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*Keimami sa vakila  
na liga ni Kalou*

(Feeling the Hand of God):

**Human and Nonhuman  
Impacts on Pacific  
Island Environments**

Patrick D. Nunn



**East-West  
Center**



*Keimami sa vakila  
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Revised Edition

*by*  
Patrick D. Nunn



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## SUMMARY

This paper describes the nature and likely causes of environmental changes on Pacific islands both before and after their initial settlement by people. There were significant climate changes immediately before initial settlement that must have affected contemporary island landscapes. These changes would have continued after initial settlement, and their effects on postsettlement environments are comparable to those caused directly by human activities. Of particular note are the effects of the Little Climatic Optimum, the Little Ice Age, and the climatic amelioration of the past 150 to 200 years or so.

The effects of climate, sea level, and tectonic changes on many island environments during their postsettlement history have been great. In much previous work on this topic, the importance of nonhuman agents of environmental change appears to have been underestimated, and the importance of direct human impact overstressed.

### 1. PREAMBLE

In March 1990, while undertaking geomorphic fieldwork on the island of Nayau in the Lau group of eastern Fiji, I stopped on the high plateau of Bucavakanayau (Plate 1) to talk to some of the local people. I asked them whether the plateau, where soils are thin and vegetation is dominated by a fern-grassland assemblage known as *talasiga*, had always been in its present state. "No," came the reply, "our ancestors were able to grow crops here but now the soil is no good." I asked, "What caused this change?" They were unsure. One man said, "*Keimami sa vakila na liga ni Kalou*" ("We feel the hand of God").

The role of God in everyday life is perceived very strongly by most Pacific islanders, especially those living in the more rural parts of the region. A belief that God, or at least some nonhuman agency, has brought about changes in the environment is not uncommon in my experience. Yet such a view runs contrary to the conclusions of many investigations of recent environmental change in the Pacific islands.

Actions taken to prevent the spread of degraded land, conserve soil, and ameliorate other undesired environmental changes have concentrated on making Pacific islanders desist from what are regarded as unsuitable agricultural practices in particular environments. These actions have undoubtedly done some good but have also produced much frustration.

I have seen rural dwellers, mostly subsistence farmers, who have been repeatedly instructed not to clear the steepest mountain slopes



Plate 1. *The high plateau of Bucavakanayau on the island of Nayau in eastern Fiji. According to local people, the area was once considerably more agriculturally productive than it is today. Photo by author.*

because of the danger of rendering them unstable. Yet the people never did clear those slopes; they never would. Still these slopes fail. During prolonged periods of storm rain, landslides develop on high island slopes often irrespective of whether or not they were cleared. Elsewhere, particularly where small-scale commercial farming is dominant, advice about which crops to plant to conserve rather than lose soil is plentiful, yet often ineffective. The soil continues to erode irrespective of what is planted, the farmers say. Why is this? It is not the people's doing. Comes one response, "*Keimami sa vakila na liga ni Kalou.*"

## 2. INTRODUCTION

The Pacific islands are unique. Sometimes they seem invisible. When the Pacific Basin is viewed from the communications satellite in geostationary orbit over the equator at 149° W, "the impression is of an earth empty of land and people" (Ward 1989:235). Most non-Pacific islanders regard the Pacific Basin as a region to be crossed and of little significance in its own right—a view unlikely to be widely dislodged during the forthcoming "Pacific Century." Inevitably Pacific islanders regard the Pacific Basin quite differently. The earliest saw it not as a vast, empty trackless ocean but as "a sea scattered with many islands" (ibid.:239).

Although the Pacific islands remain comparatively unknown to most people, their inhabitants have become increasingly dependent on interaction with the world outside the region. Few islands are self-sufficient nowadays, and some have reached a point where their inhabitants are sustained only by migration, remittances, aid, and bureaucracy—the so-called MIRAB economies (Bertram and Watters 1985).

Far-sighted leaders of Pacific island nations realize the threats posed to national integrity and autonomy by increased dependence on the world outside the region. Therefore, many countries are vigorously pursuing programs aimed at increasing self-sufficiency and boosting economic growth under the cachet of sustainable development.

The threat from future climate change is more recent. Appropriate remedial measures have not yet been incorporated into long-term development plans of most island nations for two reasons: (1) Pacific island decision-makers have not received sufficient balanced and authoritative advice about climate change and (2) scant data exist on environmental processes in the Pacific islands. Thus, it has proved difficult to demonstrate the nature of current change and to predict the manifestations of future climate change with precision.

A major problem has been engendering awareness about recent and continuing changes in environmental variables that will act as background trends to future changes. As in other parts of the world, many Pacific island decision-makers believe that the only environmental changes in the discernible past were those caused by human activities and that if human impacts were to be stopped or reversed, then the environment would return to a condition of equilibrium. This view is wrong.

This paper outlines some of the major environmental changes that have occurred on Pacific islands (Figure 1) within the recent past. The adjective "recent" is used deliberately. It refers both to the geologically recent past—the last few thousand years—and to the historically recent past—the last 200 years or so—for which much more information is available.

The immense effects of humans on Pacific island environments are indisputable. Particularly in the last hundred years or so, biocultural and socioeconomic effects, such as species extinctions, declines in native habitats, eutrophication, vegetation clearance for agriculture, and water pollution, have been widespread (Farrell 1972; Dahl 1980, 1984; Dahl and Baumgart 1983; Carpenter and Maragos 1989). Many of these effects are linked directly to increasing populations, the shift from subsistence to commercial agriculture, and the loss of traditional knowledge relating to resource management (Clarke 1990).

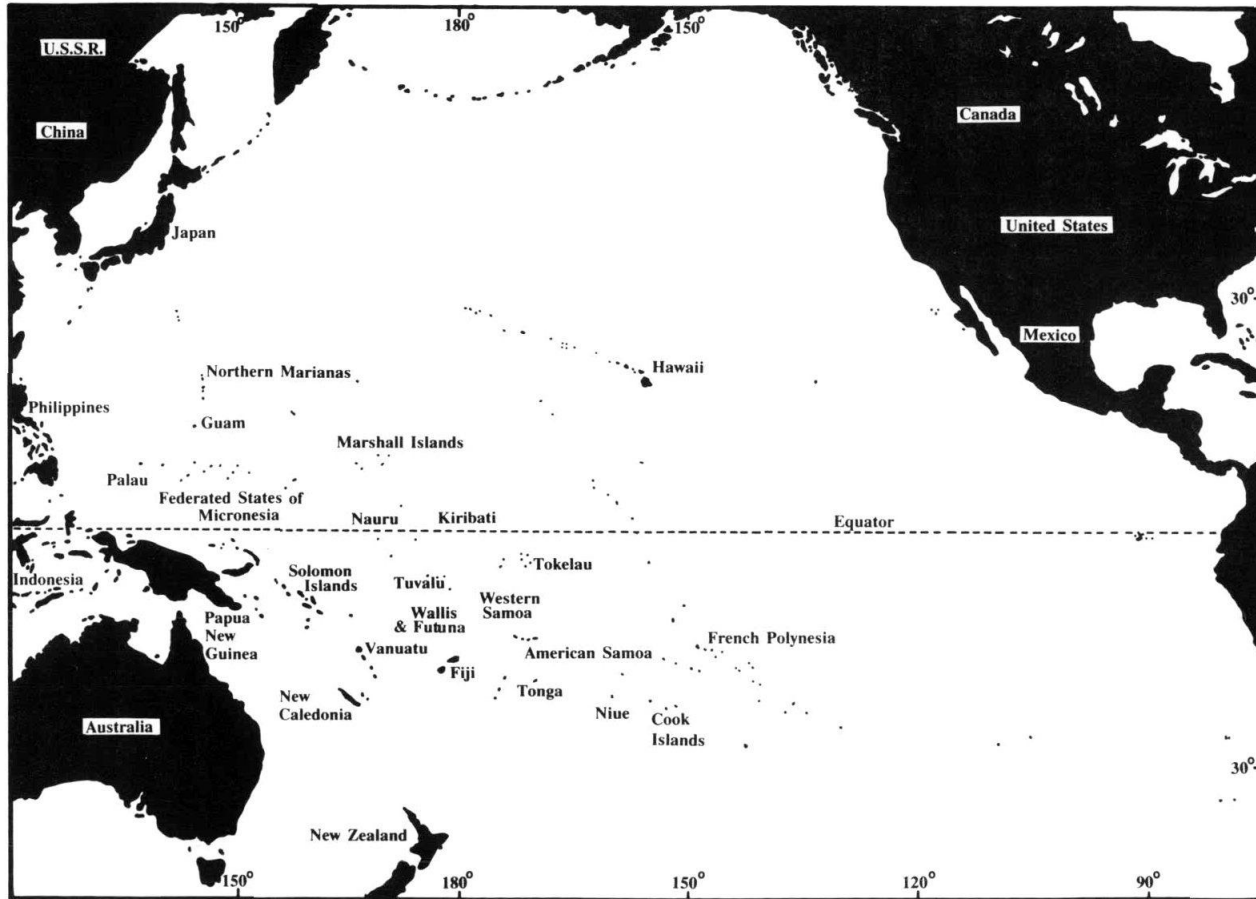


Figure 1. Main islands and island groups in the Pacific Basin mentioned in the text.

The environmental changes on which this paper focuses are those whose causes are less readily identifiable. Such changes include soil erosion, land degradation, and coastline changes.

The attribution of certain environmental changes to particular causes poses a philosophical dilemma. The deleterious effects of goats, for example, on many island environments are well documented; but are goats the principal cause of these changes, or should they be more properly attributed to the humans who introduced the goats to the island in the first place? For this paper, the view is taken that goats, not humans, were responsible for such changes.

### **3. THE NATURE OF ENVIRONMENTAL CHANGES IN THE PACIFIC ISLANDS**

The Pacific islands experienced Quaternary<sup>1</sup> climate and environmental changes similar in complexity, if not entirely correlatable, with those elsewhere in the world. The few studies on the islands themselves have come mostly from pollen analyses that allow the history of vegetation change to be worked out (e.g., Flenley and King 1984). These studies have been complemented by paleoclimatic analyses of ocean cores, using mainly oxygen-isotope ratios as indicators of past ocean-water temperatures (e.g., Shackleton and Opdyke 1973; see Figure 2A).

Specifically for the late Pleistocene and Holocene,<sup>2</sup> techniques such as pollen and oxygen-isotope analysis have allowed detailed reconstructions of contemporary vegetation and climate changes for many island groups. The results of these studies do not correlate particularly well with each other, which is not surprising considering the great distances between islands. Furthermore, there is little or no pertinent information available for many parts of the Pacific region. Despite these drawbacks, the Last Glacial<sup>3</sup> in the tropical Pacific islands is known to have been marked by a period of comparative aridity (e.g., Colinvaux 1972).

Pollen analyses have been particularly important in unravelling the precise changes to island vegetation that followed the arrival of humans on the islands. It is important to remember, however, that causal links between human activities and vegetation change can only be inferred,

- 
1. The last 1.8 million years of earth history.
  2. The Quaternary is divided into the Pleistocene (1,800,000 to 10,000 years ago) and Holocene (last 10,000 years).
  3. The Last Glacial (or Ice Age) began about 70,000 years ago and ended about 10,000 years ago at the beginning of the Holocene Interglacial.

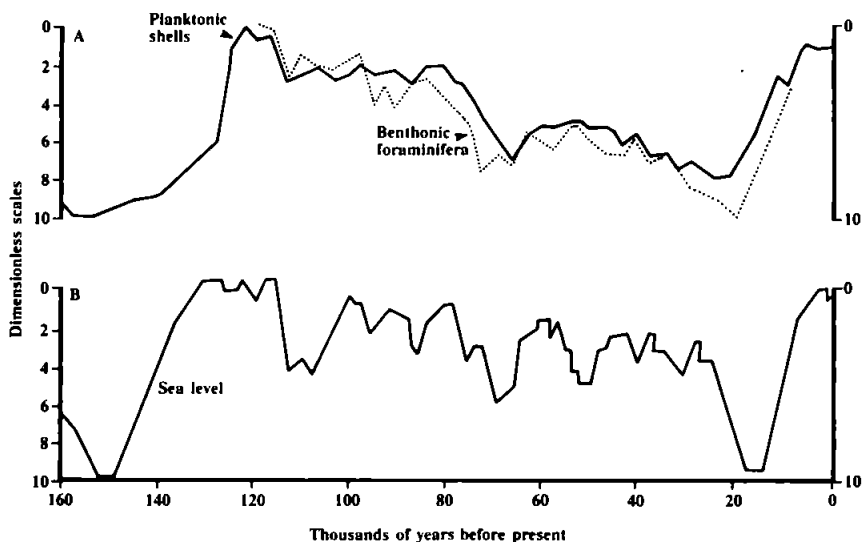


Figure 2. Examples of indicators of environmental changes in the Pacific Basin over the last 160,000 years.

A. Oxygen-isotope ratios for planktonic shells and benthonic foraminifera from equatorial Pacific deep-sea core V28-238 (after Shackleton and Opdyke 1973). Oxygen-isotope ratios have been used to indicate temperature variations in the distant past.

B. Changes in sea level determined from the ages and elevations of fossil coral reefs on the Huon Peninsula, Papua New Guinea (after Chappell 1983).

In both A and B, the low temperatures and low sea levels that characterized the glacial (Ice Age) maxima 150,000 and 18,000 years ago can be clearly seen, as can the interglacial peaks 125,000 and ~5000 years ago.

not demonstrated. Dates of earliest-known settlements on the main groups of Pacific islands are listed in Table 1. These dates give a general idea of the timescales over which the changes described in this paper occurred within particular island groups.

On most islands where pollen analyses of sediments, whose age ranges straddle the time of initial human settlement, have been carried out, marked increases in charcoal and decreases in woody taxa have been observed following human arrival. Subsequent increases in grass pollen appear to confirm the long-held view that most Pacific island grasslands are anthropogenic. This is not the case. Although most



Table 1. Earliest-known settlement dates of selected Pacific islands

Island group	Island site	Date (years B.P.)	Source
MELANESIA			
Papua New Guinea	Huon Peninsula	> 40,000	Groube et al. (1986)
New Ireland	Matenkupkum cave	32,700 $\pm$ 1550	Allen et al. (1988)
Solomon Islands	Kilu	~ 28,000	Wickler and Spriggs (1988)
New Britain	Misisil cave	11,400 $\pm$ 1200	Specht et al. (1981)
Fiji	Natunuku, Viti Levu	3240 $\pm$ 100	Shaw (1975)
New Caledonia	Naia	3165 $\pm$ 120	Green and Mitchell (1983)
Vanuatu	Malo	3150 $\pm$ 70	Ward (1979)
POLYNESIA			
Tonga	Tongatapu	3540 $\pm$ 70	Poulsen (1967)
Western Samoa	Ferry Berth, Upolu	3251 $\pm$ 155	Leach and Green (1989)
Marquesas	Anapua, Ua Huka	2100 $\pm$ 95	Ottino (1985)
Hawaii	Pu'u Ali'i, Hawaii	1660 $\pm$ 60	Bellwood (1978b)
Easter Island	Tahai	1260 $\pm$ 130	Ayres (1971)
Society Islands	Huahine	1100 $\pm$ 70	Emory (1979)
Cook Islands	Ureia, Aitutaki	969 $\pm$ 83	Bellwood (1978a)
New Zealand	Wairau Bar, North Island	~ 825	Bellwood (1978b)
Henderson Island		790 $\pm$ 110	Sinoto (1979)
Mangareva		760 $\pm$ 80	Shutler (1971)
MICRONESIA			
Marianas Islands	Chalan Piao, Saipan	3479 $\pm$ 300	Spoehr (1957)
Caroline Islands	Bolipi, Lamotrek	3310 $\pm$ 85	Fujimura and Alkira (1984)

of the grasslands that developed under the arid conditions of the Last Glacial would have been replaced by forest once wetter conditions prevailed, it has become clear recently that many modern Pacific island grasslands may have persisted since Last Glacial times (Spriggs 1981; Latham 1983; Fosberg 1984; Southern 1986; Zan and Hunter-Anderson 1987; Bayliss-Smith et al. 1988; Nunn 1990d; Plate 2). Notwithstanding this, the marked reduction in forest area and the proportional increase in grasslands during the thousand years or so following initial settlement of many islands is undeniable.

Fluctuations in ice extent in the Papua New Guinea highlands (Löffler 1972), on Mauna Kea in Hawaii (Porter 1979), and elsewhere have also been useful indices of late Quaternary climate changes in the Pacific region, both before and after the arrival of people.

Data referring to sedimentation rates on many Pacific islands (Hughes et al. 1979; McGlone 1983) commonly indicate an increase in soil and regolith mobility following human arrival. This increase is attributed to forest clearance by humans, but diagnostic data are currently too few and too imprecise to establish this connection securely. Sedimentation maxima occurred 600 to 1200 years ago and about 400 years after initial settlement on Lakeba Island in Fiji and the North Island of New Zealand, respectively (Nunn 1990d), whereas on Aneityum (Anatom) Island in Vanuatu the hiatus was substantially less (Hope and Spriggs 1982). Although such variations could be the consequence of initial population size, population growth rates, and warfare, for example, they may equally indicate the influence of factors other than direct human impact in contemporary environmental transformation.

Most writers have interpreted the sedimentation records in the post-settlement period of Pacific island history solely in terms of human history. Yet there is little evidence of human impact other than a coincidence between human presence and environmental change, and, as will be discussed, there are other explanations equally, if not more, tenable. On some islands, such as Taveuni in Fiji (Southern 1986), there were no significant vegetation changes despite the undoubted human presence in the area (Best 1984).

Following reductions in upland forest area, and consequent deterioration of upland agricultural potential through soil loss, many Pacific islands experienced increased lowland sedimentation. This was manifested as the infilling of swampy valleys and shoreline progradation at their mouths. The switch from upland to lowland cultivation and subsequent agricultural intensification in the valleys is well documented (Kirch 1981, 1984; Spriggs 1986).

Following the initial spread of European settlement on Pacific islands, forest acreage declined as land was required for grazing and com-

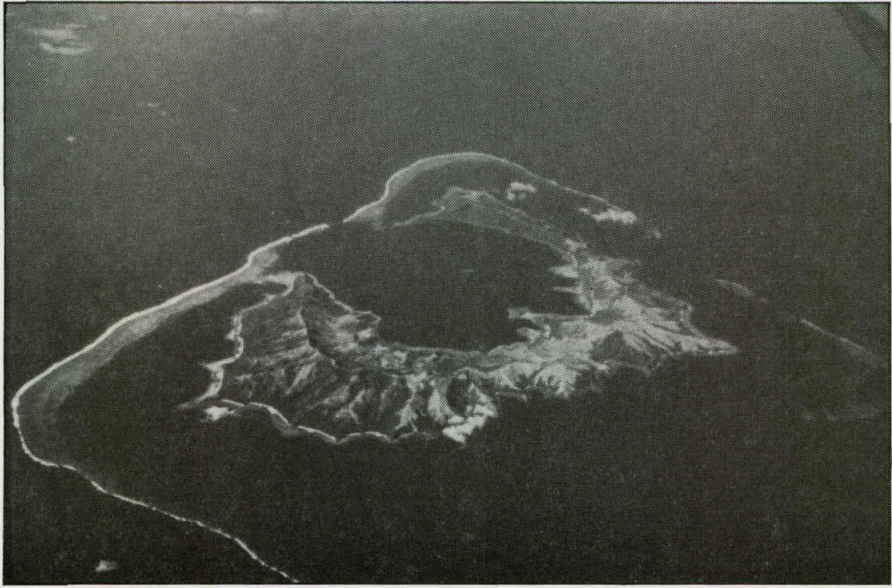


Plate 2. *Aerial view of Totoya Island, southeast Fiji. Note the concentration of grassland on the right (leeward) side of the island and the dominance of forest on the left (wetter, windward) side of the island. Leeward zone grasslands on many Pacific islands may have persisted since the Last Glacial and may not be anthropogenic. Photo courtesy of Dr. Randy Thaman.*

mercial crops. Despite programs of reafforestation on many islands, the overall trend of forest decline has continued, largely because of commercial logging in recent decades (Richardson 1981; Drysdale 1988).

Soil erosion has steadily become more of a problem on many Pacific islands in the last hundred years. Doubts regarding a connection between soil erosion and vegetation clearance or land mismanagement by people have rarely been expressed, although there are insufficient data to test the connection adequately.

Undoubtedly grasslands have spread on Pacific islands since European settlement, although large areas of upland forest regenerated following the earlier switch by indigenous agriculturalists from upland to lowland areas. The deliberate spread of the coconut palm for copra production since European settlement brought about substantial changes in the coastal vegetation of many Pacific islands, particularly resource-poor atolls (Fosberg 1984).

#### 4. PRESETTLEMENT ENVIRONMENTAL CHANGES

##### 4.1 Climate Changes

Alternate periods of warming and cooling during the Quaternary are commonly regarded to have been caused at the primary level by cyclical variations in the Earth's orbit (Chappell 1978; Emiliani 1978). The last first-order cycle began with the onset of the Last Glacial about 70,000 years ago. The Last Glacial maximum, about 18,000 years ago, was followed by rapid climatic amelioration and the start of the present interglacial (the Holocene) about 10,000 years ago (Figure 2A). The Quaternary glacial-interglacial alternation in middle and high latitudes is believed to have been broadly paralleled by an alternation between dry and wet conditions in low latitudes. The few tropical glaciers in the Pacific had histories similar to higher-latitude continental ice bodies. The work of Löffler (1972) in Papua New Guinea and that of Porter (1979) in Hawaii exemplify the situation.

Annual precipitation in the western Pacific was probably 25 to 50 percent less 18,000 years ago than it is today (Rind and Peteet 1985). Pollen analyses and other factors indicate aridity in the Galápagos Islands between 34,000 and 10,000 years ago (Colinvaux 1972), on Aneityum in Vanuatu 23,000 years ago (Spriggs 1981), on Easter Island 21,000 to 12,000 years ago (Flenley and King 1984), and on Taveuni in Fiji 14,300 to 13,000 years ago (Southern 1986).

The first part of the Holocene, which began 10,000 years ago, was marked by continued warming and associated changes in vegetation and climate. Sea-level rise from ice melt continued until at least 6000 years ago in most places. Temperature maxima occurred in many parts of the world about 5000 years ago, the time of the Holocene Climatic Optimum. A few data, mostly from the periphery of the Pacific, suggest that the Holocene Climatic Optimum also affected this region around the same time (McGlone and Topping 1977; Black 1980). Since this time, at the primary (first-order) level, world temperatures have decreased. In most parts of the Pacific Basin, sea level reached a maximum about 3000 to 4000 years ago (Pirazzoli 1978; Nunn 1991b). Its first-order trend since then has been a falling one.

Much confusion arises from a failure to appreciate the various scales at which these processes operate (Stockton 1990). For most of the distant past, we can recognize only first-order changes in environmental variables; for example, about 70,000 years ago, temperatures and sea level over most parts of the globe began to fall. For more recent times, additional information allows second- and third-order changes to be identified, although these are sometimes mistaken for first-order changes.

For example, although sea level has been rising in many parts of the world over the last hundred years or so, this is not necessarily a first-order change. The first-order fall in sea level over the past 3000 to 4000 years was marked by short-lived periods of sea-level rise in many places, including parts of the Pacific islands (Schofield 1980). These periods, however, were those of second-order variations within the first-order trend of sea-level fall.

Similarly, although the first-order trend of temperature in many parts of the world since the Holocene Climatic Optimum 5000 years ago has been a cooling one, there have been many lower-order changes; for example, significant warming occurred during the Little Climatic Optimum 1200 to 650 years ago. This warming did not alter the first-order cooling trend.

Writers have claimed that the environments of the Pacific islands were in a pristine condition before initial settlement (e.g., Decker 1970; Dupon 1986; Culliney 1988). Such views derive not from positive evidence but from negation; in this case, the juxtaposition of presettlement environments in an unknown condition with postsettlement environments assumed to have deteriorated as the result of human interference.

Many pollen data for the Pacific islands support Fosberg's (1963:5) notion that "the older island ecosystems had reached such relative stability that changes were mostly very slow" before initial settlement. This view is supported by a realization that the dominant controls on the weather of many tropical Pacific islands are the trade winds and the associated current system which were probably well established by the time of the Holocene Climatic Optimum and which have persisted since then (Moore 1973; Simpson 1975).

Despite this, there are currently insufficient precise data to know the state of vegetation change, and by proxy that of climate change, in the Pacific islands immediately before their initial settlement. As for Madagascar, "it is conceivable that the seemingly severe impact of human arrival may in fact be a coincidence of the arrival of Man at a time when the vegetation . . . was under climatic stress" (Burney 1987:141).

## **4.2 Sea-Level Changes**

Quaternary glacial (ice ages) were associated with periods of low sea level worldwide. At the height of the Last Glacial, sea level in the southwest Pacific was about 120 meters below its present level. Conversely Quaternary interglacial periods, such as the Holocene in which we live now, were times of high sea level worldwide. Shorelines in many places during the Last Interglacial, which peaked about 125,000 years B.P., were mostly within a few meters of modern shorelines (Figure 2B).

The rise of sea level resulting principally from ice melt since the Last Glacial maximum occupied most of the first half of the Holocene. The course of this Holocene transgression has been determined for many Pacific island groups (Figure 3). It undoubtedly exerted considerable influence on local climate and vegetation, especially in archipelagoes. Its most profound effects occurred along island coastlines. As illustrated by Gibbons (1984), the coasts of most Pacific islands prior to about 5000 to 7000 years ago comprised sheer cliffs, composed of Pleistocene coral reef, with a steeply dipping offshore and little erosional shoreline development.

Around the time of the Holocene Climate Optimum, sea level in much of the Pacific rose above its present level (Table 2) and stabilized for the first time in about 12,000 to 13,000 years, allowing lateral erosion to commence in earnest (Pirazzoli 1978; Nunn 1991b). This produced shore platforms at low-tide level which became exposed subsequently when sea level fell in the late Holocene (Figure 3). The emerged shore platforms became the bases on which alluvium, colluvium, and marine-derived material accumulated to form the coastal plains and flats that most island settlements still occupy. Nunn (1988b) argued that the emergence of coastal plains in the late Holocene was a major factor in the apparently rapid development of contemporary settlement in the south and central Pacific islands during the late Holocene.

Particularly on small islands, changes in base level (sea level) can produce rapid responses in the landscape (McLean 1980; Nunn 1987). Supposing that many small-island river channels had attained equilibrium around the Holocene Climatic Optimum, the effect of the subsequent sea-level fall would have been to cause incision of all parts of the valleys except perhaps their uppermost reaches. In the middle valleys, incision would have increased valley-side slope angles causing an increase in slope instability which would, in turn, have caused an increase in mass movements downslope and increased sediment load in the river channels. Continuing incision, as would be expected to have accompanied a slow regression, would have caused disequilibrium to have been maintained. In the lower valleys, incision would also have dominated causing formation of river terraces. The main effect of sea-level fall at the mouths of river valleys would have been to cause shoreline progradation not just as a direct consequence but also because of increased sediment supply to the river channel as the result of instability in the middle valley.

On those islands affected by uplift during the late Holocene, the instability of the valley-side slopes caused by contemporary sea-level fall would have been exacerbated. Considerable credence is given to

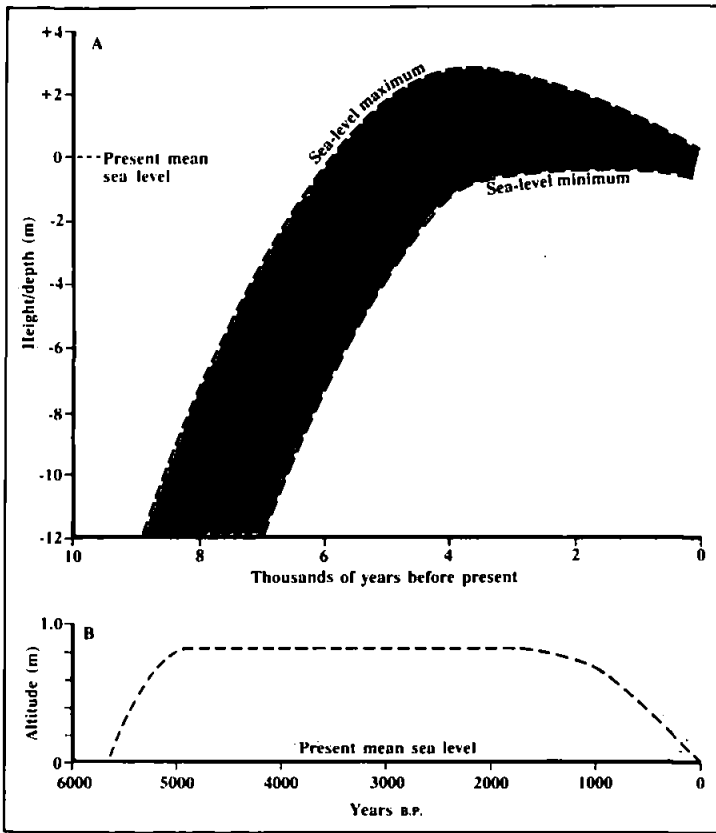


Figure 3. Holocene sea-level changes in the Pacific. (None of the data used to construct these figures are shown.)

A. Sea-level changes during the Holocene in Fiji (after Nunn 1991b). The data are not sufficiently precise to allow a single line representing the course of Holocene sea-level changes to be drawn. The envelope shown is intended to contain all possible positions for sea level at any one time.

Although only the envelope for Fiji is shown, the character of Holocene sea-level changes in most other parts of the Pacific islands is broadly similar. Note how sea level rose above its present level within the last ~5000 years.

B. Late Holocene sea-level changes in the Tuamotu Islands, French Polynesia (after Pirazzoli and Montaggioni 1986). The quantity of precise data for this period allows a line, closely approximating the actual course of mean sea level relative to the present to be drawn here. Note the apparently abrupt fall of sea level ~1500 years B.P.

Table 2. Height and timing of Holocene sea-level maxima in the Pacific Basin

Island group	Holocene sea-level maximum		Source
	Date (years B.P.)	Height (m)	
Enewetak (Marshall Is)	3500-2000	> 1.0	Buddemeier et al. (1975)
Fiji	3000-2000	1.0-2.0	Nunn (1990b)
French Polynesia	2000-1500	~ 1.0	Pirazzoli and Montaggioni (1988)
Japan	~ 5000	2.0	Gohara (1976)
Mangaia (Cook Is)	3410	1.8	Stoddart et al. (1985)
Mopelia (Society Is)	3450	0.8	Guilcher et al. (1969)
New Zealand	3500	0.5	Gibb (1986)
Rarotonga (Cook Is)	2030	1.0	Schofield (1970)
Tuamotus (northwest)	~ 3000	0.8	Pirazzoli and Montaggioni (1986)
Western Samoa	~ 1000	~ 1.0	Nunn (1991b)



this proposition by noting that those islands where late Holocene valley filling is most marked, such as Aneityum in Vanuatu (Spriggs 1981) and Futuna in the Horne Islands (Kirch 1981), are also likely to have experienced contemporary uplift.

No consensus has emerged (nor would it be expected) from studies of Holocene coral-reef growth in the Pacific Basin about whether or not reefs kept pace with sea-level rise during the early Holocene transgression. Work in French Polynesia (Labeyrie et al. 1969) and on the Great Barrier Reef (Hopley 1984) suggest not, while Marshall and Jacobson's (1985) study of Tarawa Atoll in Kiribati suggests that upward growth of the reef there did keep pace with sea-level rise. The distinction is important to an understanding of Holocene environmental changes on reef-fringed islands.

On those coasts where rates of reef growth and sea-level rise were equal, then the coastlines of associated islands would have been continuously protected from wave attack throughout the late Holocene and would be expected to have experienced a considerable extension in land area during the late Holocene as the result of (1) a low mobility of lagoonal sediment, (2) the lateral accretion of coral reefs, and (3) sea-level fall. This certainly seems to have been the case with many mid-Pacific atolls (Schofield 1977; Nunn 1988b).

On those coasts where upward reef growth did not keep pace with sea-level rise, a "high-energy window" would have opened up. While this window was open, wave attack on island coasts would have had more severe effects than at present. This would have inhibited coastal progradation, yet would have amplified lateral coastal erosion. Many coasts in the Pacific Basin exhibit landforms consistent with the opening of a high-energy window in the middle to late Holocene (Hopley 1984; Nunn 1990a). Once sea level began falling on most such coasts in the late Holocene, vertical reef growth would have reached sea level and a change from a high-energy (unprotected) to a low-energy (reef-protected) coastline would have come about.

### **4.3 Tectonic Changes**

Many Pacific islands lie in tectonically active areas, and tectonic change is often used to explain apparent anomalies in island environmental histories. Since the rates of tectonic change in all but a small part of the tectonically active areas are so slow compared to many other processes, tectonic changes have not had a major effect on environmental processes on most Pacific islands within the past thousand years or so.

Long-term continuous tectonic changes are difficult though not impossible to separate from contemporary sea-level changes. The approach used in a recent study was to compare evidence for emergence in areas

with similar tectonic histories and then treat the deviations from mean emergence as its generalized tectonic component (Nunn 1990b). Rates of tectonic change can be calculated much more precisely when that change has been intermittent (Taylor et al. 1980; Nunn 1988c).

The highest rates of uplift in the Pacific islands occur along the frontal arcs of the Aleutians, the Kuriles, the Ryukyu-Marianas, the Solomon Islands-Vanuatu, and Tonga-Kermadec-New Zealand (Yonekura 1983; Ota 1986; Hopley 1987). Some islands in these areas experienced substantial environmental transformation during the late Holocene as the result of uplift. A well-documented example is the effect of tectonic movements on pre-Hispanic agriculture in Peru (Browman 1983).

Subsidence is a much more common condition than uplift for Pacific islands and generally occurs at much slower rates. Subsidence in the Pacific Basin would not have had a significant effect on most island coastlines over periods of 3000 to 5000 years, although locally it has undoubtedly done so. Some rates of uplift and subsidence for Pacific islands are listed in Table 3.

## 5. POSTSETTLEMENT ENVIRONMENTAL CHANGES

The various causes of presettlement environmental changes identified in the preceding section naturally did not immediately cease operating during the postsettlement period. The arrival of humans in the Pacific islands was undoubtedly responsible for considerable environmental changes. Yet, whether the net effects of these changes were everywhere significantly greater over similar time periods than those that preceded human settlement is not certain. Ignorant of presettlement changes and/or assuming them to have been negligible, most writers have linked postsettlement environmental changes in the Pacific islands solely to human activities. This view can now be effectively challenged for most of the postsettlement period before about 200 years ago. For much of this most recent time, the causes of particular environmental changes can be clearly assigned, although the role of direct human impact in others appears to have also been overestimated.

Much of the uncertainty concerning the causes of postsettlement environmental change in the Pacific islands has resulted from a paucity of pertinent data. The few archeological and geomorphic investigations of sufficient detail are not yet enough to allow cogent histories of environmental change for this period to be reconstructed for large regions. Studies of contemporary histories of settled and unsettled islands, preferably in close proximity, are required to isolate actual human impacts from nonhuman impacts.

Table 3. Representative rates of uplift and subsidence for Pacific islands

Island	Rate (mm/year)
<b>UPLIFT</b>	
'Eua, Tonga	0.033
Anaa, Tuamotus	0.1
Efate, Vanuatu	0.8-1.5
Hateruma, Ryukyus	0.1-0.3
Huon Peninsula, Papua New Guinea	3.3
Maré, Loyalty Islands	0.7-1.9
Taiwan (central)	5.0
Tetepare, Solomon Islands	0.5-3.7
Tongatapu, Tonga	1.6
<b>SUBSIDENCE</b>	
Enewetak, Marshall Islands	0.1-0.2
Hawaii Island, Hawaii	0.66-4.4
Honshu, Japan	1.0-1.2
Moruroa, Gambier Islands	0.12

Source: After Nunn 1993a.

## 5.1 Climate Changes

**5.1.a The Little Climatic Optimum.** Climate changes continued to affect Pacific island environments in the postsettlement period. Of these changes, the slight first-order cooling since the Holocene Climatic Optimum is probably the least important considering the time that humans have occupied the islands (see Table 1). The effect of second-order climatic perturbations is much more relevant (Wilson et al. 1979). The most important of these are the Little Climatic Optimum (LCO) and the Little Ice Age (LIA).

Evidence for the LCO has been gathered from many parts of the world (Lamb 1977; Goudie 1983). Average temperatures during the LCO were 0.5° C to 1.0° C (0.9° F to 1.8° F) higher than at present. The average age range for the LCO is 1200 to 650 years B.P.<sup>4</sup> Although no purpose would be served by recounting the evidence for the LCO worldwide, it is relevant to describe that from the Pacific Basin and its periphery.

4. "Before present," where present is the year A.D. 1950 from which radiocarbon dates are measured.

Most late Quaternary pollen records from the Pacific islands have not yielded sufficiently detailed information to allow late Holocene climate changes to be clearly distinguished. Palynologists working in the region have therefore concluded that a similar climate to that of today has persisted since the Holocene Climatic Optimum (e.g., Southern 1986; Villagran 1988). This conclusion, which is contradicted by other paleoclimatic indicators, is not simply the function of few data but also of the increasing realization that recoveries of pollen from tropical freshwater deposits are generally poor, a problem exacerbated by the scarcity and paucity of terrestrial source plants on many Pacific islands (Powell 1976; Ward 1988).

Records of successive ice advance and recession are good indicators of climate change. On Mount Jaya in Irian Jaya, recession of valley ice around the beginning of the LCO (Hope and Peterson 1973) is consistent with contemporary warming. Similar conclusions were obtained from studies of glacier behavior in the New Zealand Alps (Salinger 1976). Along the eastern margin of the Pacific, the Little Climatic Optimum has been recognized in a number of studies of ice fluctuations (e.g., Mercer 1970, 1976).

The complexity of the climate change record for the LCO period is exemplified by Japan where many sources of data, mostly from written sources, are available (Fukui 1977). Periods of warming and cooling within the generalized time of the LCO are shown in Table 4. A likely explanation of these figures is that, although the LCO was a distinct second-order climate-change phenomenon, significant third-order changes can be recognized from such precise data.

From analyzing the composition of forests in South Island, New Zealand, Holloway (1954) argued that a warmer climate had existed 1250 to 550 years B.P. The longest paleotemperature record from New Zealand shows an abrupt decrease in temperature about 570 years B.P., which has been interpreted as signalling the end of the LCO (Wilson et al. 1979; see Figure 4B). Analysis of the tropical Quelccaya ice cap in Peru shows a significant decrease in temperature about 550 years B.P. (Thompson et al. 1986).

Although comparable data do not yet exist for the islands of the Pacific Basin, there are some indications that the LCO had a significant effect on the region. From considering the effects of the LCO on the weather of the tropical Pacific, Bridgman (1983) regarded this period as having been dominated by the Southern Oscillation and believed that the associated reduction in storminess and tropical cyclones, the clear skies, and persistent trade winds explained the comparative success of the "Polynesian migrations" at this time. From analogies with the Atlantic, where shifts in circulation zones during the LCO are better known, Bridgman (1983) and Finney (1985) argued that anomalous

Table 4. Periods of warming and cooling (in years B.P.) in Japan during the Little Climatic Optimum

Time of warming	Time of cooling
1150-1050 (1,2)	900 (3)
1100 (3)	850 (4)
800 (1)	840-750 (2)
750 (4)	
700 (3)	
690 (5)	

Source: After Fukui (1977).

- (1) generalized conclusion from diary accounts
- (2) tree-ring records
- (3) blooming dates of cherry flowers
- (4) snowy-day ratio
- (5) index of good harvests

westerlies would have been more frequent and would have greatly facilitated the process of eastward colonization of the tropical Pacific islands at this time.

Much of the tropical Pacific would have been drier during the LCO than at present. Moisture loss from soil and regolith would have rendered slopes, especially on the windward sides of islands in the trade-wind belt, more susceptible to both sheet erosion and failure through landsliding during storms. An increase in the frequency and magnitude of naturally caused fires would also be expected at this time. In a more general sense, the LCO marked a climate change that inevitably would have caused, especially at its beginning, disequilibrium in the landscape. Forest clearance and other environmental changes initiated by people at this time would probably have had much greater effects on the landscape than they would have had at other times because of landscape instability caused by climate change.

Drier conditions during the LCO may be indicated by the pause in swamp deposition on Lakeba Island in Fiji (Hughes et al. 1979), although this time was marked by increased upland erosion and coastal progradation on Tikopia in the Solomon Islands (Kirch and Yen 1982). More data are needed from this period in the Pacific islands before the contemporary climate can be convincingly reconstructed. What seems clear, however, is that the LCO did figure as an important period of climate change in the postsettlement history of many Pacific islands.

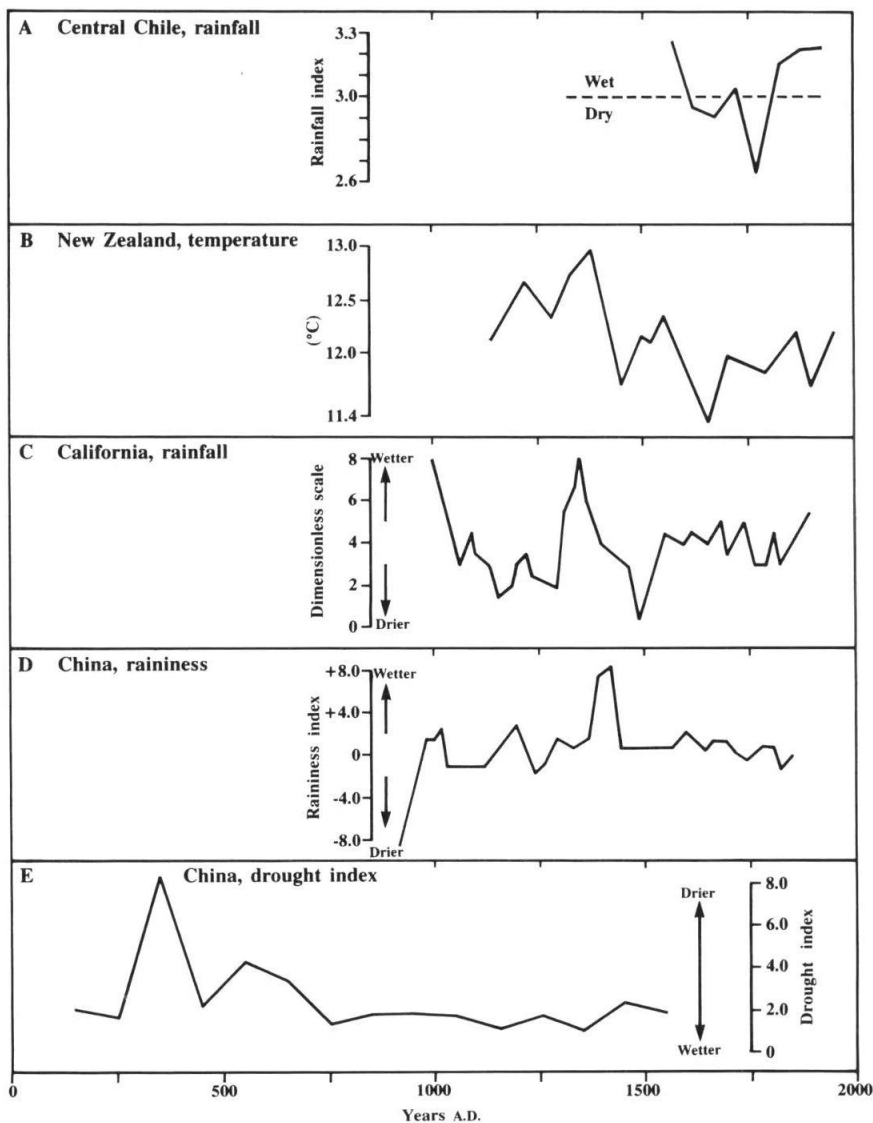


Figure 4. Climate changes around the end of the Little Climatic Optimum and the start of the Little Ice Age (650 years B.P.) in the Pacific.

A. Annual rainfall in the Santiago district of Chile based on survey of official documents by Taulis (1934). Raw data have been converted to 50-year running means for plotting. The vertical axis is the raininess index of Taulis in which 1 is very dry, 3 is normal, and 5 is very wet. Note that the wettest

period may be the end of a period of wetness, which marked the start of the Little Ice Age.

B. Variations of temperature ( $^{\circ}\text{C}$ ) derived from oxygen-isotope analysis of a stalagmite in a cave near Nelson, North Island, New Zealand (after Wilson et al. 1979). Note the rapid temperature fall around A.D. 1400, marking the beginning of a Little Ice Age in New Zealand.

C. Rainfall variations in California as determined from tree-ring widths (after Huntington 1913). Note the rapid increase in rainfall around A.D. 1300 and its decline to A.D. 1500. This period is believed to mark the beginning of the Little Ice Age.

D. Raininess in China using an index based on the numbers of droughts and floods in written sources (after Schove 1949; original data in Yao 1943, 1944). Note the abrupt increase in raininess between A.D. 1360 and A.D. 1420, which is believed to mark the period of regional wetness characterizing the start of the Little Ice Age.

E. Drought index for China based on the ratio of droughts to floods in written records (after Chu 1926). This index is cruder than that in D owing to the reduced precision of source data. Chu noted that the driest centuries were A.D. 300–400, A.D. 500–700, and A.D. 1400–1500, and that the wettest centuries on record were A.D. 1100–1200 and A.D. 1300–1400. The latter is believed to mark the beginning of the Little Ice Age.

**5.1.b The Little Ice Age.** One important reason for crediting the effects of the LCO in the Pacific Basin is that the subsequent deterioration of climate is particularly well marked (Figure 4) and can be reasonably called upon to explain contemporary changes in the pattern of successful colonization of the islands. The period of climate change that succeeded the LCO is known as the Little Ice Age (LIA), and its effects have been recognized on most major landmasses (Grove 1988). In general, LIA temperatures were  $1.5^{\circ}\text{C}$  ( $2.7^{\circ}\text{F}$ ) below those of the LCO. The maximum time limits for the LIA are 650 to 50 years B.P.

Ice advances and recessions on mountains along the periphery of the Pacific Basin provide some of the most convincing evidence for the LIA in this part of the world; for instance, in Papua New Guinea and Irian Jaya (Peterson et al. 1973) and the Southern Alps of New Zealand (Wardle 1973; Gellatly 1985). From a variety of sources, a second-order climate deterioration corresponding to the LIA has also been recognized in Japan (Fukui 1977). In China, temperatures were lower 650 to 100

years B.P., the time of maximum coolness being around 250 years B.P. (Ya-Feng and Jingtai 1979). This figure is close to those for dates of 200 to 161 years B.P. for the outermost moraines in Alaska (Vierech 1968). In the middle Canadian Rocky Mountains, these moraines, which indicate the time of maximum glacier extent, date from 420 to 245 years B.P. (Luckman and Osborn 1979). The corresponding date for the latest ice advance in Patagonian Chile is 190 years B.P. (Mercer 1970). Such variations point to considerable variability in the exact timing and temperature history of the LIA around the Pacific rim and, by inference, across the Pacific islands. Such variations do not, however, suggest that the LIA cannot be recognized as a discrete period within the Pacific, although this may be the case for North America when regarded as a whole (Fritts and Lough 1985).

As for the LCO, indisputable evidence that the LIA affected most Pacific islands is absent to date. The end of successful long-distance voyaging by the earliest settlers in the Pacific coincides with the beginning of the LIA. Bridgman (1983) argued that the persistence of the Southern Oscillation would have diminished as temperatures fell and storminess increased in the central Pacific about the beginning of the LIA. Using trace-element analyses of soils in a rock shelter on Nuku Hiva in the Marquesas, Sabels (1966) concluded that the site had first been occupied about 500 years ago when the climate was significantly cooler and wetter than today. Data quoted by Sanchez and Kutzbach (1974) suggest that the Galápagos Islands were much wetter 300 to 100 years B.P. than at times immediately before or after.

The onset of LIA conditions was roughly coincident with a number of important changes in human history inferred from archeological investigations; for example, the end of settlement expansion within archipelagoes such as the Marquesas (Suggs 1961), and the collapse of ceramic exchange networks involving isolated islands (Kirch 1978). These examples are both consistent, as are other indicators, with a reduction in the success of long-distance voyaging at this time. This reduction may have been caused by meteorological changes, particularly an increase in cyclonic storms, which came about during the transition from LCO to LIA conditions.

The period of transition between the LCO and LIA is also straddled by the early part of the Vuda phase (850–150 years B.P.) in Fiji history. This was a time which saw greatly increased numbers of fortifications and other signs of increased societal conflicts which may have been, in part at least, responses to deteriorating climate and environmental conditions.

Probably the most severe environmental changes during the LIA occurred at its beginning on Pacific islands when a fairly rapid change,



maybe only 100 years or less in duration, from warm, comparatively arid conditions with a low storm frequency to cool, comparatively wet conditions with a much higher storm frequency took place. Landforms, which would have been adapted to LCO conditions, would have been abruptly thrown into disequilibrium by this change. Increased precipitation and increased storminess would have led to massive soil erosion and land degradation, especially on the steep slopes of the drier parts of high islands within the trade-wind belt. Maxima of such processes around this time are recorded from a variety of sites in the Hawaiian Islands (Kirch 1985) and elsewhere; for example, Yasuda wrote of "catastrophic forest destruction" (1976:56) in Japan 650 years B.P. Valley-floor aggradation and coastal progradation around the mouths of major rivers would have accelerated about this time (Kirch 1982).

The rise in precipitation at the beginning of the LIA is marked in rainfall (proxy) records from Chile, California, and China (Figure 4). A marked rise in precipitation about 260 years B.P. is clear in tree-ring width data from Taiwan (Outi 1961/62). Since this time, there seems to have been an inverse relationship between precipitation in Taiwan and in northeast Japan (Outi 1964). In Tahiti, evidence for increased erosion 450–250 years B.P. may have been the consequence of an increased frequency of tropical cyclones (Flenley et al. 1991).

Once sea-surface temperatures fell during the main part of the LIA, there would probably have been a reduction in cyclonic-storm activity (Wendland 1979) that may have allowed many Pacific island landscapes to approach equilibrium once more. This was likely to have been disrupted anew with the climatic amelioration, manifested as warming and possibly an associated increase in storminess, which signalled the end of the LIA.

**5.1.c Recent Climatic Amelioration.** Meteorological records contain good evidence for net warming in many parts of the world over the past hundred years or so (Jones et al. 1986), although evidence relating specifically to the Pacific islands has been compiled only recently (Nullet 1989; Nunn 1990e). Skepticism surrounds the nature of much of this evidence because it has been used or is believed to support the reality of human-induced climate change—the ubiquitous "greenhouse effect." There is no clear evidence of such a link. The warming trend in most of the Pacific Basin seems to have begun long before anthropogenic warming could conceivably have had an effect and is better explained as the climatic amelioration signalling the end of the LIA.

A general recession of glaciers on the periphery of the Pacific Basin has occurred during the past 100 to 200 years (Figure 5); this has been carefully monitored in China (Ya-Feng and Jingtai 1979; sources

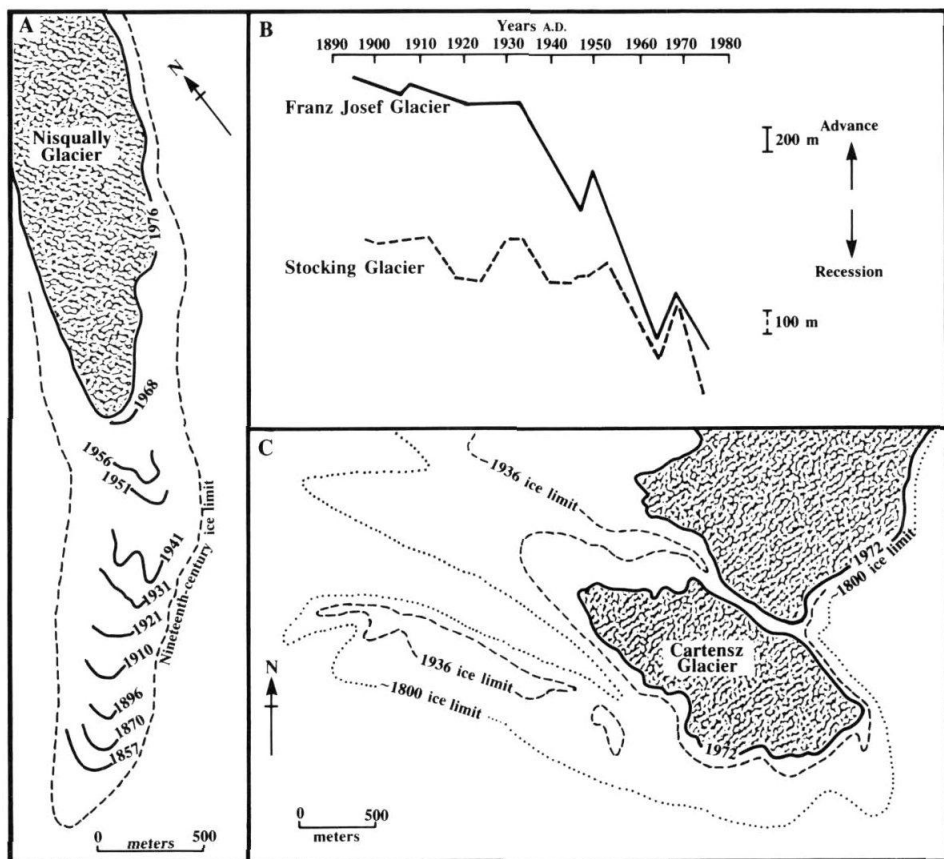


Figure 5. Examples of glacier recession in the last 200 years from the Pacific rim. (All dates shown are in years A.D.)

A. Frontal positions of the Nisqually Glacier, Mount Rainier, northwest USA (after Porter 1981).

B. Variations of ice fronts of the Franz Josef and Stocking glaciers, New Zealand (after Salinger et al. 1983).

C. Changing extent of ice on Mount Jaya (Cartensz), New Guinea (after Allison and Peterson 1976).

in Grove 1988), in New Zealand (Wardle 1973; Salinger 1976, 1979; Salinger et al. 1983), in tropical South America (Grove 1988), in the Cascades, northwest USA (Porter 1981), and Alaska (Heusser and Marcus 1964; sources in Grove 1988). The predominant cause of glacier recession is believed to be temperature rise, although changes in precipitation volume and seasonality are also important.

Since meteorological records exist for much of the last 150 years in many parts of the Pacific region, the nature and complexity of the record can be much better appreciated than for earlier periods. The longest-term temperature records for Pacific islands are summarized in Table 5 and selected series shown in Figure 6. Although the record for Tokyo is undoubtedly affected by the urban heat island, the data for Taiwan indicate that the mean rate of warming is greater at the rural rather than the industrialized stations implying heat-island effects are obscured or nonexistent here (Nunn 1990d).

These data clearly favor a warming throughout the Pacific islands within the last hundred years or so. Although some confirmatory data are available (Karoly 1988), most meteorological stations in the central Pacific have not been operating for a sufficient and/or sufficiently continuous period to allow what is probably a second-order trend to be identified. The danger with using shorter-term records is that they may indicate only a short-term, perhaps third-order, trend which is a less useful basis for prediction than the second-order trend.

Other meteorological variables do not show such clear long-term trends as does temperature. This is largely because these variables are dominated by local rather than regional factors. Mean annual precipitation, for example, in the central Pacific is highly variable and shows a strong correlation with the Southern Oscillation Index (Burgess 1987; Nunn 1990e).

As for many other ocean basins (Milton 1974), analyses of tropical-cyclone frequency in the Pacific Basin show an increase in recent decades (Grant 1981; Thompson 1986; Nunn 1990d, 1990e; Figure 7). For example, tropical cyclones that developed hurricane-force winds (hurricanes) numbered twelve in Fiji between 1941 and 1980, an average of 3.2 per decade. Between 1981 and 1990, ten such tropical cyclones affected Fiji, an average of 12.5 per decade. For the atoll nation of Tuvalu in the South Pacific, decadal cyclone frequency has increased as follows: five cyclones from 1941 to 1950; two cyclones, 1951 to 1960; four cyclones, 1961 to 1970; seven cyclones, 1971 to 1980; and 11 cyclones, 1981 to 1990 (Figure 7C).

Because of the short period over which accurate records of tropical cyclones have been kept, it cannot be known whether this recent increase in their frequency indicates a long-term (perhaps second-order)

Table 5. Summary of long-term temperature records using meteorological data for Pacific islands

Site, island group	Age range (years A.D.)	Approximate net change (°C)	Source
Tokyo, Japan	1885-1965	+1.41	Fukui (1977)
Suva, Fiji	1887-1986	+0.7	Nunn (1990d)
Compilation, Hawaii	1905-1985	+1.3	Nullet (1989)
Compilation, New Zealand	1935-1970	> +1.0	Salinger and Gunn (1975)
Mean, Taiwan	1896-1987	+0.74	Chiang et al. (1989)

*Note:* See also Figure 6.

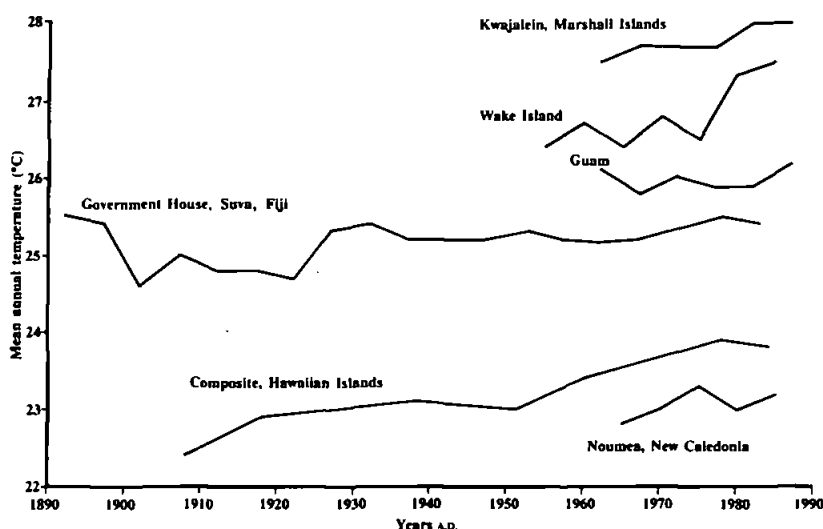


Figure 6. Selected series of air temperature measurements for Pacific islands. Raw data for Kwajalein, Wake, and Guam are from NOAA (National Oceanic and Atmospheric Administration) Local Climatic Summaries: these data were converted to 5-year running means. Suva data are after Nunn (1990d). Hawaii data are from Nullet's (1989) summary. The raw data for Noumea are from Service de la Météorologie, *Résumés Climatologiques* issued annually for various stations in New Caledonia: these data were analyzed to give 5-year running means.

Note the warming trends indicated by two longest series: that for Suva shows a correlation coefficient of  $+0.326$  significant at the 0.1 percent level. The shorter series are not long enough to yield clear evidence of long-term trends, although they support the idea of a regional temperature rise in the past 30 years or so. Karoly (1988) presented radiosonde temperature series from the lower troposphere, which also suggest that temperatures have risen in the South Pacific over this time period.

trend or whether it is only a shorter-period (third-order) variation of minor significance to questions of recent and future climate change. The longer-term records (Figures 7A, B) suggest the former, but problems with the quality of older data may give rise to a misleading picture. Increases in tropical-cyclone frequency would be expected with increases of sea-surface temperature in oceanic regions distant from large continental land masses (Holland et al. 1988; Nunn 1990e). Analyses of the comparatively few serial sea-surface temperature data from

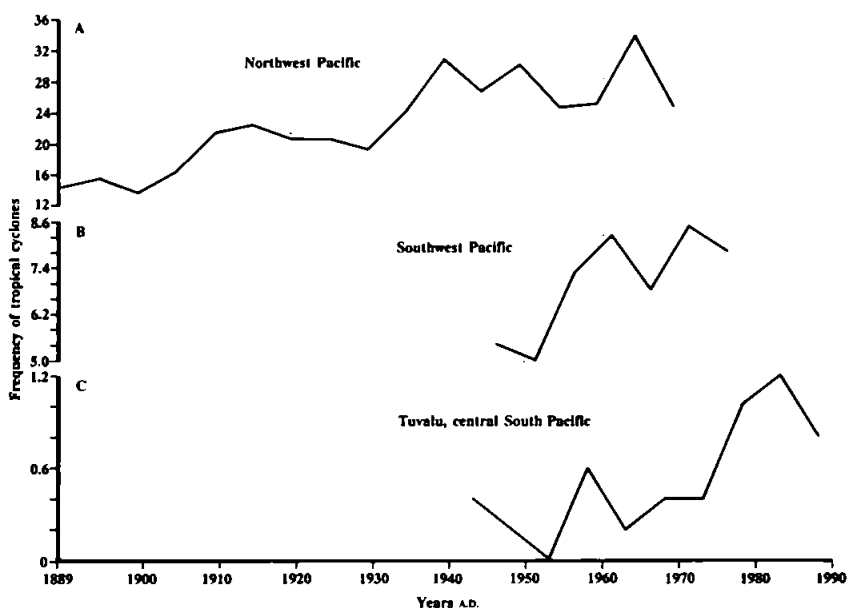


Figure 7. Changes in tropical cyclone frequency within the Pacific Basin. All data are unsmoothed 5-year running means.

A. Northwest Pacific (raw data in Lamb 1977, from U.S. National Climate Center archives).

B. Southwest Pacific (raw data in Grant 1981).

C. Tuvalu, central South Pacific (raw data in Nunn 1990d).

the Pacific Basin show net increases of  $0.5^{\circ}\text{C}$  to  $1.0^{\circ}\text{C}$  since 1912 (Folland et al. 1984); the 1955–85 record for Hawaii indicated a rise of about  $0.4^{\circ}\text{C}$  (Nullet 1989).

**5.1.d Climate Change, Human Impact, or a Combination of Both?** The role of direct human impacts on the Pacific island environment is not denied (Section 2). Yet many postsettlement environmental changes, especially before about 200 years ago, have been uncritically attributed in their entirety to human impact. A central theme of this paper is the demonstration of the likelihood that nonhuman activities, particularly climate change, contributed significantly to such environmental changes. For many such changes, especially within the last 200 years, human and nonhuman factors are inextricably confused; human im-

pacts may exacerbate nonhuman impacts. Yet the variations in nonhuman processes demonstrated above are enough to challenge the widely held idea that all recent changes are the result of human activity.

Owing to the comparatively long settlement history of most Pacific islands, often interpreted as being proportional to the degree of human impact, and because of the paucity of diagnostic data, the presumed dominance of human impact in recent environmental changes thereon has been challenged only recently (Brookfield and Overton 1988; Nunn 1990d). In contrast, both because of its comparatively short settlement history and a relative abundance of information, an effective challenge to the dominance of human impact in postsettlement environmental changes in New Zealand was made much earlier by Holloway (1954, 1964).

Drawing on the ideas of earlier workers (Speight 1910; Raeside 1948), Holloway argued that a drier, cooler climate within the last 750 years was the most plausible explanation for contemporary vegetation changes, notably the replacement of upland *matai* (*Libocedrus bidwillii*) forest with grassland. Holloway supported his argument with evidence for warm-climate crops having been grown earlier in South Island and by pointing to the unusual heterogeneity of its forests.

Holloway's ideas were challenged by those who favored human disruption of the natural order. One of Holloway's most outspoken critics was Cumberland (1962, 1965) who cautioned that

Although cultural disturbance is historically cumulative, it is a common mistake to underrate the effect which the earliest human groups to enter the ecosystem have had. . . . Because this ancient disturbance is remote in time and difficult to reconstruct, and because the evidence for it is often confused and obscure, care must be taken not to overlook or depreciate its significance (1965:188).

The contemporary importance of Holloway's views should not be overestimated. The great weight of informed opinion opposed him, and his ideas did not remain at the forefront in the development of subsequent thinking about environmental change. Yet it seems likely that Holloway's ideas about a significant amount of environmental change during the postsettlement history of New Zealand having been climatic rather than anthropogenic are due to be rehabilitated in the light of subsequent investigations of the area's recent climate history (Salinger 1979; Gellatly 1985).

The potential effects of climatic change in the Pacific have been "largely ignored outside of New Zealand" (Kirch 1984:125), although "the problem of long-term climatic change in the Pacific islands deserves more attention than it has hitherto received" (ibid.:127).

Since Kirch wrote, there has been an attempt to challenge the orthodoxy of a human origin for Micronesian savannas (Zan and Hunter-Anderson 1987). Recent studies of traditional agricultural practices in Micronesia showed that, contrary to the orthodox view, they were highly unlikely to have led to the formation or indeed a significant spread of savanna. Specifically, fire was only sparingly used in forest clearance. In addition, most plant species in Micronesian savannas are endemic and the climatic conditions to which they are suited have persisted for much longer than people have occupied the islands.

## 5.2 Sea-Level Changes

Although it seems likely that sea level fell by 1.0 meter or more in most parts of the Pacific Basin during the late Holocene (Table 2), the data used to identify this trend are not sufficiently precise to allow an accurate picture of the last thousand years or so to be developed for most island groups (see Figure 3). This situation changes when one reaches the period of direct sea-level monitoring.

During the early part of the postsettlement period on most Pacific islands, the environmental effects of a falling sea level were probably most noticeable (Figure 8). Continued shoreline emergence would have caused coastline extension with the result that many of the earliest settlements would have found themselves at increasingly greater distances from the sea. The northern coasts of Tongatapu Island in Tonga exemplify this situation (Poulsen 1967, 1987) which would have been most marked on gently sloping coasts.

The shore platforms cut at the time of relative sea-level stability around the Holocene Climatic Optimum (~5000 years B.P.) on many islands would have emerged subsequently and formed the foundations of coastal plains on many islands (Figure 9).

On gently sloping reef-enclosed coasts, large areas of the lagoon floor would have gradually emerged during the late Holocene regression. In those places where the lagoon-floor sediment consisted largely of fine-grained particles, much would have been blown onshore and accumulated as coastal dunes. An excellent example of this is provided by low Vatulele Island in Fiji where the limestone terrain did not allow the island to become permanently inhabited until the accumulation of the dunes, mostly along the east coast, about 1500 to 2000 years ago (Nunn 1988d). The largest dune field in the Pacific islands, at Sigatoka on Viti Levu island in Fiji, may also have experienced accumulation maxima during the late Holocene regression, although tectonic uplift may have had an effect (Nunn 1990b).

In those parts of the region where vertical reef growth had been able to keep pace with the early Holocene transgression, emergence



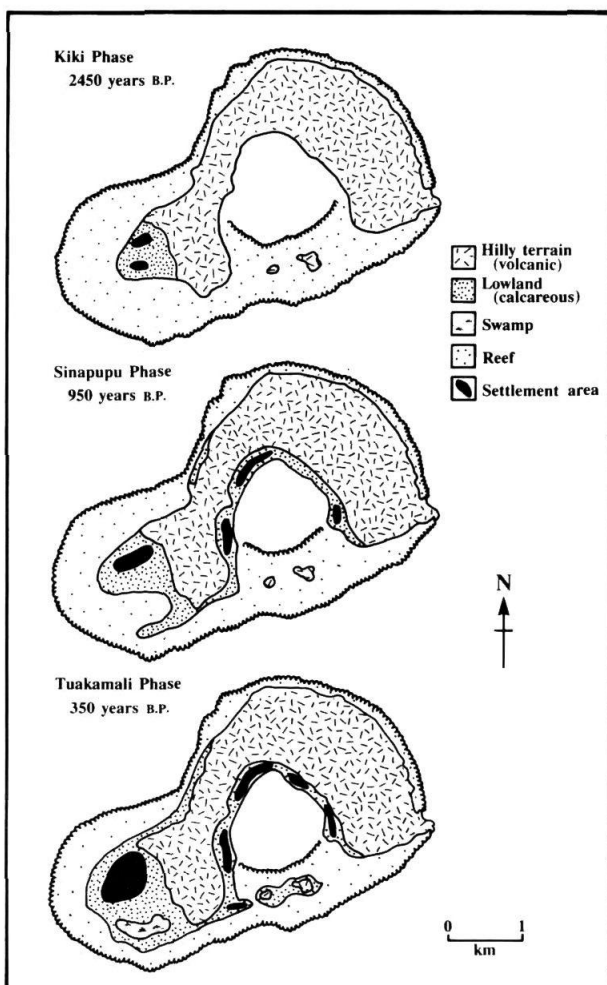


Figure 8. Paleogeographic maps of Tikopia Island in the eastern Solomon Islands showing its development at three stages during the late Holocene. (After Kirch and Yen 1982. Reprinted by permission of the B.P. Bishop Museum.)

Note particularly the emergence of the small islands at the entrance to the lagoon, which is now brackish and not flushed regularly with ocean water as it was during the earliest settlement period.

Note also the growth of the calcareous lowlands in the west of the island, which was the consequence of both sea-level fall and aggradation resulting from up-land soil loss.

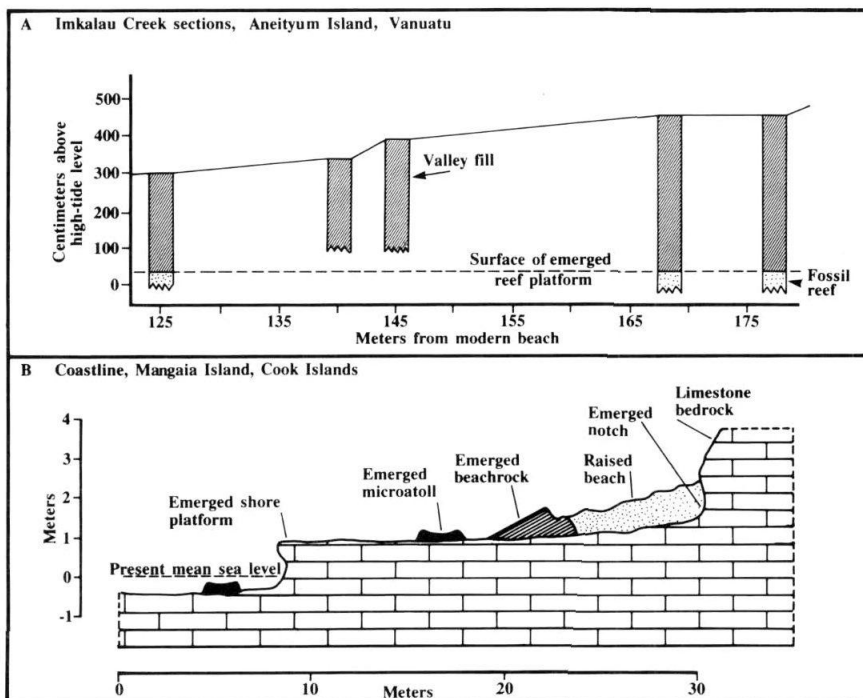


Figure 9. Examples of Holocene coastal environmental changes produced by emergence (sea-level fall and/or uplift) on reef-fringed coasts.

A. Sections logged in the Imkalau Creek valley on Aneityum Island in Vanuatu (revised by Nunn 1990d; after Spriggs 1981). The usual interpretation of such data is that upland soil loss following forest clearance by humans resulted in valley filling and coastline extension. The emergence of the reef platform that underlies the valley fill could only have been produced by emergence of the land relative to the sea. Evidence for such emergence may have been overlooked in situations such as this in favor of human impact. It is likely that this reef is about 3000 years old and emerged as the result of subsequent sea-level fall and/or uplift.

B. Coastal section recorded on Mangaia Island in the Cook Islands (after Yonekura et al. 1988). The emerged shorelines (shore platform, microatoll, beachrock, beach and notch) were formed in an analogous fashion to the modern shoreline and indicate relative emergence of about 1.5 meters here. A date of 5020 years B.P. for the emerged microatoll gives a maximum age for shoreline emergence that was probably associated, at least in part, with the late Holocene sea-level fall. More extensive shore platforms became covered with detrital sediments following emergence and were favored sites for the earliest settlements on many Pacific islands.

of offshore reefs would have occurred during the late Holocene regression. Owing to the comparative vulnerability of the juvenile late Holocene reefs to erosion, many, especially in exposed locations, are thought to have disappeared since emergence. Those reefs that had developed close to the shoreline, especially in sheltered locations, have been preserved in many places, although the contribution of tectonic uplift cannot be discounted in most instances (Figure 9). Good examples occur on Aneityum in Vanuatu (Spriggs 1981; Nunn 1990d) and in many parts of Tonga and Fiji (Nunn 1990b, 1991b).

It may appear paradoxical but the emerged Holocene reefs of many midocean atolls, although they could hardly be more exposed, became foci for accumulation of marine sediments and are therefore found to underlie many of the *motu* (sand islands) found on modern atolls (Schofield 1977).

Coastal progradation at river mouths during the postsettlement period has commonly been supposed to have been the result of the influx into valleys of sediment released from uplands during forest clearance by humans. The importance of this process is greatly diminished by noting that many of the infilled valleys and prograded coasts are underlain by emerged reef: examples include Futuna and Alofi islands (Kirch 1981), the south coast of Vanua Levu Island in Fiji (Roy 1986), and Aneityum Island in Vanuatu (Figure 9A). If one allows that sea-level fall would have caused slope instability, especially in the middle parts of river valleys, and therefore would have increased sediment supply to lower reaches, there is actually no need to cite human impact to explain valley infilling and coastal progradation in the early part of the postsettlement history of Pacific islands.

Infilling of coastal embayments has also been regarded as the consequence of human activities although, using the preceding arguments, many instances of such infilling can be reinterpreted as the result, direct and indirect, of sea-level fall; the work of Hunt and Kirch (1988) on the coastal marshes of the Manu'a islands in American Samoa exemplifies the situation.

Within the last thousand years or so, the rate of sea-level fall is believed to have diminished so that, about 800 to 400 years ago in most parts of the Pacific Basin, sea level had stabilized and lateral shoreline erosion had resumed in earnest. This period saw the development of broad reef flats and the lateral growth of barrier reefs in many places.

The widespread stability of the land-sea interface at this time would have had environmental consequences, many of which are so site-specific that it is potentially misleading to generalize. Stability would have seen a degree of equilibrium return to the valley systems; infilling and coastal progradation would have ceased in most places as river

channels adjusted to sediment loads. Broadening of the mangrove fringe would have occurred along many coasts at this time.

Where small lagoons effectively enclosed by reefs existed, this time probably marked the beginning of lagoon infilling, mostly as the consequence of calcareous (reef-derived) sediment introduction and its subsequent reworking and redeposition. Examples of such situations include the small islands of Kabara (Galzin et al. 1979) and Vatulele (Nunn 1988d), both in Fiji; the coast at Lotofaga on Upolu island in Western Samoa (Davidson 1969); and the Makaha Valley coastline on Oahu in Hawaii (Yen et al. 1972).

Within the most recent part of the postsettlement period in the Pacific islands and certainly within the period of direct monitoring, it seems that the sea level has been rising (Figure 10 and Table 6). It is important to identify accurately the beginning of this current phase of sea-level rise because this has a bearing on its principal cause.

If this sea-level rise is regarded mainly as the result of thermal expansion of ocean water because of warming, and melting of ice mostly from small glaciers (Meier 1984), then it seems reasonable to suppose that it may have been continuing since the maximum of the Little Ice Age in the Pacific region, perhaps about 250 years ago (Section 5.1.b). Not surprisingly, there are few data available to test this idea, although those reported by Šnitnikov (1969) for three unspecified stations in the Pacific Ocean suggest a net rise of 11.8 centimeters between 143 and 0 years B.P. (A.D. 1807-1950). Data referring to sea-surface temperatures, which would be expected to correlate well with sea-level rise resulting from thermal expansion of ocean-surface waters, have been derived for the upwelling region off Southern California. These data indicate a net rise of about 2° C in the period A.D. 1611-1964 (Douglas 1974).

The longest direct-monitoring series of sea level are generally along the periphery of the Pacific Basin, although the Honolulu (Hawaii) record is of similar duration (Figure 10 and Table 6). Most long-term series show a sea-level rise in the last hundred years or so which is not largely the product of tectonic movements. A eustatic signal within time-series data from the region's western margins cannot be isolated because of oceanographic and tectonic effects (Aubrey and Emery 1986; Emery and Aubrey 1986).

This sea-level rise is most likely a second-order trend within the longer-term first-order sea-level fall that has occurred since the Holocene Climatic Optimum about 5000 years ago (Section 4.2). Shorter-term (less than 30 years) records of sea level are not sufficient to establish the nature of the second-order trend (Pirazzoli 1986), and their use to deny the existence of such a trend is misleading.

The lack of long-term sea-level data from most Pacific islands led

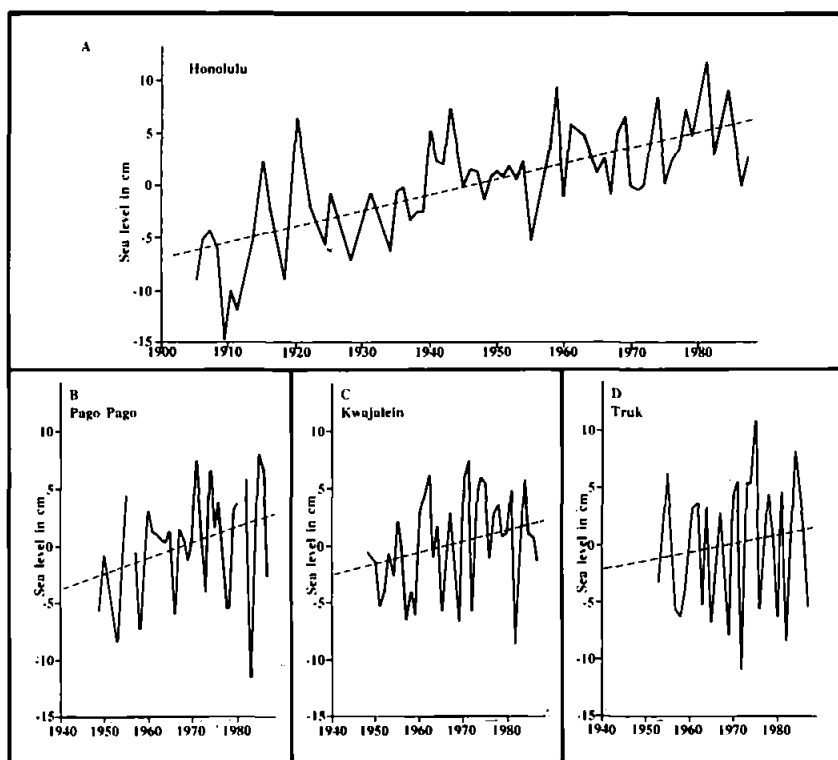


Figure 10. Series of directly measured sea-level changes in the Pacific islands. (After Wyrтки 1990. Figures 10B, C, and D reprinted from Wyrтки, *Pacific Science* 44:1-16, 1990, by permission of the University of Hawaii Press and the author.)

A. Honolulu, Hawaiian Islands. The long-term record of sea-level rise at this site, on the tectonically stable island of Oahu, is +1.5 mm/year.

B. Pago Pago, Tutuila, American Samoa. Although this record is too short to identify the long-term trend with certainty, the most likely interpretation of this relatively stable site is that sea level is rising at 2 mm/year.

C. Kwajalein Atoll, Marshall Islands. Although this record is too short to identify the long-term trend with certainty, the most likely interpretation of this relatively stable site is that sea level is rising at 0.8 mm/year.

D. Truk Island, Federated States of Micronesia. Although this record is too short to identify the long-term trend with certainty, the most likely interpretation of this relatively stable site is that sea level is rising at 0.6 mm/year.

Table 6. Rates of sea-level rise in the Pacific Basin (in part from Wyrтки 1990) with comments on specific tectonic conditions over the last 200 years

Site, island group	Rate (mm/year)	Comments
Honolulu, Oahu, Hawaiian Is	+1.5	Island stable <sup>1</sup>
Hilo, Hawaii, Hawaiian Is	+3.8	Island sinking <sup>1</sup>
Kwajalein, Marshall Islands	+0.9	Island stable
Naloto, Fiji <sup>2</sup>	+2.5	Site stable
Pago Pago, Tutuila, American Samoa	+1.4	Island stable
Suva, Fiji	No trend	Site unstable <sup>3</sup>
Truk, Federated States of Micronesia	+0.6	Island stable
Wellington, New Zealand	+1.6	Site stable <sup>4</sup>
(Pacific mean)	+1.0 <sup>5</sup>	—
(Global mean)	+1.4 <sup>6</sup>	—

Note: See Figure 10.

1. Moore (1970)
2. All data for Naloto from Nunn (1990b)
3. Nunn (1990b)
4. Most tectonic effects removed—Hannah (1988)
5. Figure with large error margins from Wyrтки (1990)
6. Barnett (1984)

Nunn (1990c) to establish sea-level behavior over similar time periods using surrogate data. A sample was taken of long-established coastal settlements from the Solomon Islands to the Cook Islands in the South Pacific, and interviews were conducted by university students from those settlements with their elderly inhabitants to find out how the shoreline had changed since the time they could remember. On the 19 percent of settlements (in Tonga and Vanuatu) that were known to be tectonically rising, shoreline extension was recorded. More significantly, at the 81 percent (59) of settlements that were not in unstable areas, lateral inundation was reported as having occurred over at least the last 90 years (Figure 11 and Table 7). Lateral inundation at a single site would be a poor indicator of sea-level rise because of the potential role of undetermined local factors. Yet, the consistent evidence for inundation across a large area that includes a great variety of shoreline situations suggests that the principal cause of inundation is operating at a regional scale. Evidence of contemporary sea-level rise elsewhere in the Pacific region led Nunn (1990c) to conclude that this was the most plausible explanation for lateral inundation in the South Pacific.

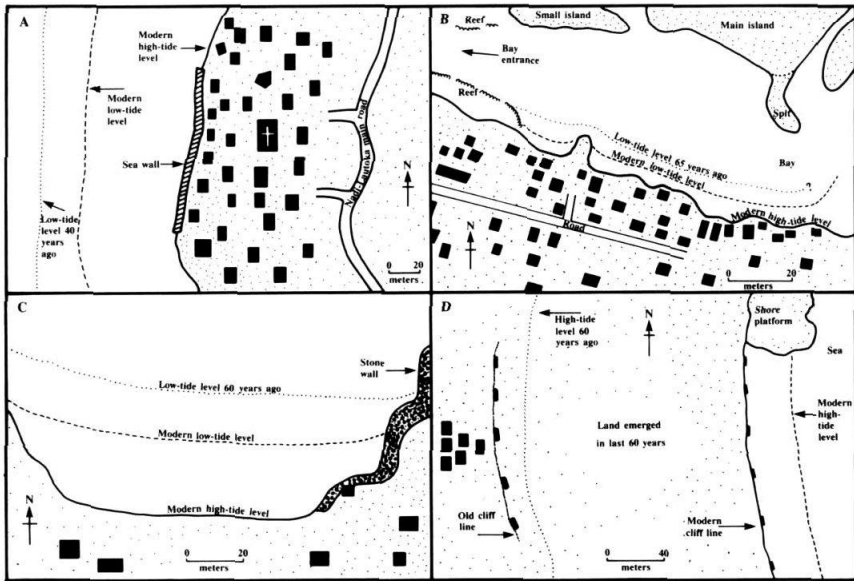


Figure 11. Examples of coastal settlements in the Pacific islands that have experienced lateral inundation in living memory.

A. Viseisei village, west coast Viti Levu Island, Fiji. Original survey by Alumecei Lumuni.

B. Ghatere village, Kolombangara Island, Solomon Islands. Original survey by Lore Reuben.

C. Hunda village, Kolombangara Island, Solomon Islands. Original survey by Lore Reuben.

D. Sameou village, southeast Ambrym Island, Vanuatu, showing recent coast-line emergence resulting from uplift. Original survey by David Hopa.

The amount of vertical sea-level rise associated with the lateral inundation recorded in the study by Nunn is exceedingly difficult to calculate precisely because sea-level rise will itself change offshore processes and morphology. In most cases, this means that increased nearshore sediment mobility following sea-level rise will cause deepening of the area offshore. During an earlier study on the very low-energy central east coast of Viti Levu Island in Fiji, Nunn (1988a) found that a lateral inundation of about 130 meters was equated with an actual sea-level rise of 10 to 30 centimeters (Nunn 1990b).

Table 7. Rates of lateral inundation for island groups in the South Pacific

Island group	Stable sites (no.)	Rate of lateral inundation (cm/year)
Cook Islands	2	8.4
Fiji	16	15.0
Hawaii <sup>1</sup>	1	125.0
Solomon Islands	20	10.8
Tonga	4	10.0
Tuvalu	1	18.0
Vanuatu	1	7.8
Western Samoa	4	51.4 <sup>2</sup>

Source: After Nunn 1990c; see also Figure 11.

1. Data from Waimea Bay on Oahu (Campbell and Hwang 1982), which is regarded as the only stable island in the Hawaii group (Moore 1970).
2. This figure is greatly influenced by the high rate at Satalo on Upolu island.

### 5.3 Tectonic Changes

Available data for most parts of the Pacific Basin do not allow rates of tectonic changes during the postsettlement period to be calculated precisely. For example, most Holocene uplift rates have been determined simply from the ages of emerged shoreline features and their height above their modern analogs, thus excluding the effects of contemporary sea-level changes (see Table 3). This approach is useful in only a general sense (Nunn 1986). The results obtained cannot be applied uncritically throughout a particular area because of the large variations in tectonic processes and rates that exist within many island groups. Vanuatu (Greene and Wong 1988) and Fiji (Nunn 1990b, 1991c) provide good examples.

No general approach to tectonic changes and their environmental impacts in the postsettlement period is valid for Pacific islands, and only detailed, island-specific works can provide credible information.

Of all the tectonic processes operating during the postsettlement period, uplift has had the most profound impact on the environment (Figure 12). The most rapidly rising areas are generally along frontal arcs, close to sites of lithospheric plate convergence in ocean trenches. Niuaotoputapu Island at the northern end of the Tonga frontal arc has experienced "an increase of 312% in the amount of land, and a concomitant decrease of 50% in reef/lagoon microenvironments" (Kirch 1988:248), mostly because of uplift (Nunn 1990d). The preliminary results of recent fieldwork by the author on the south coast of Tongatapu



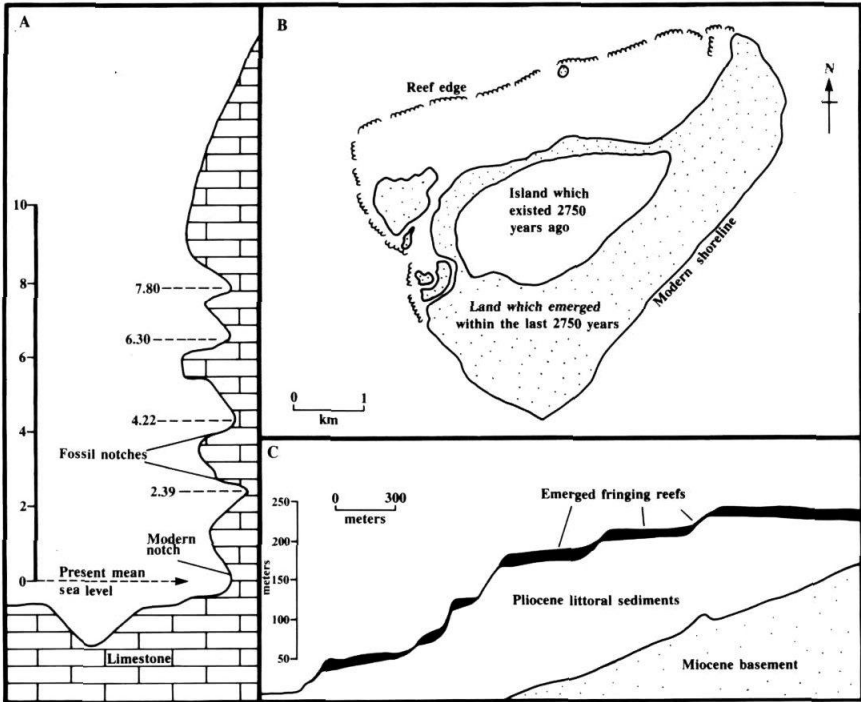


Figure 12. Examples of the effects of uplift on Pacific islands.

A. Late Quaternary coseismic-uplift series from Gusuniqara Point, Vatulele Island, Fiji (Nunn 1988d). Each notch formed in the same way as the modern notch and was rapidly uplifted during a large-magnitude earthquake.

B. The island of Niutopotapu in northern Tonga showing the island that was first settled ~2750 years ago and the increase in land area (~312 percent), which has occurred since as the combined result of sea-level fall and uplift (after Nunn 1990d).

C. Quaternary uplift indicated by a vertical succession of emerged reefs on north Malakula Island in Vanuatu (after Mitchell 1968).

island in Tonga suggests uplift, which occurred at a net rate of 1.6 mm/year, was coseismic. The shoreline was intermittently uplifted during large-magnitude low-frequency earthquakes, the last of which in 1853 was graphically described by Sawkins (1856).

Coseismic uplift also dominates along the Vanuatu-Solomons, Marianas-Ryukyu, and Aleutian frontal arcs (Plafker 1965; Pirazzoli and

Kawana 1986; Taylor et al. 1987). In the most active parts of these areas, uplifts of 1.0 to 1.5 meters every decade or so have been recorded (Hopley 1987), and flights of emerged reefs testify to the antiquity of such processes (Nunn 1986).

While coseismic uplift is usually limited to shallow earthquake activity, deeper seismicity may produce a more continuous type of uplift often known as aseismic uplift or vertical creep. This is believed to have been responsible for the Pliocene and Quaternary updoming of Viti Levu Island in Fiji (Nunn 1988c, 1990d, 1991c). The effects of this process within the postsettlement period have probably been confined to the high plateau around the top of the dome, which is cut by parallel valleys following the lines of epianticinal faults. Formation of these valleys, which are prime sites for settlement on the otherwise inhospitable plateau, was probably fairly recent in geological time.

Another type of aseismic uplift seems to be associated with heat within the uppermost lithosphere. Highly localized uplift on Savai'i Island in Western Samoa is believed to be the result of thermal uplift associated with volcanic activity during the later part of the island's postsettlement history. Similar processes may be responsible for recent uplift close to lithospheric melting anomalies ("hot spots") within the Pacific Basin, although subsidence is more often regarded as characterizing island coasts in such locations (Moore 1970).

As mentioned earlier, most subsidence in the Pacific Basin occurs at such slow rates that it is not pertinent to incorporate it into evolutionary models for the (late) Holocene. This is true of the most widespread cause of subsidence in the Pacific, namely that resulting from lithospheric cooling and shrinkage. Elsewhere, especially close to some active volcanoes, more rapid subsidence occurs. Using the figure for sea-level rise at Honolulu, Hawaii (Table 6), and Apple and MacDonald's (1966) submergence rate for the southern part of the island of Hawaii, a rate for subsidence of 0.66 mm/year is calculated for the last hundred years or so.

Much more rapid rates of subsidence can occur locally resulting from either rifting during lithospheric extension or slope instability, particularly on the flanks of oceanic central volcanoes.

An example of the former type comes from Moala Island in southeast Fiji, which is bisected by a rift valley interpreted as the result of extension when the island reached the crest of a lithospheric rise (Nunn 1988c). Unlike the other coasts of Moala, those along the sides of the rift show no indications of emergence and are therefore concluded to have subsided (Figure 13A). In support of this, the traditional chiefly settlement of Namoala within the rift is now mostly underwater.

Examples of rapid subsidence caused by instability of underwater

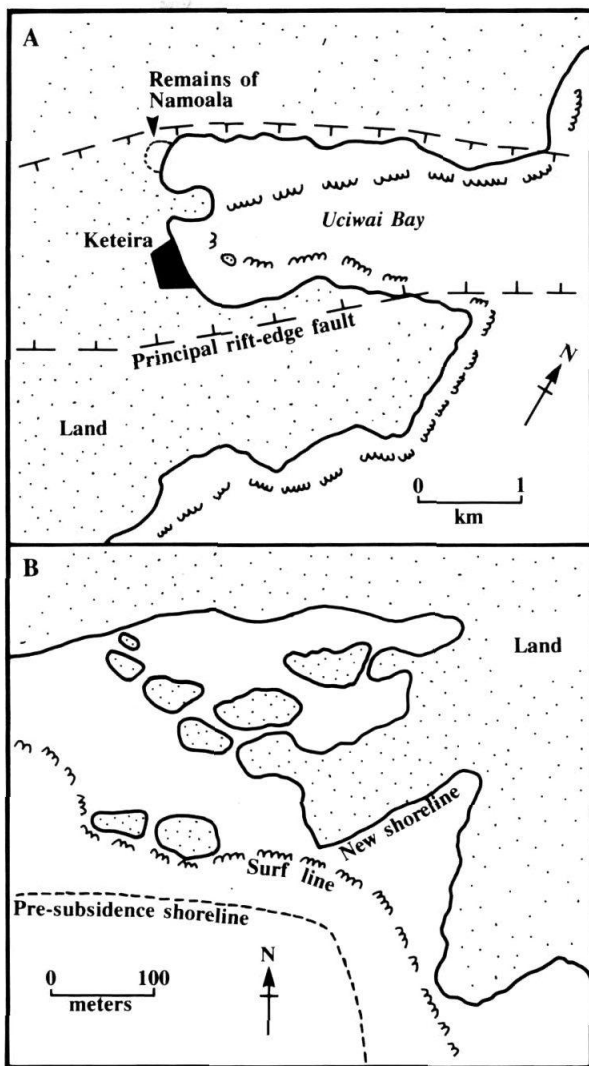


Figure 13. Examples of rapid subsidence along Pacific island coasts.

A. Subsidence within the Uciwai Bay rift valley in the center of Moala Island, southeast Fiji, caused the submergence of much of the settlement of Keteira and most of Namoala in the past ~ 300 years. Boundaries of the rift from Nunn (1988c).

B. During an earthquake on November 29, 1975, parts of the south coast of the island of Hawaii subsided about 4.5 meters. The section shown is that of Keauhou Bay (after Henderson 1980).

slopes of recent volcanoes have been recorded from southeast Upolu Island in Western Samoa (Kear and Wood 1959) and from Kilauea in southeast Hawaii (Henderson 1980; Figure 13B).

#### **5.4 Mammalian and Associated Impacts**

This section concentrates on what the author regards as undoubted human and other mammalian impacts on Pacific island environments.

Within the last two decades, much has become known about the earliest inhabitants of Pacific islands and the things they were likely to have done following establishment of a permanent settlement. One must, however, be wary of circular argument.

One useful approach is that based on the idea of transported landscapes; that, in colonizing new lands, people

carry with them a cultural concept of landscape, which causes them to actively shape a new environment in that mold. For . . . [the earliest settlers in Hawaii], this cultural concept of landscape, transferred from previously settled archipelagoes in the south and southwest Pacific, included such notions as the suitability of valley bottoms for irrigated terracing (Kirch 1982:3).

The idea of transported landscapes is potentially useful in understanding how particular landscapes may have been transformed following initial settlement, but it becomes potentially misleading if it is assumed that the transformation was of wholly human causation. When one talks of transported landscapes, one is comparing the landscape on an already-settled island *A* to that of just-settled island *B*. A potential fallacy derives from failing to realize that one is not comparing the landscapes of islands *A* and *B* at the time of the latter's settlement but perhaps millennia later. Unless great care is taken to remove the accumulated effects of changes that took place during those millennia, one is certain to end up with only a general picture of prehistoric environments that can be interpreted superficially in a variety of ways.

The first settlements on many Pacific islands established before the main Holocene sea-level fall were on upland hillsides above the swampy valleys (e.g., Aneityum, Vanuatu; Spriggs 1981). Clearance of forest and grassland by burning principally to plant crops would probably have been localized; the structure of secondary forest growth testifies to this in many places (e.g., Western Samoa; Cameron 1962). Yet, especially on the dry leeward sides of islands within the trade-wind belts and especially during the Little Climatic Optimum arid period, human-initiated fires may have gotten rapidly out of control and have accounted

for the destruction of much more forest and/or grassland than intended. The spread of Pacific island grasslands in the postsettlement period is largely attributable to burning, although how much of this was human initiated and how much was natural is pure conjecture.

The sheer scale of pre-European fires in New Zealand led Holloway (1954) and others to question the contemporary orthodox view that they were wholly human initiated. This view contrasts with that of McGlone (1983) who believed that human-initiated forest burning in New Zealand began abruptly a considerable time after initial settlement. The coincidence of the time of forest destruction with the Little Climatic Optimum (Section 5.1.a), when forests may have been more vulnerable to burning because of the drier conditions, is highly significant.

In a recent study of Holocene fires in the northern Amazon Basin, Saldarriaga and West (1986) found evidence for large fires since 6260 years B.P., yet indications of human occupation only since 3750 years B.P. The authors' conclusion that humans played a significant role in firing the forest during the latest Holocene is based only on assumptions about their behavior that appear to be undermined by observations that fires began without the involvement of humans for at least 2510 years before their arrival in the area. It is likely that the situation in the Pacific islands was similar.

The pre-European settlers of Pacific islands brought a number of animals with them that must have had an effect on the environment. Two groups of faunal impacts can be usefully distinguished: impacts on endemic fauna and impacts on flora. Both impacts would have ultimately caused ecosystem changes and, in view of the known severe impacts of exotic fauna on twentieth-century Pacific island environments, it is perhaps surprising that more emphasis has not been attached to faunal impacts on the earliest postsettlement environments. This situation seems certain to change with the realization "that the spread into the Pacific of endemic Melanesian mammals, probably associated with humans, was much more extensive than has been previously suspected" (Flannery et al. 1988:93).

One of the commonest of the animals transported throughout the Pacific islands by the earliest settlers was the pig (*Sus scrofa*). Although "domesticated," pigs undoubtedly escaped from captivity or perhaps, on smaller islands, were intentionally released. Long-established feral pig populations are known on many Pacific islands (Table 8). Today, feral pigs are often regarded as undesirable because of their environmental impact. Pigs eat almost anything; they are the ultimate opportunistic predators. As Oliver (1984:112) wrote,

Table 8. Pacific islands with long-established feral pig populations

Island group	Island(s)
Caroline Islands	Pohnpei, Kosrae
Cook Islands	Suvarrow, Penrhyn
Fiji	(many)
Galápagos	(many)
Hawaii	(many)
Line Islands (Kiribati)	Malden
Marianas Islands	Guam, Aguijan
Marquesas (French Polynesia)	Eiao, Fatu Hiva
New Caledonia	Walpole
Palau	Babeldaob
Phoenix Islands (Kiribati)	Orona, Manra
Society Islands (French Polynesia)	Mehetia, Tahiti, Huahine
Solomon Islands	Nendö
Tonga	Tofua
Tubuai Islands (French Polynesia)	Raivavae, Tubuai, Rurutu
Vanuatu	(many)

Source: In part from Oliver 1984.

Feral pigs damage natural plant communities . . . by the intensive forage of preferred foods and incidental damage by exposure through rooting [rooting]. Intensive rooting certainly changes population structure, and in some areas is believed to give competitive advantage to exotic plant species over populations of fragile native plants.

Empirical work has shown that understory cover of 80 to 100 percent in beech forest fell to 2 to 15 percent following rooting by feral pigs (Howe and Bratton 1976). On Phillip Island, just off Norfolk Island in the southwest Pacific, pigs were introduced in the mid-nineteenth century and by 1865 had transformed the island from one that was thickly forested to one where much of the undergrowth was gone and serious erosion had begun (Watson 1961).

The history of isolated Clipperton Island in the eastern Pacific is also instructive in this context. Not having had a pre-European population, Clipperton was reported to be infested with land crabs, particularly *Gecarcinus planatus*, upon discovery: about 5 million crabs lived there around the turn of the century and effectively prevented plants from growing. Two pigs arrived with guano diggers in 1897 and eventually made such an impact on the crab population that coconut palms

were able to grow in many parts of the island without needing protection from crabs, as they had at first. By 1958, the crab population had declined considerably and the feral pigs were regarded as undesirable and were exterminated. The crab population has since increased phenomenally and the terrestrial flora is rapidly disappearing (Skaggs 1989).

Clearly, even with small densities of feral pigs, the potential for them to rapidly introduce a significant degree of instability into established ecosystems is great and needs to be borne in mind when evaluating the causes of postsettlement environmental changes on Pacific islands (Kirch 1984).

Wallabies (*Thylogale* spp.) accompanied the earliest settlers in parts of island Melanesia and were probably valued trade items (Flannery et al. 1988). Environmental impact studies of feral rabbits are probably close to what would have occurred had populations of feral wallabies been established on Pacific islands, as seems certain (Flannery et al. 1988). The awesome impact of feral rabbits on Pacific islands was detailed by Watson (1961). For example, Laysan Island in the Hawaii group, once covered by groves of sandalwood interspersed with bushes and fan palms, had a few rabbits introduced about 1903. By 1923 the island "had been reduced to a barren waste of sand with a few stunted trees, only 4 of the 26 species of plants [earlier] recorded from the island were found" (Watson 1961:591).

Several species of rat (*Rattus* spp.) accompanied the earliest settlers on Pacific islands. Although the effects of rats on endemic plants were probably comparatively small, they may have caused or facilitated ecosystem collapse through predation (Knox 1973). It is strange how rat impacts have been apparently considered insignificant in the early postsettlement environmental history of the Pacific islands, particularly when their numbers may have been so great. From work in the Marquesas, Decker (1970:85) considered that "rats, surrounded by abundant food of all sorts, may have multiplied to plague proportions within a few years [of initial introduction]."

The question of how exotic fauna and flora were introduced in the presettlement period is important to any inferences about the likely size of feral populations and their impacts on particular island environments. It seems probable that larger mammals, such as wallabies, were regularly traded and subsequently escaped, while smaller mammals, particularly rats, were unintentionally carried on large voyaging canoes.

Given the foregoing, there seems little support for the common view that the impact of exotic fauna (nonhuman) on the earliest postsettlement ecosystems on Pacific islands was negligible. The commonly held corollary to this, that direct human impact was correspondingly

great, can also be effectively challenged on this basis.

The dispersal of exotic flora, particularly weeds, would have been facilitated by the seeds or spores in the mud packed around corms of taro and other staples during transportation between islands (St. John 1978). This is particularly true of *Ludwigia octovalvis*, which is frequently associated with taro grown under irrigation in Polynesia (Kirch 1984). Dispersal of weeds, especially *Digitaria setigera*, by pigs is also pertinent (Kirch 1982). Although the immediate effect of weeds and other exotic flora on postsettlement Pacific island ecosystems is more conjectural than faunal impacts, exotic flora would have exploited ecosystem instabilities arising from faunal and human impacts.

Increasingly it is being realized that introduced (nonhuman) mammals on Pacific islands have the capacity to alter their ecosystems entirely (Taylor 1968; Brooke 1984). In many cases, it may not be necessary to cite any direct human impact to account for the observed changes. For example, with reference to the influence of feral goats on *Koa* (*Acacia koa*) forest in Hawaii, the entire forest stand structure is directly related to herbivore feeding (Spatz and Mueller-Dombois 1973).

It is in discussing faunal and floral impacts on Pacific island environments that the potential for confusion about human and nonhuman causation is greatest. In this paper, human impact is used to mean direct human impact, that is, not an impact achieved through a nonhuman biotic medium.

In the period following European settlement of Pacific islands, the potential for identifying the principal causes of observed environmental change has increased, mainly because empirical data have become available. Besides faunal (Taylor 1968; Knox 1973) and floral (Kirch 1984) impacts, there have been compilations of direct human impacts (Fosberg 1963; Dahl 1980, 1984). Many such works, however, overstate direct human impacts (Nunn 1990d).

The least contentious human impacts in the Pacific islands since European settlement are those based on detailed local work, such as the effects of dredging and filling (e.g., Maragos 1985; Carpenter and Maragos 1989), sand and other mining (e.g., Ricard 1980; Manner et al. 1984), waste disposal (e.g., Brown 1974), and causeway construction (Dawson 1959; Smith and Henderson 1978). The most contentious situation arises when all terrestrial changes are routinely ascribed to one or more forms of direct human activity, ignorant of or ignoring the potential contribution of changing climate and other nonhuman factors, including those associated with exotic fauna and flora.

Although it is unlikely that any particular series of environmental changes in the past 150 years could be wholly ascribed solely to climatic rather than climatic-human causes, the reluctance of many



authorities, especially those in advisory roles, to acknowledge the potential for nonhuman causation is unfortunate. It is unfortunate not simply because it obscures the nature and therefore the potential solution to a particular environmental problem, but also because it has resulted in many Pacific island decision-makers creating a rigid distinction between (past) anthropogenic and (future) climatogenic environmental changes. This has implications for planning (Warrick and Farmer 1990; Nunn 1991a), not least of which is the widespread fallacious belief that predicted future climatic changes will take effect in an environment where, was it not for human impact, nothing would have altered significantly since some distant point in the nebulous past.

### **5.5 Catastrophic Events**

There is a contradiction between the way in which virtually all recent environmental changes in the Pacific islands (and elsewhere) are routinely attributed to human activities and the way in which nonhuman causation of catastrophic events such as hurricanes and large earthquakes is never questioned. The unarticulated assumption seems to be that human impact results in slow change, whereas nonhuman impact is rapid. Such ideas are erroneous.

Catastrophic events have the potential to transform environments irreversibly and much more rapidly than more frequently occurring processes (Plates 3 and 4). Although there are great problems in determining the frequency and precise impact of catastrophic events for pre-European settlement times on most Pacific islands, the growing realization over the last decade that punctuational rather than gradual change has been of greater significance in Earth history (Berggren and van Couvering 1984) should encourage research.

Although the often catastrophic effects of phenomena such as hurricanes and large-magnitude earthquakes are well known in Pacific islands, the exclusion of catastrophic events from most scenarios of environmental development for the region suggests that most authorities doubt the capability of catastrophic events to produce significant and lasting effects on island environments.

For most Pacific islands, tropical cyclones and kindred storm-producing phenomena cause the most frequently experienced catastrophic events. The few quantitative studies of their effects have confirmed the ability of such storms to release huge quantities of material from catchments into river channels as the result of both sheet erosion by runoff and landsliding (Crozier et al. 1981; Howorth et al. 1981).

On many volcanic islands with high relative relief, the characteristic amphitheater-shaped valleys erode headwards through the process of avalanching of soil and regolith. Times of maximum erosion occur



Plate 3. *Damage caused by storm waves to Apia waterfront in Western Samoa during Tropical Cyclone Ofa in February 1990. Photo by author.*

when the soil/regolith becomes supersaturated during prolonged periods of intense precipitation, such as commonly accompanies tropical cyclones, and widespread slope failure occurs. Much of the pioneer work on this topic was done in the Hawaiian Islands (Scott 1975; Scott and Street 1976). Similar processes have been observed in the mountain valleys of the central (Nadrau) plateau of Viti Levu in Fiji (Nunn 1993b). Using data referring to the distribution of landslides in the Waimanu catchment on the same island that developed during a prolonged storm, Nunn (1990b) showed that areas of undisturbed secondary forest were apparently affected much more than agriculturally developed parts of the catchment. From this, it can be concluded that recent human impacts, in this case the clearance of secondary forest for arable farming, do not automatically reduce the vulnerability of particular environments to erosion under certain conditions.

The effect of storm rain on those parts of Pacific islands already severely destabilized by human activities is exemplified by studies of mined regions—in New Caledonia (Benezit 1981) and Misima Island in Papua New Guinea (Hughes 1989), for example.

The potentially devastating effects of cyclonic storms on vegetation are familiar to most Pacific islanders. The question as to whether such



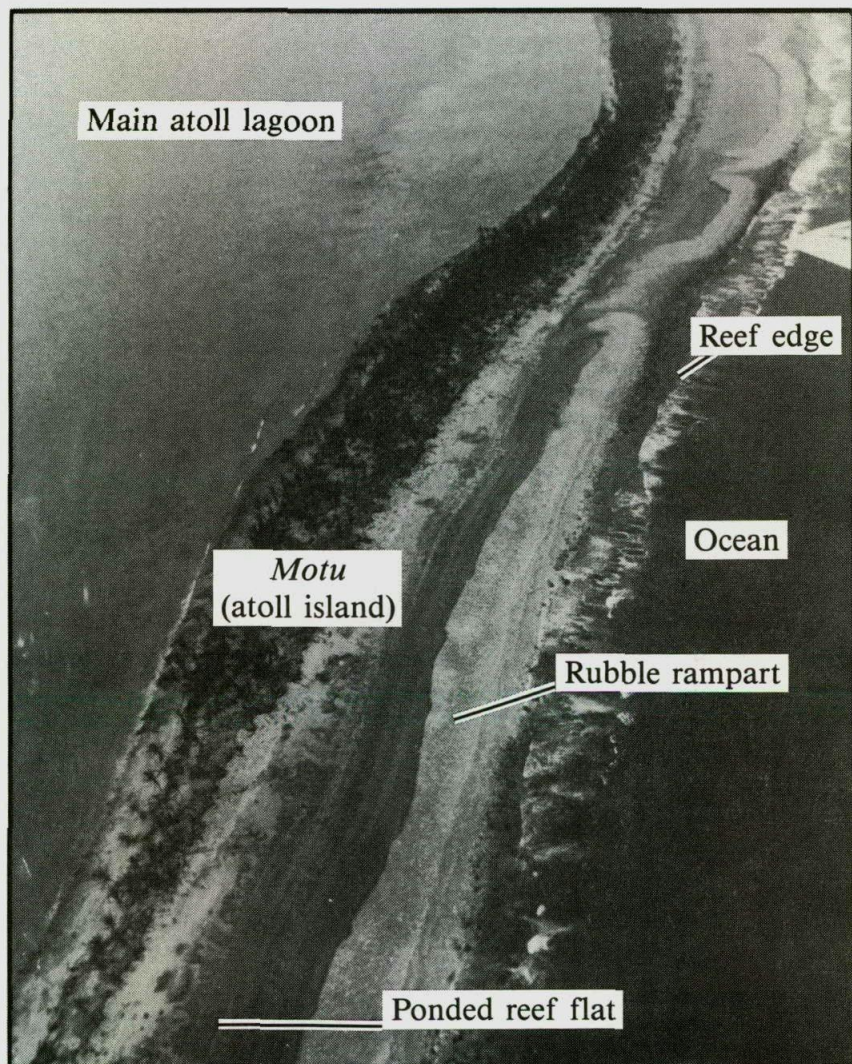


Plate 4. The rubble rampart created along the eastern side of Funafuti Atoll in Tuvalu during Tropical Cyclone Bebe in October 1972. This rampart increased the land area of Funafuti by about 20 percent. Had the storm surge that caused deposition of the rampart been stronger or had it approached Funafuti from a different direction, net erosion rather than net accretion of the atoll may have resulted. Photo courtesy of Dr. James Maragos.

events can destroy the vegetation of a particular area to the extent that it will not regenerate in its original form is contentious. Yet, by virtue of attributing major enduring changes only to human impact, most writers imply that the vegetation will return to its precatastrophe state. This view is contrary to that of many ecologists working in the Pacific: for both the Solomon Islands (Powell 1976) and part of North Island, New Zealand (Grant 1963), the effects of catastrophic events have been regarded as highly significant in the history of postsettlement vegetation changes. Brookfield and Overton (1988:95-96) recently went further by suggesting that "an episodic rather than a continuous pattern of deforestation has . . . characterized Fiji and other parts of Oceania for a period that may extend back more than a thousand years."

Reefs and reef islands are particularly vulnerable to significant change during cyclonic storms (Stoddart 1971; Harmelin-Vivien and Laboute 1986; Fitchett 1987). In such cases, catastrophic change may result in significant and enduring increases in island area (Maragos et al. 1973; Baines and McLean 1976; Bayliss-Smith 1988; Plate 4). In other situations, less desirable changes are brought about. Sinoto (1973) argued that a pre-European human population of Tabuaeran (Fanning Island) became extinct because of a catastrophic event that closed a lagoonal pass, thereby causing rapid deterioration of lagoonal resources.

Tectonic instability may significantly increase the vulnerability of island environments to subsequent change during catastrophic events. This is believed to be the case with the island of Taiwan where rapid uplift has been linked to some of the highest denudation rates in the world (Li 1976).

The link between major earthquakes and catastrophic erosional impacts on many Pacific islands is undoubted, although the connection requires more quantitative studies such as that of Pain and Bowler (1973) before it can be clearly elucidated. The effects of earthquake damage to reefs was summarized by Stoddart (1972).

## 6. CONCLUSIONS

Most writers have attributed the environmental changes that occurred within the postsettlement history of Pacific islands to human impact (e.g., Marsh 1864; Cumberland 1962, 1963; Cochrane 1969; Farrell 1972; Strong 1975; Dahl 1980, 1984; Dahl and Baumgart 1983; Kirch 1982, 1983; Lal and Minerbi 1985; Dupon 1986). This is not an orthodoxy confined to the Pacific. Lamb (1977:243) concluded that "because Man is so adaptable and so apt to personalize the blame for his misfortunes by finding scapegoats and making victims of his fellows, the evidence of climatic causes is commonly obscured."

Vegetation change from forest to grassland was presumed to have been contemporary with human occupation of the islands and to have come about through massive forest clearance by humans, a process which has also been routinely blamed for upland soil erosion, valley-floor aggradation, and coastal progradation. It is a measure of the degree of entrenchment of these ideas that the major twentieth-century debate about recent environmental changes in the Pacific islands has *not* been about whether human or nonhuman factors were mainly responsible but about which particular group of humans caused the most damage.

Climatic and associated environmental changes occurred continuously throughout the Quaternary on Pacific islands. These changes did not abruptly cease once humans settled the islands, so why should most postsettlement changes have been commonly ascribed to human rather than to nonhuman activities or a combination of both? There is no single answer. Clearly, at the time when little was known about the nature or indeed global extent of presettlement climate change, it would have been reasonable to assume that the more easily discerned environmental changes of the late Holocene were the sole result of human impacts. But the way in which such a view has remained entrenched in the face of increasing knowledge about past climate changes is more difficult to explain. It may be that people were reluctant to abandon the potential of environmental change as a key to human history in postsettlement times by admitting the likelihood of nonhuman causes. It may simply be that the link between postsettlement environmental changes and human activities had become so secure that successive generations of investigators neither knew nor cared to challenge its premises. Whatever the reason, the probability needs to be recognized now that those environmental changes which were caused by nonhuman agencies during the late Holocene on Pacific islands have at least been comparable to those environmental changes caused by direct human impact.

The main priority for future research on recent environmental changes in the Pacific islands is to gather more data in greater quantities from more islands to enable clearer insights into the nature of such changes and their causes at a regional scale. At a local level, many data do exist for some situations, and this has led to appropriate solutions to many environmental problems being found. Environmental problem-solving in the Pacific islands has been documented elsewhere (e.g., Carpenter and Maragos 1989; Clarke 1990).

Over the last two decades, as more has become known about the recent past in the Pacific islands, the conclusions of research have become more specific and the contributory causes of particular environmental changes have become more securely established.

Three examples illustrate the point. The investigations by Kirch and Yen (1982) on Tikopia Island in the eastern Solomon Islands allowed them to conclude that late Holocene emergence of the island was the product of both sea-level fall and increased amounts of terrigenous sediment being deposited on the coastal flats. Detailed surveys of "fire areas," long believed to have been created by humans, on the northern Channel Islands off California led Cushing et al. (1986) to conclude that these were more likely the product of low-temperature, non-heating processes occurring in groundwater. The study by Spennemann (1987:91) on shellfish resources on Tongatapu Island in southern Tonga enabled him to demonstrate that the decreasing supply of large *Anadara* was "caused both by predation and (mainly) changing environment."

Future research on recent environmental changes in the Pacific islands has immediate practical use, for it is only by understanding past changes and their causes that effective plans can be made for the future. Like the inhabitants of Nayau (Section 1), I believe that the hand of God has made as strong an impression as the hands of people on the postsettlement environments of the Pacific islands.

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