warm Period and Little Ice Age in the Central Pacific. Jones et al. (1998), having analysed 17 temperature reconstructions from both the Northern and Southern Hemispheres and compared them with a General Circulation Model, were among the first to suggest that Late Holocene climate conditions in the central Pacific may have differed from those in the better-known Northern Hemisphere. Their ideas were echoed by Rind (1998, 2000), who explored the relationships between changes in latitudinal temperature gradients, atmospheric dynamics, and climate response through a series of experiments; his results suggested, among other things, that the LIA was restricted to higher latitudes. Further, in synthesizing the global ENSO record, Markgraf and Diaz (2000, 478) raised the possibility that prolonged droughts in the American Southwest and wetter-than-normal conditions in the American Northwest could have stemmed from normal to cooler conditions in the equatorial Pacific during the Northern Hemisphere MWP. These more general ideas are now being borne out by paleoclimate proxy records from Pacific island localities.

Most important among these is the coral $\delta^{18}O$ record from Palmyra, which covers several time intervals over the past millennium. As do paleoclimate reconstructions from the Northern Hemisphere, where the warmest and coldest decades over the past millennium differ by less than 1.0°C (Jones and Mann 2003, 20), the Palmyra record suggests relatively modest temperature fluctuations, with *average* temperature varying by no more than 0.6°C, if $\delta^{18}O$ values are scaled to temperature alone (Cobb et al. 2003*a*, 274). However, two time intervals stand out in the Palmyra case, the tenth century AD, which was the coolest and/or driest period, and the late twentieth century, the warmest and wettest period (fig. 2). The cold interval, centred on the early tenth century (AD 928–61), appears to have been of some amplitude and its onset relatively abrupt. Below-average temperatures (relative to the period AD 1886–1975) are also apparent in the mid-twelfth- to early-thirteenth-century window (AD 1149–1220). In contrast, during the seventeenth century (AD 1635–1703) temperatures on Palmyra were comparatively warmer, more like those of the recent past.

Because other tropical Pacific records of similar temporal duration were lacking, Cobb et al. (2003*a*) compared their findings with a multiproxy reconstruction from the Northern Hemisphere (Mann, Bradley, and Hughes 1999), with unexpected results. Surprisingly, the coolest and/or driest period on Palmyra coincides with the Northern Hemisphere MWP, while the height of the LIA (the seventeenth century) is registered in the Palmyra corals as a comparatively warm period, particularly in relation to temperatures observed in the tenth and to a lesser extent the twelfth century. Corroborative evidence for what some have called the Pacific's "Little Warm Age" comes from the 271-year Rarotongan record of coral Sr/Ca, where mean annual sea surface temperatures appear to be ~ 1°–1.5°C higher than the long-term average between AD 1726 and 1765 (Linsley, Wellington, and Schrag 2000, 1146).[1] A more modest sea surface temperature increase of 0.4° C (relative to the long-term average) is also registered on the Great Barrier Reef beginning around AD 1700, a condition which persists through the eighteenth and nineteenth centuries (Hendy et al. 2002, 1512).[2] Further, the Great Barrier Reef reconstruction indicates that when warmer conditions returned to the Northern Hemisphere in the late nineteenth to early twentieth century, the tropical Pacific cooled. The evidence as a whole suggests that the Medieval Warm Period in the central Pacific was cool (not warm) and the Little Ice Age, at its height, was comparatively warm (not cool) but less warm than today. Further, if twentieth-century sea-surface-temperature–rainfall relationships held through the past millennium, then we might infer that the MWP in the central Pacific was comparatively dry while the LIA was relatively wet, a proposition that is also supported by the foregoing reconstructions.

1. The authors note that the finding of warmer temperatures in this subtropical region was unexpected (Linsley, Wellington, and Schrag 2000, 146) and inconsistent with data from New Caledonia (see Salinger et al. 1995 and discussion below).

2. The ~ 0.2–0.3°C cooler sea surface temperatures in the period between AD 1565 and 1700 (not represented on Palmyra) should not go unremarked, but their significance is uncertain in the absence of additional records; the comments below regarding regional variation may be relevant.

In attempting to explain the relatively stable average temperatures on Palmyra vis-à-vis the more marked temperature changes elsewhere, Cobb et al. (2003a) suggest that the east-west gradient of sea surface temperature may have had a greater influence than average sea surface temperature on global climate patterns, an idea explored by others as well (see Rind 2000; Tudhope et al. 2001). Drawing on both the Palmyra data and "a handful of ENSO-sensitive proxy records," the authors propose that during the MWP the Pacific's zonal sea surface temperature gradient may have been larger and potentially played a role in prolonged droughts in Mesoamerica, the Sierra Nevada, and Kenya (Cobb et al. 2003*a*, 275; see also Markgraf and Diaz 2000), much like La Niña conditions today (see below). During the LIA, they suggest, this Pacific sea surface temperature gradient decreased, leading to El Niño–like conditions. Recent numerical experiments using a well-established coupled ocean-atmospheric model (the Zebiak-Cane model) provide further support for these ideas. Specifically, the model experiments, which explored the role of volcanic and solar forcing in tropical Pacific climate change over the past 1,000 years, replicated an "El Niño–like state" (i.e., warmer conditions in the eastern equatorial Pacific and increased ENSO variability) in the tropical Pacific during the LIA and a "La Niña–like state" (cooler conditions in the eastern equatorial Pacific and decreased ENSO variability) during the MWP (Mann et al. 2005, 455).

Changes in ENSO activity. The Palmyra record also provides insights into interannual climate variability and, in particular, changes in the strength and frequency of ENSO activity. Under normal conditions, sea surface temperatures in the eastern Pacific are relatively cold, while those of the western Pacific are exceptionally warm. The sea surface temperature gradient maintains an east-west atmospheric pressure gradient which in turn drives a circulation system formally known as the Walker Circulation (after Bjerknes 1969). Cool, dry air from the eastern Pacific flows westward along the equator, gathering heat and moisture, particularly as it moves over the western Pacific "warm pool." This moist air then rises to high atmospheric levels over Indonesia and northern Australia, resulting in marked cloudiness and high rainfall. The cycle is completed with the high-atitude transport of air, which cools and dries along the way, to the far eastern Pacific.

For reasons that are not fully understood, the Walker Circulation occasionally breaks down and the normal zonal atmospheric pressure gradient is altered. During El Niño warm phases, which occur on average every two to seven years, the eastern trade winds weaken or even reverse, and atmospheric pressure in the eastern Pacific is reduced (Labeyrie et al. 2003). These conditions, along with enhanced atmospheric pressure in the west, allow warm waters from the western Pacific to extend eastward along the equator, leading to a reduction in the zonal sea surface temperature gradient. Along the equator, where cloud development is already concentrated, cloudiness intensifies and storm clouds are drawn eastward. The result is that the central eastern Pacific (from roughly 180°W long.) experiences warm and wet conditions with frequent tropical cyclones and storms, while torrential rains often fall on coastal Mexico and the western coast of equatorial South America. The western Pacific, in contrast, becomes cool and dry, and Australia and Indonesia may experience intense droughts. During La Niña phases, the trades are enhanced and warm waters move westward, leading to warmer conditions and intensified storms in the western Pacific while the eastern Pacific is comparatively cool, dry, and settled.

Fossil coral records from northern Papua New Guinea indicate that the ENSO system has been in place for at least 130,000 years, crosscutting global changes in background climate (Tudhope et al. 2001, 1995). However, it appears that its intensity has varied over time, and, most notably, the amplitude and frequency of ENSO events have increased since the mid-Holocene (e.g., Clement, Seager, and Cane 2000; Moy et al. 2002*a*; Rodbell et al. 1999; Tudhope et al. 2001). Palmyra Island lies in a region that is highly sensitive to the ENSO cycle and provides a Pacific-centred view of ENSO variability during the Late Holocene. The Palmyra corals indicate that during the seventeenth century, the coldest period of the LIA elsewhere in the world (see Jones, Osborn, and Briffa 2001, 664; Fagan 2000), ENSO activity was more intense in this equatorial setting than at any other time period represented by these corals (Cobb et al. 2003*a*, 275) (but see below). Not only is there a significant increase in the number of El Niño events but event amplitude is marked, with some rivalling the "Giant El Niño" of 1997–98, one the largest events of this century. Cobb et al. note that the apparent changes in El Niño frequency and amplitude are supported by a variety of time-series-analysis techniques, including spectral analysis and a range of different bandpass filters. Putting these findings in cultural context, the 1997–98 El Niño resulted in devastating droughts, extensive forest fires, intense cyclones, and record flooding, causing an estimated $33 billion in property damage, despite being the first well-predicted El Niño event (Suplee 1999). Increased ENSO activity is also suggested in the late twelfth to early thirteenth century, albeit at a lower frequency and amplitude (Cobb et al. 2003*a*, fig. 6). The work of Hendy et al. (2002) on the Great Barrier Reef provides further modest support for enhanced ENSO variability during the LIA. The authors argue that decreases in sea surface salinity most likely relate to intensified large-scale atmospheric dynamics (e.g., the Hadley Circulation) in the sixteenth to nineteenth century AD, a pattern which typically accompanies a weakening of the Walker Circulation.

Additional insights on ENSO activity over the past millennium come from a ~15,000-year record of laminated lake sediments from Laguna Pallcacocha, a high-altitude site in the Ecuadorian Andes (Moy et al. 2002*a*; Rodbell et al. 1999). This particular record is highlighted here for two reasons. First, although the site lies outside the Pacific Basin, its latitudinal location is such that the area is potentially influenced by a related set of climate conditions. Second, coherence between the Palmyra and Laguna Pallcacocha reconstructions has been quantitatively assessed. The last 1,100 years of Pallcacocha sequence indicate that the seventeenth century was a period of more frequent ENSO activity. The Pallcacocha record further suggests that El Niño events were even more frequent during the twelfth to fifteenth centuries, a period that is poorly represented by the Palmyra corals. Graham and Cobb (in Graham 2004, 437) recently directly compared the Palmyra and Laguna Pallcacocha records as part of a larger effort to analyse Late Holocene teleconnections with regard to paleoclimate in the western United States and the tropical Pacific. They found moderate-to-strong correlations: 0.42 for the period AD 1642–96, 0.63 for AD 1324–1456, and 0.80 for AD 1893–1968 (dates refer to the smoothed portions of the records; linear least-squares trends were removed from each record). These findings suggest that the Pallcacocha record may be a useful first approximation of ENSO variability during time periods not yet directly represented by Pacific island records. However, variability in the degree of coherence across the different time periods and uncertainties associated with chronological aspects of the Pallcacocha record (see Graham 2004, 437) underscore the importance of obtaining data from Pacific localities.

Differences between the foregoing records and those derived from the Nile River Valley, as used by Nunn (2000*a*), also warrant comment. The latter indicate marked changes in El Niño frequency beginning around AD 1300 and continuing to 1650, while the records reviewed herein identify two periods of enhanced ENSO variability, the mid-seventeenth century, when events were both common and of significant amplitude, and a second period centred on AD 1200–1300, when the Laguna Pallcacocha records indicate El Niño events more frequent than at any other time during this millennium. While the available records from the Pacific are far from complete, those offered here are reasonably consistent and, when contrasted with the Nile River record, highlight the importance of further development of Pacific-based paleoclimate reconstructions.

Evidence for an "AD 1300 Event." In his most recent discussions of central Pacific climate, Nunn (2000*a*, 2003) has suggested that AD 1300 was an important crossover period in which changes in climate were so abrupt and of such magnitude as to constitute an "environmental catastrophe." In particular, he posits that the combined effects of rapid cooling (associated with onset of the LIA), a substantial but short-term increase in precipitation, and increased storminess greatly stressed Pacific marine and terrestrial ecosystems. These conditions, which are thought to have lasted for about 200 years, are hypothesized to have resulted in as much as an 80% reduction in food resources (Nunn 2003, 224). The evidence for this rapid climate and environmental change comes from around the Pacific rim, including North, Central, and South America, East Asia, Australia, and New Zealand, and is varied in form, including precipitation increases, glacial advances, temperature falls, and cultural changes (Nunn 2000*a*, table 1). Nunn's temperature reconstructions are largely based on Northern Hemisphere data, although an exploratory study of a New Zealand stalagmite by Wilson, Hendy, and Reynolds (1979) indicated a ~1° C fall which began late in the fourth century and reached a minimum in the early fifteenth century. Nunn (2000*a*, 719) also argues for a rapid sea-level fall, on the order of 75 cm, between AD 1270 and 1325.

Are the paleoclimate records discussed above supportive? On Palmyra, the ten-year running average of monthly-resolved $\delta^{18}O$ suggests that early in the fourteenth century temperatures were on average *higher*, not lower, in relation to (1) subsequent temperature averages in this same interval, (2) the twelfth-to-thirteenth-century window, and (3) the 1886–1975 mean. While this is the inverse of the conditions specified by Nunn, a marked temperature increase could have been as disruptive for Pacific peoples as a decline, given the sensitivity of tropical reefs to thermal stress. More generally, the emerging evidence indicates that paleoclimate conditions in high-latitude New Zealand (the basis for Nunn's temperature reconstruction) were similar to those of the Northern Hemisphere and thus may be a poor basis for reconstructing central Pacific climate.

The Laguna Pallcacocha sedimentary record also identifies the period around AD 1200–1300 as climatically significant, with a marked increase in El Niño frequency. Perhaps most interesting are the findings of Mann et al. (2005) in concert with the Pallcacocha record. Generally, these modelling experiments, along with observational data, suggest that explosive volcanic events are typically followed by multiyear ENSO responses. Of particular note is an exceptionally large volcanic eruption recorded at AD 1259 (Crowley 2000). Although not currently represented in the available Pacific island coral proxy records, the modelling results suggest that this event was followed by a marked temperature increase as well as enhanced ENSO activity (Mann et al. 2005, fig. 3). Taken as a whole, these findings suggest that the more general claim of Nunn (2000*a*, 2003) for significant environmental perturbation(s) around AD 1300 warrants continued consideration, although the timing of these perturbations may be somewhat earlier and the direction of the temperature anomaly appears to be in the opposite direction from that originally proposed. Also of potential relevance is the change in background climate from cool, dry to warm, wet conditions, rather than the reverse.

Intraregional Variability within the Pacific

There is growing recognition that regional variability characterized the Late Holocene in many areas of the world. A recent review of Northern Hemisphere paleoclimate records produced little evidence for a discrete MWP (Jones et al. 1998, 64), while a comparison of proxy temperature reconstructions from several global regions showed considerable variation in the timing, magnitude, and intraperiod variability of both the

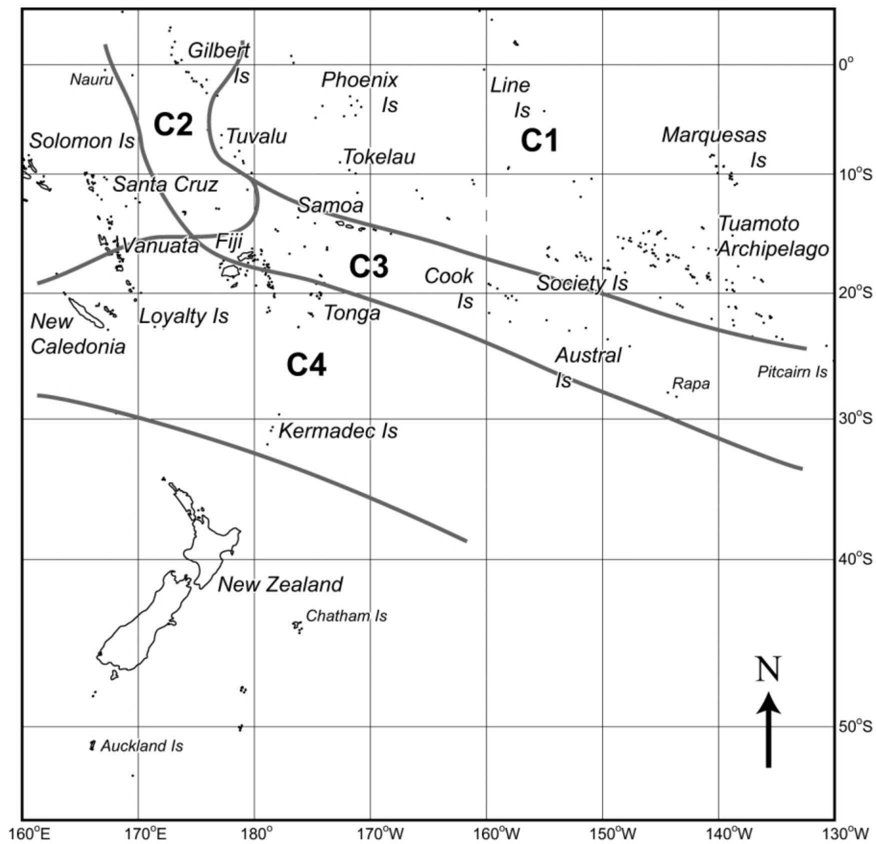

Figure 3. Climatic response regions of the southwestern Pacific based on air temperature and precipitation patterns (after Salinger et al. 1995; Salinger, Renwick, and Mullan 2001).

MWP and the LIA (Jones and Mann 2004, fig. 4). In this context it is perhaps not surprising that the newly available Pacific proxy records, in concert with more general models, indicate that conditions in the central Pacific did not mimic those of the Northern Hemisphere over the past millennium. The available Pacific paleoclimate proxy records also raise the possibility of intraregional variation, particularly variation along a latitudinal axis. Modern instrument studies are informative on the character and spatial patterning of climate during the historic period and may offer insights as to the long-term climate histories of particular archipelagos, assuming some degree of stationarity in climate-control features.

At the outset, it is important to recognize that the geographic regions traditionally defined and used by Pacific social scientists and biologists are not isomorphic with those of climatologists. While major water crossings, which act to impede biotic dispersals, are critical to defining patterns of human settlement, cultural differentiation, and ongoing interaction, other variables are structuring Pacific climate. Of particular note in this regard is the location of the South Pacific Convergence Zone, one of the most significant and extensive features of equatorial and tropical southwestern Pacific climate (Folland et al. 2003; Mullan 1991; Salinger et al. 1995; Salinger, Renwick, and Mullan 2001). The convergence zone is a band of low-level wind convergence, cloudiness, and precipitation that extends across the central Pacific from Vanuatu in the west to the Austral Islands in the east. It is a pivotal feature with respect to the patterning of temperature and precipitation in the southwestern and central Pacific (Salinger et al. 1995). However, it is not stationary, and it systematically shifts from its mean climatological position in response to the polarity of ENSO activity. During El Niño events it moves northeast, while cyclonic activity extends eastward and often increases in frequency (Folland et al. 2002; Hay et al. 1993; Salinger et al. 1995). In contrast, during La Niña events, it moves southwest. It also responds to decadal-to-multidecadal-scale influences, in particular the Interdecadal Pacific Oscillation,[3] a ~ 15–30-year time scale fluctua-

3. The terminology here follows Folland et al. (2002; see also Salinger, Renwick, and Mullan 2001), who argue that the Interdecadel Pacific Oscillation can be regarded as the quasi-symmetric Pacific-wide mani-

tion in sea surface temperature and precipitation defined for the Pacific Basin at large and relevant to at least the past 300 years (Deser, Phillips, and Hurrell 2004; Folland et al. 2002; Linsley, Wellington, and Schrag 2000; Power et al. 1999; Salinger, Renwick, and Mullan 2001). The Interdecadal Pacific Oscillation consists of alternating warm and cool phases, and historically warm phases have been associated with stronger and more frequent El Niño activity. As is the case during El Niño events, the South Pacific Convergence Zone shifts to the northeast in response to positive phases of the Interdecadal Pacific Oscillation. Examining recent temperature and precipitation patterns, modulated by ENSO and the Interdecadal Pacific Oscillation, Salinger et al. (1995; Salinger, Renwick, and Mullan 2001) have identified four distinct climatic response regions in the southwestern Pacific (fig. 3). Regions C1 and C4 are climatically the most stable over time, while C2 and C3 are strongly influenced by the position of the South Pacific Convergence Zone and the Intertropical Convergence Zone to the north.

The antiquity of these climate response regions, which are defined largely on the basis of modern instrument records, is not known. However, the coral reconstructions discussed above suggest some temporal depth, at least with respect to temperature. Specifically, New Caledonia, for example, falls within the C4 region of Salinger and colleagues (1995; Salinger, Renwick, and Mullan 2001). During recent El Niño events, New Caledonia has experienced declines in sea surface temperature, "with a maximum peak to trough (i.e. La Niña to El Niño) amplitude of interannual SST anomaly reaching ~ 1.5° C" (Corrège et al. 2001, 477). Further, a 335-year coral record from Amédée Lighthouse indicates that temperatures between AD 1701 and 1761 were 1.4° C cooler (relative to the past 30 years) (Corrège et al. 2001; see also Quinn et al. 1998). Therefore this higher-latitude locality fails to replicate the warmer conditions recorded for Palmyra, Barotonga, and, to a lesser extent, the Great Barrier Reef during the LIA (see fig. 2). This suggests that climate variability in New Caledonia and other C4-region islands, over both recent and longer time scales, may have more in common with that in New Zealand (see Corrège et al. 2001, 3478; McKinzey et al. 2004) than with central Pacific localities, possibly including cooler temperatures during the LIA and warmer temperatures during the MWP. More generally, this finding supports the idea that latitude plays a key role in climate variation in the Pacific (see Rind 1998, 2000). Similarly, weaker correspondence between the paleotemperature record of the Great Barrier Reef and those of Palmyra and Rarotonga may reflect shared changes in background climate mediated by variable east-west responses to ENSO.

The foregoing suggests that not only is it necessary to begin remodelling central Pacific climate but care must be taken in extrapolating from proxy records of any one archipelago to the Pacific at large. The work of Salinger and colleagues highlights regional variability in temperature, precipitation, and the effects of both ENSO and the Interdecadal Pacific Oscillation. The accumulating evidence indicates that these patterns have some antiquity, the former having been in place throughout the Holocene and the latter having a temporal depth of at least 300 years and possibly longer. Further, it has been suggested that the basic physics associated with ENSO are relevant to longer time frames, including not only the Interdecadal Pacific Oscillation but also background climate (i.e., centennial-scale shifts like those of the MWP and the LIA) (Labeyrie et al. 2003; Mann et al. 2005). Given these factors, it may be that no one model will adequately explain climate patterns in the Pacific as a whole, particularly at the resolution needed to understand the impact on and responses of human populations.

festation of the Pacific Decadal Oscillation, which has been described for the North Pacific alone (see Mantua et al. 1997).

Discussion and Conclusions

Assessment of the impact of climate and human response is necessarily reliant on accurate information on past climate conditions. The central point of this paper is that new paleoclimate evidence significantly changes our understanding of century-scale climate variability during the Late Holocene in the central Pacific. More specifically, while the rest of the world was experiencing a warm Medieval Warm Period, conditions in the central Pacific were cool and possibly dry. During the so-called Little Ice Age the central Pacific was comparatively warm and possibly wet and stormy conditions more common. Given the increasing evidence for hemispheric and even regional variability in climate during the Late Holocene, some paleoclimatologists now argue that the descriptors "Medieval Warm Period" and "Little Ice Age" have outlived their usefulness (e.g., Bradley and Jones 1993; Hughes and Diaz 1994; Jones and Mann 2004, 31) and climate variability should be described in reference to calendar dates (Jones and Mann 2004, 31). The tropical Pacific, where the terms become nonsensical, probably best illustrates their point. A second issue raised here is that, even within the Pacific, climate is far from homogeneous. Variation is apparent both across the region and latitudinally, reflecting the complex ocean-atmosphere relations that operate over this vast geographic feature. Modern instrument studies offer insights into the patterning and sources of variability, but clearly a denser assemblage of paleoclimate proxies is needed, and some parts of the basin, particularly the northern Pacific (e.g., the Hawaiian Islands and parts of Micronesia), remain very poorly known.

Given the limited number and incomplete nature of the available records, it is perhaps most useful at this stage to consider how these new data might influence existing archaeological models. As observed above, several Pacific researchers have focused on how environmental variability, including but not limited to variation in precipitation, temperature, and cyclonic activity, might structure human behaviour (e.g., Graves and Ladefoged 1995; Graves and Sweeney 1993; Hunt and Lipo 2001). Drawing on the theoretical ideas of Dunnell (1989) and more recently Madsen, Lipo, and Cannon (1999), these scholars have considered how environmental predictability might influence cultural behaviours that do not directly relate to basic subsistence requirements and reproduction, most notably cultural elaboration (e.g., monument construction, ritual behaviour, body ornamentation, etc.). They argue that cultural elaboration is more likely to appear and persist in unpredictable environments, where it may function dampen fertility or otherwise direct energy away from reproductive activities—making it advantageous when critical resources fluctuate to a significant degree. These arguments are at least partially reliant on demonstrations that cultural elaboration is correlated with environmental variability in either time or space, but they also make predictions about the demographic structure of populations engaging in such activities (see Madsen, Lipo, and Cannon 1999; Hunt and Lipo 2001). The new paleoclimate evidence reviewed herein provides a more highly resolved record of spatial and temporal variability in climate with greater chronometric precision than has hitherto been available. It will therefore allow more rigorous assessment of ideas such as these about the interplay between environmental variability and cultural practices. It should also help identify time periods of heightened climate variability (e.g., the seventeenth century and the thirteenth to fourteenth century) and localities of particular instability.

Others have argued that specific dimensions of climate change have resulted in particular environmental or cultural outcomes. On Rapa Nui, for example, several researchers have related vegetation change and cultural adjustments to increased climatic variability, particularly greater aridity (Hunter-Anderson 1998; see also McCall 1994; Orliac 2000). The evidence reviewed above, however, suggests that warmer, wetter conditions prevailed during the LIA and, by extension, precipitation on Rapa Nui may have been enhanced. Having said this, a recent analysis of Rapa Nui's meteorological records indicated that, although local rainfall is highly variable and unpredictable, the island is relatively unaffected by ENSO (Genz and Hunt 2003). Given the island's extreme isolation and geographical position in the far southeastern Pacific, local climate proxies may be necessary to resolve questions of the timing and character of climate variability in this particular locality.

Nunn (2000*a*, 719, 728) also links particular cultural practices to specific parameters of climate. The onset of cooler temperatures associated with the LIA, for example, is posited to have led to the appearance of storage facilities for root crops on Tikopia in the western Pacific (as a buffer against crop failure), the abandonment of pearl-shell fishhooks on Aitutaki in the southern Cook Islands (as cooler temperatures adversely affected reefs and drier conditions led to sea-level fall), and declines in terrestrial productivity on Rapa Nui. Since the LIA saw warmer, wetter conditions in the central Pacific, one might argue that climate did not play a causal role in these developments. Indeed, other explanations are possible, as, for example, on Aitutaki, where there is no direct evidence for sea-level change during the proposed MWP/LIA transition and pearl-shell appears to be the only marine species that declined, becoming archaeologically less visible around AD 1500 on several islands (Allen 1998, 2002).

More generally, Nunn has argued that increasing competition, the development of irrigation devices, declines in voyaging, and population migrations away from the coast stem from a traumatic transition between the MWP and the LIA. As reviewed above, the Laguna Pallcacocha ENSO record (Moy et al. 2002*a*) does indeed suggest increased ENSO variability between AD 1100 and 1400, while the more general model of Mann et al. (2005) points to a potential cause. Further, the Palmyra coral record indicates a shift from relatively cooler conditions sometime after AD 1200, with the possibility of a marked warm interval around AD 1300. As suggested above, elevated temperatures could have been as disruptive for Pacific peoples as a temperature fall, if not more so. This is because of the potential for coral reef-bleaching, mass coral mortality, and the attendant loss of marine resources. The 1997–98 El Niño, for example, is estimated to have killed 16% of the world's corals (Hughes et al. 2003). The flow-on effects of coral reef-bleaching and mass coral mortality are not particularly well understood (Hoegh-Guldberg et al. 2000, 53–54), but some estimates are available. Wilkinson et al. (1999), for example, suggest losses in reef-related fisheries on the order of 25% over a 20-year period, while a World Bank model (cited in Hoegh-Guldberg et al. 2000) suggests losses on the order of 50%. Declines in marine productivity on the scale predicted by these models should have clear archaeological signatures, and marine fauna may have a key role to play in evaluating both the occurrence and timing of climate change and its effects on prehistoric Pacific peoples. Although the new paleoclimate records indicate a different array of climatic signals from those predicated by Nunn and the timing is somewhat (though only slightly) at variance with his original proposal, the idea of climatically induced cultural change (but not necessarily a regionwide "catastrophe") warrants more in-depth consideration.

Field's (2003, 2004) analysis of settlement patterns, competition, and the development of social complexity in Sigatoka Valley, Fiji, takes an important step in this direction. Initially, Field builds a model of spatial differences in productivity and risk through a GIS analysis of local environmental patterning (soils, topography, stream flow, etc.) and recent ENSO effects. She then evaluates the archaeological record of settlement, population mobility, competition, and patterns of exchange against this model. She demonstrates that between AD 1300 and 1500 there were marked increases in fortified sites, abrupt population movements into previously uninhabited areas of only moderate productivity, increased exchange of subsistence goods, and a broadening of diet breadth—all changes that are consistent with increasing competition and resource stress and potentially climate change. A second period of intensified competition is indicated around AD 1700, when labour-intensive ring ditch fortifications appear for the first time in highly productive valley-bottom areas, a trend which Field links to the diffusion of new ideas and population increases. The intensified ENSO conditions indicated by the paleoclimate proxies reviewed herein raise the possibility that climatic instability was again a contributing factor. In short, Field offers the most detailed and convincing case to date for Nunn's (2000*a*) model of a traumatic MWP/LIA transition. It is important to note, however, that her analysis focuses primarily on changes in settlement distribution and kind, not direct physical manifestations of climate variability (Field 2004, 87), the latter being evidence that is needed before the causal role of climate variability can be fully evaluated.

While the new paleoclimate records are highly resolved and offer unprecedented opportunities for evaluating the effects of climate on various components of human society, there are a number of barriers to full use of them. Pacific archaeological chronologies are typically coarse-grained, and one of the potentially most interesting periods in terms of sociopolitical developments and adjustments to changing climatic conditions, post-AD 1600, lies beyond the point at which radiocarbon dating is useful. Recent efforts to develop novel dating techniques, such as application of high-resolution uranium-thorium isotope dating to corals in archaeological contexts (Kirch and Sharp 2005; Weisler et al. 2006), improved statistical approaches (e.g., Jones 2002), and calibration improvements (e.g., Hogg et al. 2002) all offer significant opportunities for chronometric refinement.

It is also important to move beyond correlations and plausible explanations of causality and begin to explore linking mechanisms between specific climate parameters (e.g., precipitation, temperature, ENSO variability) and proposed cultural response(s). Grayson (1984, 819–20) made a similar argument some time ago with respect to the megafauna-extinction debate in North America, highlighting both the importance and the difficulty of establishing such relationships. In the Pacific, many of the proposed cultural responses to climate change, such as increased competition, subsistence change, and altered settlement patterns, are presumably intimately tied to variations in resource availability. Little effort, has, however, been made to identify and map in detail alterations in marine and terrestrial productivity in relation to climate, and, as this review suggests, at least some ideas about Late Holocene climate change in the Pacific have been erroneous. Further, the loss or reduced availability of important resources should be reflected in the health of both humans and their commensal animals; more effort should be directed to studies of human demography (e.g., Hunt and Lipo 2001), bone chemistry, and other indicators of changing diet and nutritional stress. Altered climatic conditions should also be reflected in Pacific landscapes through sea-level fluctuations, sediment regimes, coastal dynamics, etc.; Nunn (1998, 2000*a*) usefully summarizes a number of regional records that might be reevaluated in terms of the revised climatic model presented herein. Finally, alternative explanations for cultural change should be assessed as well. The impact of climate change on local resources needs to be differentiated from that of population growth, economic intensification, and/or island-specific historical factors if we are to develop robust models of climate causality.

The paleoclimate records reviewed here also have relevance for modern Pacific peoples. Climate change and accelerated sea-level rise and their associated social and environmental costs are among the most pressing concerns of Pacific island nations today. However, not only are the rate and magnitude of change uncertain but the uncertainties are "magnified many times over due to incomplete knowledge of individual ecosystems, and patterns of causality and interaction between social and ecological systems" (Barnett 2001, 977). The new Pacific coral records offer long-term perspectives on climate variability and are critical to efforts to model future climate change both in this region and globally. In tandem with archaeology, they have the potential to show not only how Pacific environments were affected but also how Pacific peoples dealt with changing conditions. Particularly important are periods of past heightened temperature, specifically the climate and cultural records of the seventeenth to nineteenth century, which offer insights into the potential effects of modern global warming, including sea-level rise, drought, coral bleaching, and the spread of disease vectors. Anthropologists and natural scientists working together can potentially evaluate how widespread these conditions were in the past and assess patterns of regional variability, cascade effects, and both human and biotic recovery times with an eye to the future.

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References Cited

Allen, M. S. 1998. Holocene sea-level change in Aitutaki, Cook Islands: Landscape change and human response. *Journal of Coastal Research* 14:10–22.

———. 2002. Resolving long-term change in Polynesian marine fisheries. *Asian Perspectives* 41:195–212.

———. 2005. Late Holocene climate change in the central Pacific: New views, old problems, and human responses. Paper presented at "Environmental Variability and Human Adaptation in the Pacific Rim," the 5th Asian Lake Drilling

Programme Workshop, Palmerston North, New Zealand, February 28–March 5.

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

Anderson, R. Y. 1992. Long-term changes in the frequency of occurrence of El Niño events. In *El Niño: Historical and paleoclimate aspects of the Southern Oscillation*, ed. H. F. Diaz and V. Markgraf, 193–200. New York: Cambridge University Press.

Bahn, P. G., and J. R. Flenley. 1992. *Easter Island, earth island.* London: Thames and Hudson.

Barnett, J. 2001. Adapting to climate change in Pacific Island countries: The problem of uncertainty. *World Development* 29:977–93.

Betancourt, J. L., and T. R. Van Devender. 1981. Holocene vegetation in Chaco Canyon, New Mexico. *Science* 214: 656–58.

Bjerknes, J. 1969. Atmospheric teleconnections from the equatorial Pacific. *Monthly Weather Review* 97:163–72.

Bradley, R. S., and P. D. Jones. 1993. "Little Ice Age" summer temperature variations: Their nature and relevance to recent global warming trends. *The Holocene* 3:367–76.

Bridgman, H. A. 1983. Could climate change have had an influence on the Polynesian migrations? *Palaeogeography, Palaeoclimatology, Palaeoecology* 41:193–206.

Clement, A., R. Seager, and M. Cane. 2000. Suppression of El Niño during the mid-Holocene by changes in the Earth's orbit. *Paleooceanography* 15:731–37.

Cobb, K. M., C. D. Charles, H. Cheng, and R. L. Edwards. 2003*a.* El Niño/Southern Oscillation and tropical Pacific climate during the last millennium. *Nature* 424:271–76.

Cobb, K. M., C. D. Charles, H. Cheng, M. Kastner, and R. L. Edwards. 2003*b.* U/Th-dating living and young fossil corals from the central tropical Pacific. *Earth and Planetary Science Letters* 210:91–103.

Corrège, T., T. Quinn, T. Delacroix, F. Le Cornec, J. Récy, and G. Cabioch. 2001. Little Ice Age sea surface temperature variability in the southwest tropical Pacific. *Geophysical Research Letters* 28:3477–80.

Crowley, T. J. 2000. Causes of climate change over the past 1000 years. *Science* 289:270–77.

Cumberland, K. B. 1962. Climate change or cultural interference? New Zealand in Moa-hunter times. In *Land and livelihood*, ed. M. McCaskill, 88–142. Wellington: New Zealand Geographical Society.

Dean, J. S., R. C. Euler, G. J. Gumerman, F. Plog, R. H. Hevly, and T. N. V. Karlstrom. 1985. Human behavior, demography, and paleoenvironment on the Colorado Plateau. *American Antiquity* 50:537–54.

deMenocal, O. B. 2001. Cultural responses to climate change during the late Holocene. *Science* 292:667–73.

Deser, C., A. S. Phillips, J. W. Hurrell. 2004. Pacific interdecadal climate variability: Linkages between the tropics and the North Pacific during the Boreal Winter since 1900. *Journal of Climate* 17:3109–24.

Diamond, J. 2005. *Collapse: How societies choose to fail or survive.* Victoria: Allen Lane, Penguin Group.

Dunnell, R. C. 1989. Aspects of the application of evolutionary theory in archaeology. In *Archaeological thought in America*, ed. C. C. Lamberg-Karlovsky, 35–99. Cambridge: Cambridge University Press.

Fagan, B. 2000. *The Little Ice Age: How climate made history 1300–1850.* New York: Basic Books.

Field, J. S. 2003. The evolution of competition and cooperation in Fijian prehistory: Archaeological research in the Sigatoka Valley, Fiji. Ph.D. diss., University of Hawaii.

———. 2004. Environmental and climatic considerations: A hypothesis for conflict and the emergence of social complexity in Fijian prehistory. *Journal of Anthropological Archaeology* 23:79–99.

Finney, B. 1985. Anomalous westerlies, El Niño, and the colonisation of Polynesia. *American Anthropologist* 87:9–27.

Folland, C. K., J. A. Renwick, M. J. Salinger, and A. B. Mullan. 2002. Relative influences of the Interdecadal Pacific Oscillation and ENSO on the South Pacific Convergence Zone. *Geophysical Research Letters* 29(13):1643, doi: 10.1029/2001GL014201.

Folland, C. K., M. J. Salinger, N. Jiang, and N. A. Rayner. 2003. Trends and variations in South Pacific Island and ocean surface temperatures. *Journal of Climate* 16:2859–74.

Gagan, M. K., L. K. Ayliffe, J. W. Beck, J. E. Cole, E. R. M. Druffel, R. B. Dunbar, and D. P. Schrag. 2000. New views of tropical paleoclimates from corals. *Quaternary Science Reviews* 19:45–64.

Genz, J., and T. L. Hunt. 2003. El Niño/Southern Oscillations and Rapa Nui prehistory. *Rapa Nui Journal* 17:7–14.

Gillespie, A., and W. Burns, eds. 2000. *Climate change in the South Pacific: Impacts and responses in Australia, New Zealand, and small island nations.* Dordrecht: Kluwer.

Graham, N. E. 2004. Teleconnections between the tropical Pacific and precipitation in the western USA. *The Holocene* 14:436–47.

Graves, M. W., and T. L. Ladefoged. 1995. The evolutionary significance of ceremonial architecture in Polynesia. In *Evolutionary archaeology: Methodological issues*, ed. P. A. Teltser, 149–74. Tucson: University of Arizona Press.

Graves, M. W., and M. Sweeney. 1993. Ritual behaviour and ceremonial structures in Eastern Polynesia. In *The evolution and social organisation of prehistoric society in Polynesia*, ed. M. W. Graves and R. C. Green, 102–21. Auckland: New Zealand Archaeological Association.

Grayson, D. K. 1984. Explaining Pleistocene extinctions: Thoughts on the structure of a debate. In *Quaternary extinctions: A prehistoric revolution*, ed. P. S. Martin and R. G. Klein, 807–23. Tucson: University of Arizona Press.

Green, R. C. 1963. *A review of the prehistoric sequence of the Auckland Province.* 2d ed. Dunedin: University Bookshop.

———. 1991. Near and Remote Oceania: Disestablishing

"Melanesia" in culture history. In *Man and a half: Essays in Pacific anthropology and ethnobiology in honour of Ralph Bulmer*, ed. A. W. Pawley, 491–502. Auckland: Polynesian Society.

Grove, J. M. 1988. *The Little Ice Age.* New York: Methuen.

Hay, J. E., J. Salinger, B. Fitzharris, and R. Basher. 1993. Climatological "see-saws" in the Southwest Pacific. *Weather and Climate* 13:9–21.

Hendy, E. J., M. K. Gagan, C. A. Alibert, M. T. McCulloch, J. M. Lough, and P. J. Isdale. 2002. Abrupt decrease in tropical Pacific sea surface salinity at end of Little Ice Age. *Science* 295:1511–14.

Higham, T., and M. Jones. 2004. Chronology and settlement. In *Change through time: 50 years of New Zealand archaeology*, ed. L. Furey and S. Holdaway, 215–34. Auckland: New Zealand Archaeological Association.

Hodell, D. A., M. Brenner, J. H. Curtis, and T. P. Guilderson. 2001. Solar forcing of drought frequency in the Maya lowlands. *Science* 292:1367–70.

Hoegh-Guldberg, O., H. Hoegh-Guldberg, D. K. Stout, H. Cesar, and A. Timmerman. 2000. *Pacific in peril: Biological, economic, and social impacts of climate change on Pacific coral reefs.* New York: Greenpeace. http://www.greenpeace.org/~climate/science/reportsGR249-Coralbleaching3.pdf.

Hogg, A., F. G. McCormac, T. F. G. Higham, P. J. Reimer, M. G. L. Baille, and J. G. Palmer. 2002. High-precision radiocarbon measurements of contemporaneous tree-ring dated wood from the British Islands and New Zealand: AD 1850–950. *Radiocarbon* 44:633–40.

Hughes, M. K., and H. F. Diaz. 1994. Was there a "Medieval Warm Period" and, if so, when and where? *Climate Change* 26:109–42.

Hughes, T. P., A. H. Baird, D. R. Bellwood, M. Card, S. R. Connolly, C. Folke, R. Grosberg, O. Hoegh-Guldberg, J. B. C. Jackson, J. Kleypas, J. M. Lough, P. Marshall, M. Nystrom, S. R. Palumbi, J. M. Pandolfi, B. Rosen, and J. Roughgarden. 2003. Climate change, human impacts, and the resilience of coral reefs. *Science* 301:929–33.

Hunt, T. L., and C. P. Lipo. 2001. Cultural elaboration and environmental uncertainty in Polynesia." In *Pacific 2000: Proceedings of the Fifth International Conference on Easter Islands and the Pacific*, ed. C. M. Stevenson, G. Lee, and F. J. Morin, 103–15. Los Osos, Calif.: Easter Island Foundation and Bearsville Press.

Hunter-Anderson, R. L. 1998. Human vs. climatic impacts at Rapa Nui: Did the people really cut down all those trees? In *Easter Island in Pacific context, South Seas Symposium: Proceedings of the Fourth International Conference on Easter Island and East Polynesia, University of New Mexico, Albuquerque, 5–10 August 1997*, ed. C. M. Stevenson, G. Lee, and F. J. Morin, 85–99. Los Osos, Calif.: Bearsville Press and Cloud Mountain Press.

Jones, M. D. 2002. A brief history of time. Ph.D. diss., University of Auckland.

Jones, P. D., K. R. Briffa, T. P. Barnett, and S. F. B. Tett. 1998. High-resolution palaeoclimate records for the last millennium: Interpretation, integration, and comparison with General Circulation Model control-run temperatures. *The Holocene* 8:455–71.

Jones, P. D., and M. E. Mann. 2004. Climate over past millennia. *Reviews of Geophysics* 42, RG2002, doi: 10.1029/2003RG000143.

Jones, P. D., T. J. Osborn, and K. R. Briffa. 2001. The evolution of climate over the last millennium. *Science* 292:662–67.

Jones, T. L., G. M. Brown, L. M. Raab, J. L. McVickar, W. G. Spaulding, D. J. Kennett, A. York, and P. L. Walker. 1999. Environmental imperatives reconsidered: Demographic crises in western North American during the Medieval Climatic Anomaly. *Current Anthropology* 40:137–70.

Kennett, D. J., and J. P. Kennett. 2000. Competitive and cooperative responses to climatic instability in coastal southern California. *American Antiquity* 65:379–96.

Kiladis, G. N., and H. F. Diaz. 1989. Global climatic anomalies associated with extremes in the Southern Oscillation. *Journal of Climate* 2:1069–90.

Kilbourne, K. H., T. M. Quinn, F. W. Taylor, T. Delcroix, and Y. Gouriou. 2004. El Niño-Southern-Oscillation-related salinity variations recorded in the skeletal geochemistry of a *Porites* coral from Espiritu Santo, Vanuatu. *Paleooceanography* 19, PA4002, doi: 10.1029/2004PA001005.

Kirch, P. V., and J. Ellison. 1994. Palaeoenvironmental evidence for human colonisation of remote Oceanic islands. *Antiquity* 68:310–21.

Kirch, P. V., J. R. Flenley, D. W. Steadman, F. Lamont, and S. Dawson. 1992. Ancient environmental degradation. *National Geographic Research and Exploration* 8:166–79.

Kirch, P. V., and W. D. Sharp. 2005. Coral ^{230}Th dating of the imposition of a ritual control hierarchy in precontact Hawaii. *Science* 307:102–4.

Labeyrie, L., J. Cole, K. Alverson, and T. Stocker. 2003. The history of climate dynamics. In *Paleoclimate, global change, and the future*, ed. K. Alverson, R. S. Bradley, and T. Petersen, 33–61. Berlin: Springer-Verlag.

Lamb, H. H. 1965. The early medieval warm epoch and its sequel. *Palaeogeography, Palaeoclimatology, Palaeoecology* 1: 13–37.

———. 1977. *Climate history and the future.* Vol. 2. *Climate: Past, present, and future.* New York: Methuen.

Leach, H. M., and B. F. Leach. 1979. Environmental change in Palliser Bay. In *Prehistoric man in Palliser Bay*, ed. B. F. Leach and H. M. Leach, 229–40. National Museum of New Zealand Bulletin 21.

Linsley, B. K., G. M. Wellington, and D. P. Schrag. 2000. Decadal sea surface temperature variability in the subtropical South Pacific from 1726 to 1997 A.D. *Science* 290: 1145–48.

Lockerbie, L. 1950. Review of Raeside. *Journal of the Polynesian Society* 59:87–90.

Loubere, P., M. Richaud, Z. Liu, and F. Mekik. 2003. Oceanic conditions in the eastern equatorial Pacific during the onset of ENSO in the Holocene. *Quaternary Research* 60:142–48.

McCall, G. 1994. Little Ice Age: Some proposals for Polynesia and Rapanui (Easter Island). *Journal de la Société des Océanistes* 98:99–104.

McCulloch, M. T., G. Mortimer, T. Esat, L. Xianhua, B. Pillans, and J. Chappell. 1996. High-resolution windows into early Holocene climate: Sr/Ca coral records from the Huon Peninsula. *Earth and Planetary Science Letters* 138:169–78.

McKinzey, K., W. Lawson, D. Kelly, and A. Hubbard. 2004. A revised Little Ice Age chronology of the Franz Josef Glacier, Westland, New Zealand. *Journal of the Royal Society of New Zealand* 34:381–94.

Madsen, M., C. Lipo, and M. Cannon. 1999. Fitness and reproductive trade-offs in uncertain environments: Explaining the evolution of cultural elaboration. *Journal of Anthropological Archaeology* 18:251–81.

Mann, M. E., R. S. Bradley, and M. K. Hughes. 1999. Northern Hemisphere temperatures during the past millennium: Inferences, uncertainties, and limitations. *Geophysical Research Letters* 26:759–62.

Mann, M. E., M. A. Cane, S. E. Zebiak, and A. Clement. 2005. Volcanic and solar forcing of the tropical Pacific over the past 1000 years. *Journal of Climate* 18:447–56.

Mantua, N. J., S. R. Hare, J. M. Wallace, and R. C. Francis. 1997. A Pacific interdecadal oscillation with impacts on salmon production. *Bulletin of the American Meteorological Society* 78:1069–79.

Markgraf, V., and H. F. Diaz. 2000. The past ENSO record: A synthesis. In *El Niño and the Southern Oscillation: Multiscale variability and global and regional impacts*, ed. H. F. Diaz and V. Markgraf, 465–88. Cambridge: Cambridge University Press.

Moy, C. M., G. O. Seltzer, D. T. Rodbell, and D. M. Anderson. 2002*a*. Variability of El Niño/Southern Oscillation activity at millennial timescales during the Holocene epoch. *Nature* 420:162–65.

———. 2002*b*. Laguna Pallcacocha Sediment Color Intensity Data IGBP PAGES/World Data Center for Paleoclimatology Data Contribution Series #2002–76. Boulder: NOAA/NCDC Paleoclimatology Program.

Mullan, B. A. 1991. Atmospheric circulation processes and features in the South Pacific. In *South Pacific environments: Interactions with weather and climate, Auckland, 1991*, 15–24. Environmental Science Occasional Publication 6.

Nunn, P. D. 1991. Keimami sa Vakila na Liga ni Kalou *(Feeling the hand of God): Human and nonhuman impacts on Pacific Island environments*. Honolulu: Environmental and Policy Institute, East-West Center.

———. 1998. Sea-level changes over the past 1000 years in the Pacific. *Journal of Coastal Research* 14:23–30.

———. 1999. *Environmental change in the Pacific Basin: Chronologies, causes, consequences*. Chichester: John Wiley.

———. 2000*a*. Environmental catastrophe in the Pacific Islands around A.D. 1300. *Geoarchaeology* 15:715–40.

———. 2000*b*. Illuminating sea-level fall around A.D. 1220–1510 (730–440 cal yr BP) in the Pacific Islands: Implications for environmental change and cultural transformation. *New Zealand Geographer* 56:4–12.

———. 2003. Revising ideas about environmental determinism: Human-environment relations in the Pacific Islands. *Asia Pacific Viewpoint* 44:63–72.

Nunn, P. D., and M. R. Britton. 2001. Human-environment relationships in the Pacific Islands around A.D. 1300. *Environment and History* 7:3–22.

Orliac, C. 2000. The woody vegetation of Easter Island between the early 14th and mid-17th centuries A.D. In *Easter Island archaeology: Research on early Rapanui culture*, ed. C. M. Stevenson and W. S. Ayres, 211–20. Los Osos, Calif.: Bearsville Press.

Power, S., T. Casey, C. K. Folland, A. Colman, and V. Mehta. 1999. Inter-decadal modulation of the impact of ENSO on Australia. *Climate Dynamics* 15:319–23.

Quinn, T. M., T. J. Crowley, F. W. Taylor, C. Henin, P. Joannot, and Y. Join. 1998. A multi-century stable isotope record from a New Caledonia coral: Interannual and decadal sea surface temperature variability in the southwest Pacific since 1657 A.D. *Paleoceanography* 13:412–26.

Quinn, T. M., F. W. Taylor, and T. Crowley. 1993. A 173-year stable isotope record from a tropical South Pacific coral. *Quaternary Science Reviews* 12:407–18.

Raeside, J. D. 1948. Some post-glacial climatic changes in Canterbury and their effects on soil formation. *Transactions of the Royal Society of New Zealand* 77:153–71.

Richerson, P. J., R. Boyd, and R. L. Bettinger. 2001. Was agriculture impossible during the Pleistocene but mandatory during the Holocene? A climate change hypothesis. *American Antiquity* 66:387–411.

Rind, D. 1998. Latitudinal temperature gradients and climate change. *Journal of Geophysical Research* 103:5943–71.

———. 2000. Relating paleoclimate data and past temperature gradients: Some suggestive rules. *Quaternary Science Reviews* 19:381–90.

Rodbell, D. T. G. O. Seltzer, D. M. Anderson, M. B. Abbott, D. B. Enfield, and J. H. Newman. 1999: An ~ 15,000-year record of El Niño-driven alluviation in southwestern Ecuador. *Science* 283:516–20.

Salinger, M. J., B. B. Fitzharris, J. E. Hay, P. D. Jones, J. P. MacVeigh, and I. Schmidely-Leleu. 1995. Climate trends in the south-west Pacific. *International Journal of Climatology* 15:285–302.

Salinger, M. J., J. A. Renwick, and A. B. Mullan. 2001. Interdecadal Pacific Oscillation and South Pacific climate. *International Journal of Climatology* 21:1705–21.

Spriggs, M., and A. Anderson. 1993. Late colonisation of East Polynesia. *Antiquity* 67:200–217.

Stephans, C., T. M. Quinn, F. W. Taylor, and T. Corrège. 2004. Assessing the reproducibility of coral-based climate records. *Geophysical Research Letters* 31, L18210, doi: 10.1029/2004GL020343.

Suplee, C. 1999. El Niño/La Niña: Nature's vicious cycle. *National Geographic* 195:72–95.

Thorne, R. F. 1963. Biotic distribution patterns in the tropical Pacific. In *Pacific Basin biogeography*, ed. J. L. Gressitt, 311–50. Honolulu: Bishop Museum Press.

Trenberth, K. E., G. W. Branstator, D. Karoly, A. Kumar, N-C. Lau, and C. F. Ropelewski. 1998. Progress during TOGA in understanding and modelling global teleconnections associated with tropical sea surface temperatures. *Journal of Geophysical Research* 103:14291–324.

Tudhope, A. W., C. P. Chilcott, M. T. McCulloch, E. R. Cook, J. Chappell, R. M. Ellam, D. W. Lea, J. M. Lough, and G. B. Shimmield. 2001. Variability in the El Niño-Southern Oscillation through a glacial-interglacial cycle. *Science* 291: 1511–17.

Tudhope, A. W., G. B. Shimmield, C. P. Chilcott, M. Jebb, A. E. Fallick, and A. N. Dalgleish. 1995. Recent changes in climate in the far western equatorial Pacific and their relationship to the Southern Oscillation: Oxygen isotope records from massive corals, Papua New Guinea. *Earth and Planetary Science Letters* 136:575–90.

Upman, S. 1984. Adaptive diversity and Southwestern abandonment. *Journal of Anthropological Research* 40:235–56.

Urban, F. E., J. A. Cole, and J. T. Overpeck. 2000. Influence of mean climate change on climate variability from a 155-year tropical Pacific coral record. *Nature* 407:989–93.

Watson, R., M. Zinyowera, and R. Moss, eds. 1998. *The regional impacts of climate change: An assessment of vulnerability.* Cambridge: Cambridge University Press.

Weisler, M. I., Kenneth D. Collerson, Yue-Xing Feng, Jian-Xin Zhao, and Ke-Fu Yu. 2006. Thorium-230 coral chronology of a late prehistoric Hawaiian chiefdom. *Journal of Archaeological Science* 33:273–82.

Wilkinson, C. R., O. Linden, H. Cesar, G. Hodgson, J. Rubens, and A. E. Strong. 1999. Ecological and socioeconomic impacts of 1998 coral mortality in the Indian Ocean: An ENSO impact and a warning of future change? *Ambio* 28:188–96.

Williams, L. D., and T. M. L. Wigley. 1983. A comparison of evidence for Late Holocene summer temperature variations in the Northern Hemisphere. *Quaternary Research* 20:286–307.

Wilson, A. T., C. H. Hendy, and C. P. Reynolds. 1979. Short-term climate change and New Zealand temperatures during the last millennium. *Nature* 279:315–17.

Woodroffe, C. D., M. R. Beech, and M. K. Gagan. 2003. Mid-Late Holocene El Niño variability in the equatorial Pacific from coral microatolls. *Geophysical Research Letters* 30(7), 1358, doi: 10.1029/2002GL015868.

Yen, D. E. 1961. The adaptation of kumara by the New Zealand Maori. *Journal of the Polynesian Society* 70:338–48.