RMAP WORKING PAPERS

Resource Management in Asia-Pacific

Working Paper No. 18:

Can climate shape cultural development? A view through time

Simon G. Haberle

Department of Archaeology and Natural History
Research School of Pacific and Asian Studies,
The Australian National University
email: haberle@coombs.anu.edu.au

Draft Only: Please do not cite

Paper presented in Resource Management in Asia-Pacific Seminar Series
The Australian National University, 18 June 1998

September 1998

The correct citation for this publication is:

Author: Simon G. Haberle
Year of Publication: 1998
Title: Can climate shape cultural development?: A view through time
Series: Resource Management in Asia-Pacific Working Paper No. 18
Publisher: Resource Management in Asia-Pacific Project, Division of Pacific and Asian History, Research School for Pacific and Asian Studies, The Australian National University
Editor: Anne Casson
Place of Publication: Canberra
ISSN – 1444-187X

Resource Management in Asia-Pacific

Working Papers

The Resource Management in Asia-Pacific Working Paper series seeks to provide readers with access to current research on environmental and resource issues in the Asia-Pacific. Working Papers produced by the Project aim to facilitate discussion and debate on critical resource management issues in the area, and to link scholars working in different disciplines and regions.

Publication as a 'Working Paper' does not preclude subsequent publication in scholarly journals or books, indeed it may facilitate publication by providing feedback from readers to authors.

Unless otherwise stated, publications of the Resource Management in Asia-Pacific Project are presented without endorsement as contributions to the public record debate. Authors are responsible for their own analysis and conclusions.

Resource Management in Asia-Pacific Project
Research School of Pacific and Asian Studies
The Australian National University
Canberra ACT 0200
Tel: +61 2 6125 9978
Fax: +61 2 6125 4896
Email: rmap@coombs.anu.edu.au

Can climate shape cultural development?
A view through time

Introduction

Despite the devastating impact that flooding, drought and fire associated with the 1982-83 and 1997-98 El Niño events had on both the natural environment and human society, there is little information on the impact similar events may have had in the deeper past. Historians and archaeologists have documented catastrophic events in human history from the collapse of great civilisations to the rise of devastating pandemics, that suggest human history has been shaped by extreme events and non-linear processes, many of which we know little about.

The environmental impact of recent major El Niño events have focussed attention on the impact of extreme climatic events on modern cultures and raised again the question, "How significant has climate change been in the development of human society?" The anthropological perspective of human cultures is mostly synchronic, only rarely turning to historical or prehistorical data as a means of understanding contemporary indigenous cultures. Headland (1997) points out that ignorance of the influence of past environmental changes on present-day cultures has led to the prolonged acceptance of the idea that with the utilisation of fire and the development of agriculture, human communities became the exploiters of nature. Historical ecologists, defined as those who study past ecosystems by charting the change in landscapes over time (Crumley 1994:6), have emphasised that the dichotomy between "natural" and human-influenced landscapes is a false one and that ecosystems have not only been greatly modified by humans for thousands of years, but also that natural processes have played a part in modifying human societies over this same time period. Such an historico-ecological approach makes one major prediction: that the fate of a society will be determined by the ecology of the land in which it exists. This is not to say that the traditional notion of environmental determinism is validated - that a region's natural surroundings decide the kind of culture found there. Rather, it proposes that the environment sets certain constraints on what any population can achieve within a given technology, and that natural environmental variation may play a role in changing the course of cultural development. The changes in climate, resources and habitats are not simply background information overlain by cultural change, but are considered a continually changing set of problems and opportunities altering the context for human survival. This approach challenges historical convention by the attention it gives to non-human agents in cultural transformation.

To test this hypothesis requires the data on societal and environmental transformations to have high chronological precision. This is not readily achieved given that sites containing evidence for human activity may be geographically some distance from sites containing evidence for environmental change. In addition, just because there might be a correlation between a climate event and a change in human society does not prove a causal link. Especially in cases where chronological control is poor, it is difficult to determine coincidence let alone cause and effect. An example of this problem can be illustrated in a recent debate on the causes for human evolution over the last 5 million years[1]. Researchers such as Vrba (1985), Wood (1993), Leakey (1994) and others have speculated that the global cooling and the subsequent drying of Africa was the driving force behind the evolution of *Homo* (Fig. 1). Leakey (1994) suggested that as the local climate became drier the vegetation became more open and hardier, this would have prompting the evolution of a species i.e. *Homo*, which was more mobile and had a more omnivore diet. The development of society itself is also touted as a possible driving force behind early human evolution (Leakey and Lewin 1992). In this case, it remains impossible to test the hypothesis because of the inability to replicate the experiment. This is not the case in later history, when human populations spread across the globe and became geographically and culturally isolated from one another, though subject to the same global climate phenomenon.

The approach advocated here compares historico-ecological records from separate regions, allowing us to test if a similar cultural response results from a given climatic event. I present three case studies that illustrate (1) the impact of natural catastrophic and non-linear processes on the

[1] Dates and ages based on the radiocarbon method are given as uncalibrated radiocarbon years before AD 1950 (yr BP). Other dates are given as cal yr BP (calendar years before 1950 AD). This paper adopts the terms 'glacial' and 'interglacial' to refer to periods of low or high sea-level or relatively cold and warm climate during the Quaternary (last 2.6 million years), respectively. The oxygen isotope chronostratigraphy of Martinson et al. (1987) shows that the most recent cold phase peaks at around 18,000 yr BP, when sea-level was at its lowest, and is referred to here as the "last glacial maximum". The "present interglacial" began around 10,000 yr BP.

development of human society, and (2) the adaptations made by these societies to these events and processes. These examples cross a wide range of spatial and temporal scales, though in each case there appears to be a correspondence between a major climatic (or volcanic) event and a change in cultural development in more than one geographically separated areas: the development of agriculture, the vulnerability of wetland agricultural communities and sustainability of isolated island settlements.

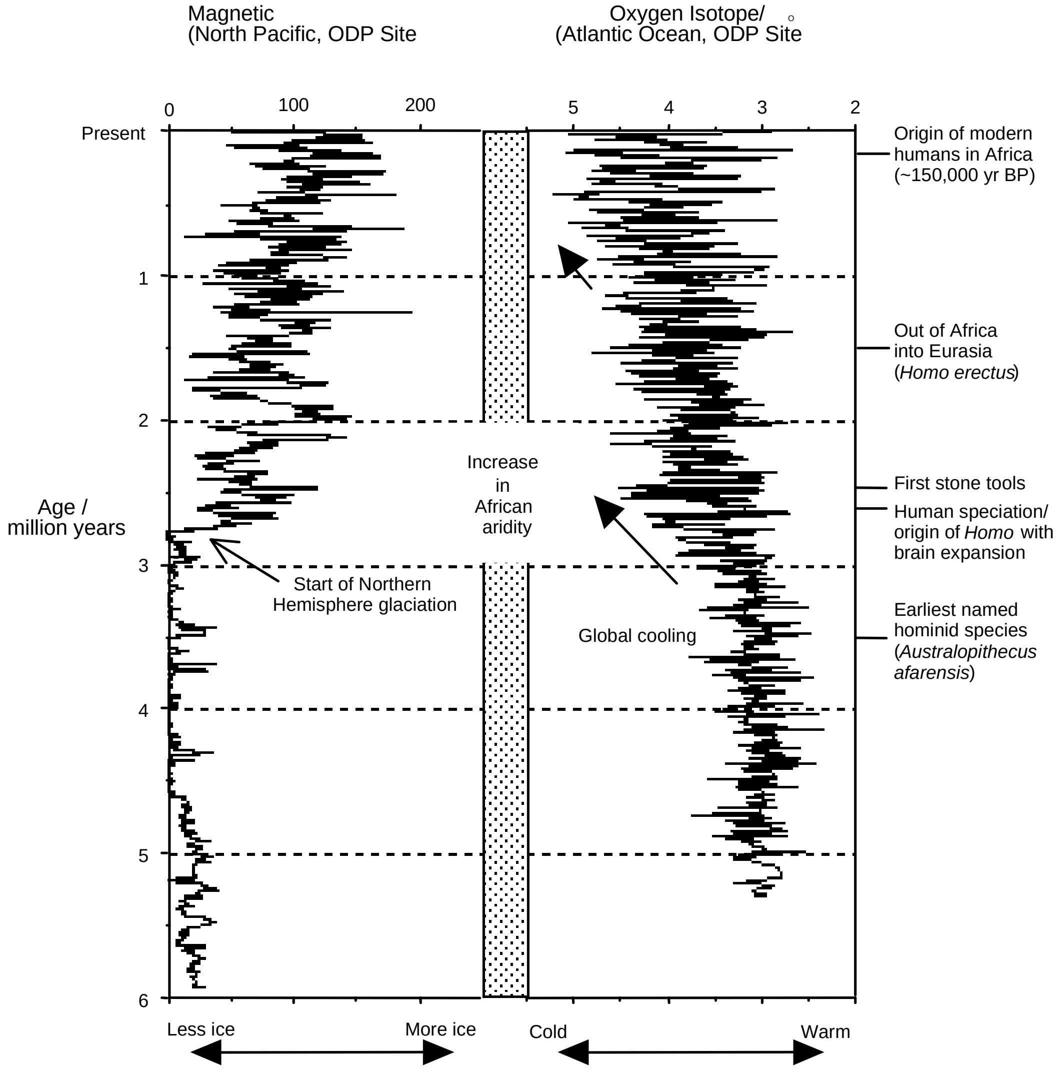


Figure 1. Major events in human evolution are compared with our knowledge of global climate change. Deep sea cores have provided continuous records of global climatic change from (a) the ratio of the different natural isotopes of oxygen, ^{16}O and ^{18}O, in the shells of the benthic foraminifera provides a proxy of global temperature (Ocean Drilling Project Site 659, Tiedemann et al. 1994), and (b) magnetic susceptibility is a proxy for the amount of icebergs in the North Pacific Ocean, which can only occur when there are large ice sheets on the Northern Hemisphere (Ocean Drilling Project Site 882, Robinson 1986). Using these proxy indicators of climate change preserved in deep ocean sediments the global climate appears to have begun to change from hot and wet at 3.2 million years ago to cold and dry by the middle Pliocene at about 2.6 million years ago. This was reflected by the gradual build up of ice in both the Arctic and Antarctic. The dramatic increase in the magnetic susceptibility from the North Pacific at 2.6 million years ago indicates that there was, for the first time, significant amounts of ice in the Arctic and on North America. After this, the global climate cycles appear to have intensified, varying from very cold glacial with huge ice sheets covering much of North America and Northern Europe, to interglacials with climate comparable to the present (adapted from Maslin 1996).

Development of agriculture: The highland[2] New Guinea case

An examination of the palynological and archaeological evidence for the earliest shifts from hunting and gathering strategies to agriculture shows a striking synchronism in a number of separate regions around the globe about 10,000 years ago (Bellwood 1996, McClung de Tapia 1991). That this significant shift in cultural adaptation should occur at the end of a period of great climatic change, when forests had largely replaced grasslands and the climate was warmer and in many cases wetter, may point to agricultural development being climatically determined. The investigation of this hypothesis is perhaps best developed in more temperate regions such as the Near East where multiple sites and detailed genetic investigations of cereal crops have shown that highly seasonal climates at the end of the last glacial strongly selected for the ancestral domesticate plants (McCorriston and Hole 1991, Blumler and Byrne 1991). Another example comes from northern China where plant domestication is considered to be well underway by 10,000 yr BP (Crawford 1992) in a favourable steppe-forest or forested environment that underwent a rapid climatic transformation towards steppe-like conditions at this time, forcing selection of specific plants to sustain subsistence in a rapidly changing environment. Certainly, in view of the different crops that have been domesticated in each area it seems likely that the development of agriculture was independent within each region and not diffused from a single centre, refuting the diffusionists ideas of Sauer (1952).

When agriculture developed in New Guinea has long been debated (Bellwood, 1996, Golson 1977, 1991a, and 1991b, Gorecki 1986, Groube 1989, Mountain 1991, Spriggs 1997, Yen 1982, 1991). The primary source of evidence for all these discussions comes from Kuk swamp where a 9000 year old sequence of swamp drainage (Golson 1977, Golson and Hughes 1980) and concomitant dryland exploitation (Golson and Hughes 1980, Hughes et al. 1991) for food production is claimed. This represents the earliest archaeological indications that subsistence strategies for highlands populations had reached a stage where parts of the environment were being manipulated for food production. However, there is fragmentary evidence that suggests human manipulation of plant communities may be an important factor as early as 30,000 yr BP, supporting the idea of a gradual increase in environmental manipulation for at least 20,000 years prior to the first archaeological evidence for agriculture around 9000 yr BP (Haberle et al. 1991, Haberle 1993). The maintenance of grasslands in the valley floors by fire from as early as 21,000 yr BP through to at least 9000 yr BP and an intensification of burning between 14,500 and 12,000 yr BP (Haberle 1998) in the Tari Basin suggest sustained exploitation of food plants in the highlands may have occurred some 3000-5000 years before the evidence at Kuk.

The record of climate change and archaeological evidence for agriculture in the highlands of New Guinea over the last 20,000 years is compared in Fig. 2. Climatic amelioration begins soon after the last glacial maximum, though climatic variability remains high, with infrequent but severe droughts characterising the highland valleys between 16,000-12,000 yr BP. The transition from last glacial to present interglacial climates is finally achieved over a rapid transition period of at most 1000 years from 10,000 to 9000 yr BP. There are no clear indications of climate change during the present interglacial, but increased disturbance during the last 5000 years, and particularly within the last 2000 years, may be partly related to increased climatic variability brought on by the influence of ENSO-type events.

These climate changes appear to coincide with shifts in subsistence strategies recorded in the archaeological record, particularly the proposed development of agriculture around 9000 yr BP at a time of rapid climate change. If agriculture developed in the highland valleys at this time, then what plants were being exploited? Fig. 3 shows that, although a number of food species are clearly excluded from the highlands during colder periods, including tubers and fruits like yams and bananas important in traditional New Guinea agriculture, nevertheless a range of vegetable foods which are recorded as cultivated in modern gardens (Powell 1976, Haberle 1991) may have been viable in highlands valleys and basins. These included traditionally important cultigens like taro, sugar cane and gourd, if these were in fact present in the island at this date. It is important to keep in mind some obvious shortcomings to any argument that assumes the presence of these plants in the highlands before human habitation. The three crops mentioned above and many of the plants listed in Fig. 3 may in fact be ancient introductions to the island of New Guinea with their range having been extended by early agriculturalists (e.g. *Colocasia esculenta*, Matthews 1991; *Lagenaria*, Powell 1976; *Saccharum officinarum* lowlands domesticate Daniels and Daniels 1993; *Dioscorea alata* and *Musa* 'diploid' Southeast Asian introductions, Yen 1982). In addition it should be appreciated, of course, that the limits quoted for these plants in Fig. 3 are those under an agricultural regime many millennia old, so

---

[2] The use of the term "highlands of New Guinea" refers to the inland regions above an altitude of about 1200m and not exclusively to the present-day Highlands Provinces of Papua New Guinea.

that the ‘original’ limits are unknown, and the same may apply to other entries in the figure (cf. Golson 1991b, p. 83).

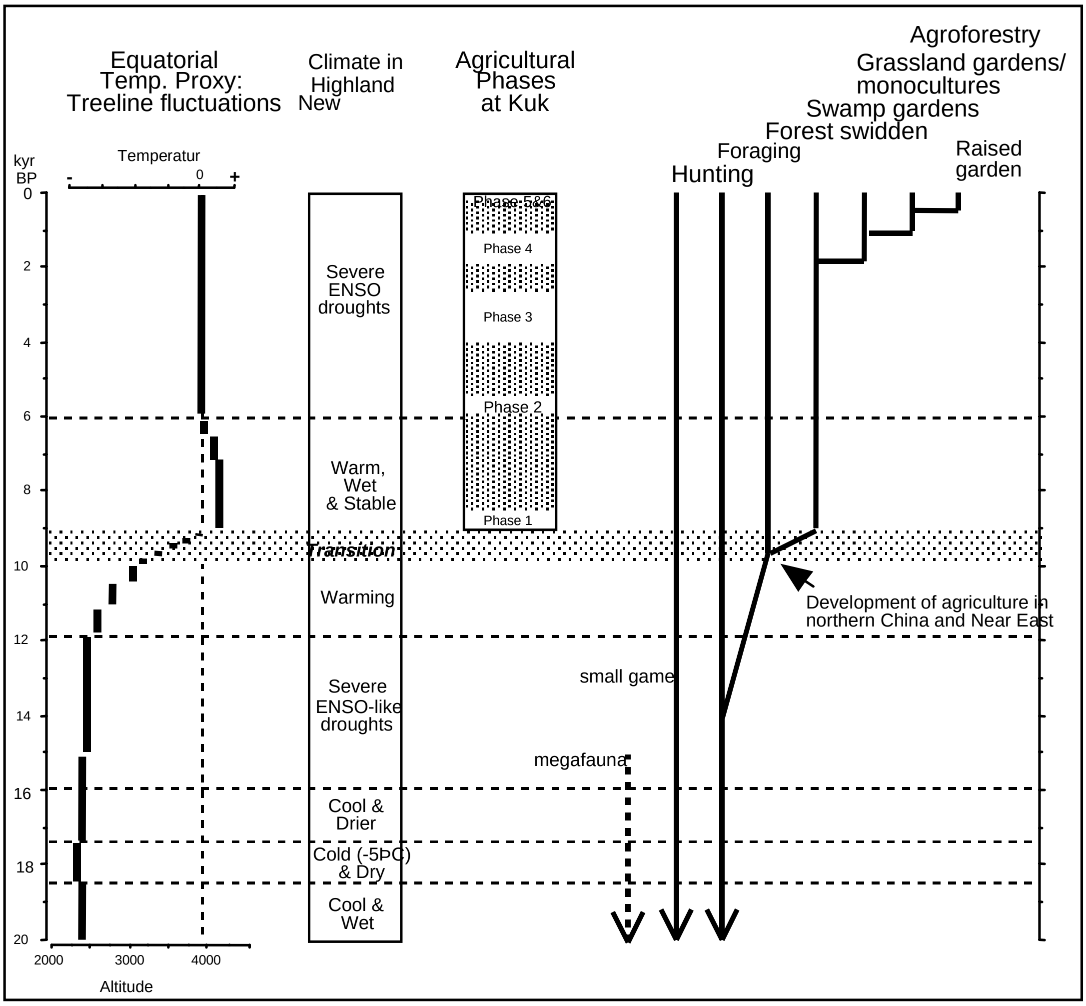


Figure 2. Climate change in New Guinea (after Hope 1976 and Haberle 1998) is compared with phases of wetland agricultural activity recorded at Kuk Swamp archaeological site (after Golson 1977 and Bayliss-Smith 1996). A possible model for the development of agriculture in the highlands of New Guinea from 20,000 yr BP through to the present is given on the right of the diagram.

Limitations on plant growth extend beyond the simple matter of temperature; other factors such as frost severity and cloudiness must be considered as limiting conditions for cultivation (Brookfield 1989). As regards to the former, in well-protected garden areas where plants can be shaded by taller trees like *Pandanus* or ring-barked forest trees, the flow of cold air that may result in frost damage is generally slight (Brown and Powell 1974). As regards to cloudiness, persistent cloud may not necessarily be evenly spread through a last glacial mountain valley due to topographic barriers and the presence of open grasslands locally reducing cloud formation. The occurrence of infrequent but severe droughts and associated frost between 16,000 and 12,000 yr BP in the Tari Basin, central highlands of New Guinea, would have put sustained production of most food plants out of question, but short-term and sporadic production would have been possible in this environment. Limited and localised as forest clearances for such purposes may have been, they would have added to other benefits of extending open vegetation for hunting and ease of communication (G. and J. Hope 1976, Haberle 1998).

A suite of tuber, vegetable and nut crops is considered on the evidence of Fig. 3 to have been candidates for successful cultivation in this environment, though we have direct evidence in the record only for the nut-producing genus *Pandanus* (Haberle 1995). This proposition gives a much fuller context for the 9000 yr BP cultivation system claimed for Kuk, where the specification of what was being grown has always been imprecise, though invariably considered to be plants brought up from lower altitudes in pace with climatic amelioration (e.g. Golson and Hughes 1980, Golson 1991a). In his most recent statement Golson (1991b) uses Yen’s (1991) conclusions about cultigens of putatively New Guinea origin to suggest that planting at Kuk could have included bananas, sugar cane, probably yams and possibly taro, which he sees as having first been taken into cultivation under more benign conditions within the *Castanopsis/Lithocarpus* forests of lower altitudes. Gorecki (1986) also proposes that agriculture had its origins earlier and at lower altitudes than Kuk. However, since, as we have seen, the altitudinal extremes of some of the plants cultivated in traditional New Guinea systems were within the highlands valleys during the last glacial, where conditions for their growth would have been more susceptible to change than at lower altitudes, it is worth considering climatic change at the "edge of the range" of crop viability (Bellwood 1996) as a major factor in shifting strategies of food production in the light of other evidence for agricultural activity throughout the tropical (and temperate) world.

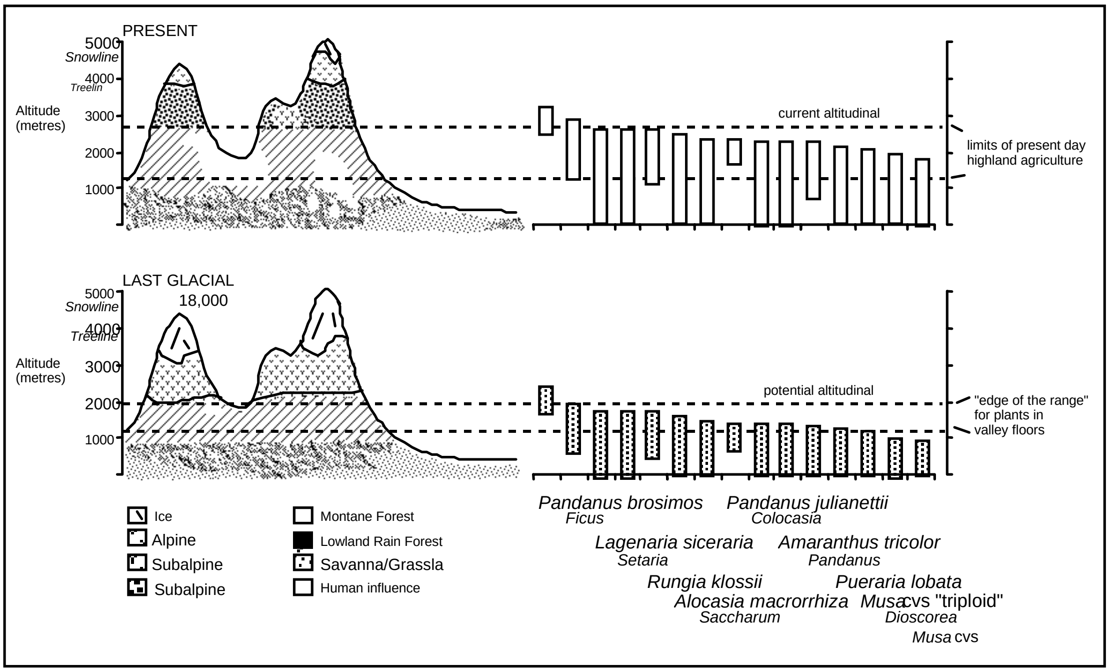


Figure 3. The present day and last glacial maximum vegetation distributions in New Guinea are shown (after Hope 1986), with the distribution of a number of important, and potentially important, food plants (after Bourke ms.). Present day distributions are compared with those that would have been likely with a theoretical reduction of vegetation zones of 850-1500 m at the height of the last glacial maximum due to cooler temperatures: the highest level at which a species might be found. Taxa considered viable crops in the highlands during glacial climates occur above an altitude of 1200 m, the lower limit of highland valley's.

In the New Guinea highlands situation subsistence strategies for managing plant food resources had been developed in the highlands under a cold, highly variable environment subject to severe drought stress between 16,000 and 12,000 yr BP. These effective strategies, operating at the "edge of the range" for a number of important plant types, were able to be intensified under the onset of rapidly ameliorating climates less subject to stress across the highlands between 12,000 and 9000 yr BP. At the same time there would have been less pressure to develop effective planting strategies at the centre of growth range for most plants, that is at lower altitude. Though this is a hypothesis needing fuller substantiation, it does not appear necessary any longer to situate agricultural origins in New Guinea, as has been regularly done, in the lower altitudes of the highlands fringes, with subsequent transplantation of plants and techniques into the highlands valleys.

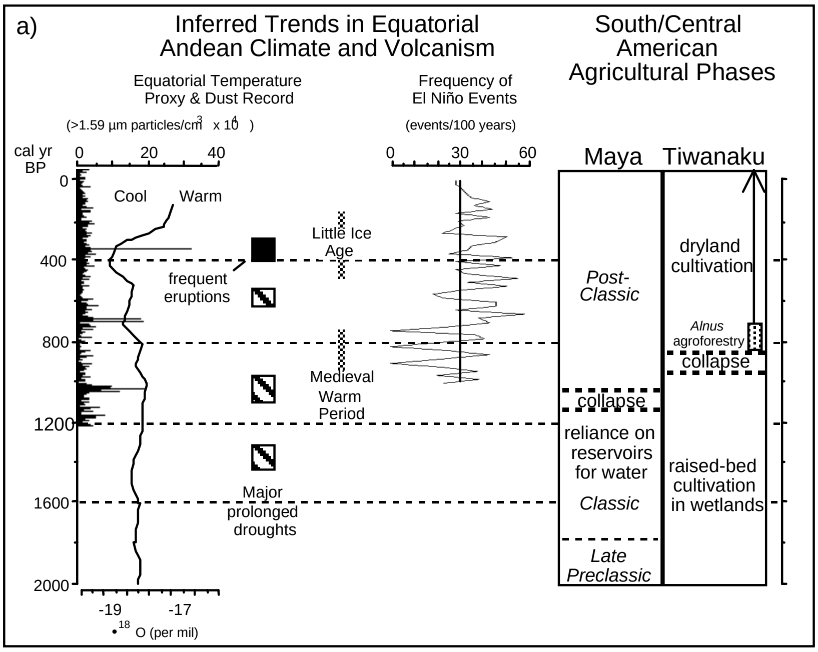
Vulnerability of wetland agriculture

Climate changes are generally considered to be relatively minor during the last 10,000 years, though it has been suggested that the impact of short-term climate variability, such as increased drought stress associated with ENSO (El Niño-Southern Oscillation) events, has had a significant influence on vegetation dynamics in the Pacific region over the last five to three millennia (McGlone et al. 1992). This has been supported further by records showing landscape destabilisation around 5000 yr BP from the South American coast (Sandweiss et al. 1996) and increased disturbance of vegetation in Australia (Shulmeister and Lees 1995) and New Guinea (Haberle 1996a) between 5000 and 4000 years ago.

In a study of the Mayan settlement, Hodell et al. (1995) suggest that there are climatic thresholds for cultural development and that abrupt, unpredictable climate changes can have devastating consequences on human populations by disrupting agricultural production. In the Maya lowlands, cultural development and population expansion occurred under conditions favourable to agriculture. The decline of the Maya cultures were associated with protracted droughts that are not explained by our current understanding of climate variability (Hodell et al. 1995, Leyden et al. 1998). A similar sequence of cultural change is linked to the failure of wetland agricultural systems in the Bolivian altiplano at Tiwanaku around 850 cal yr BP when low lake levels reflect a period of protracted dry climate (Binford et al. 1997).

A proxy record of the climate for the last 2000 cal yr BP in equatorial Andes of South America and the highlands of New Guinea (Fig. 4) comes from ice core and lake level records in the Peruvian Andes. The occurrence of major dry or wet events are likely to be synchronous across the equatorial Pacific transect to New Guinea due to physical connection through the Walker Circulation (Diaz 1992). If the Peruvian drought record does coincide with drought in highland New Guinea, as suggested by limited tree-ring and historical records from Java and Peru (Brookfield 1989), then the highlands of New Guinea may have experienced severe and prolonged drought at the same time. The major dust events recorded in ice cores from Peru (Thompson et al. 1994 and 1995) point to the possible occurrence of major El Niño-related droughts in the highlands of Peru between 1100-900 cal yr BP and between 1450-1200 cal yr BP (Fig. 4). The possibility that small-scale climate change had a significant impact on prehistoric agriculture in the highlands of New Guinea is also considered by Brookfield (1989), who suggests that the abandonment and re-use of Kuk Swamp in the highlands of Papua New Guinea may be linked to periods of greater or lesser climate variability. As yet, the palaeoecological record from New Guinea does not have the resolution of the annually laminated ice cores of Peru, so if these events did occur in the past, they are not visible in available records.

Comparison with the equatorial American record shows a striking synchrony between apparent low climatic variability during the Medieval Warm Period and the absence of swamp agriculture at Kuk (Fig. 4). Swamp cultivation appears to occur during periods of greatest climatic variability. Periods of chronic drought stress may have initiated the need for greater ground-water control leading to the development of grid patterns of field ditches, seen in Phase 4 and onwards at Kuk swamp. Long-term anthropogenic landscape change, notably forest clearance and land degradation before 1190-970 cal yr BP, has been implicated in the adoption of widespread *Casuarina* planting as an agroforestry tree (Haberle in press). A similar feature appears to have been recorded in the highlands of Peru, where pollen records show that *Alnus* was possibly planted widely as a dryland agroforestry tree after 850 cal yr BP (Chepstow-Lusty et al. 1998). Both *Casuarina* and *Alnus* are nitrogen-fixing trees used in traditional agroforestry systems that have played a significant role in sustaining human populations in a variety of tropical soil and climate conditions (Fernandes and Nair 1987), and may have been adopted as a response to low crop productivity and the need to rehabilitate abandoned dryland crop lands after prolonged climatic stress.



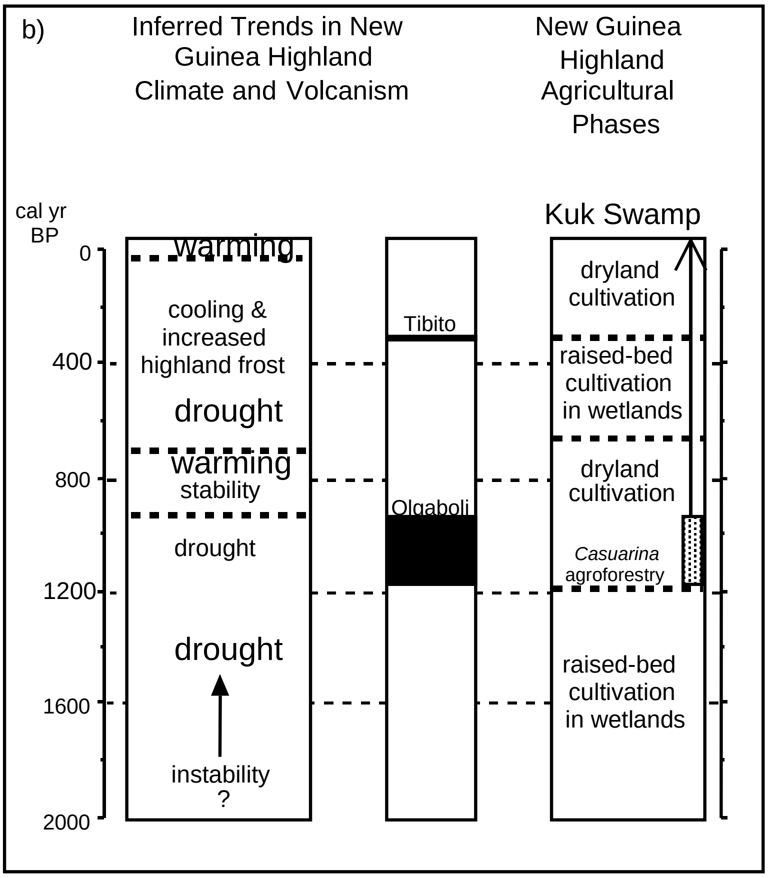


Figure 4. Natural causes of cultural change in equatorial Americas and New Guinea. A series of climate proxy records from **a)** equatorial South America (temperature from Huascar‡n ice core $\delta^{18}O$ record, Thompson et al. 1995; drought periods from Quelcaya ice core dust particles >1.59 µm, Thompson et al. 1994; a composite time series for the recurrence of El Ni–o events since 1000 cal yr BP and the occurrence of the Little Ice Age and Medieval Warm Epoch, after Anderson 1992) and archaeological phases from the Yucatan lowlands (Maya, Hoddel et al. 1995) and the Bolivian altiplano (Tiwanaku, Binford et al 1997; *Alnus* agroforestry, Chepstow-Lusty

et al. 1998), are compared with **b)** inferred climate and cultural changes in highland New Guinea over the last 2000 cal yr BP. Kuk swamp agricultural phases and the development of *Casuarina* agroforestry (Haberle in press) show the switching from wetland to dryland agriculture under the influence of tephra impact and climate change.

Sustainability of Pacific Island societies

The prehistory of human colonisation across the Pacific is relatively well known, providing information on the chronology for the presence and absence of humans in the region. Fig. 5 shows the progression of human populations from Asia eastward across the Pacific. The islands west of the Bismark Archipelago have been occupied by humans for at least the last 28,000 years (Wickler and Spriggs 1988). The initial phase of Polynesian migration eastwards into the central and eastern Pacific, including Fiji, only began in earnest after about 3500 yr BP (Enright and Gosden 1992), some 1500 years after the proposed establishment of ENSO variability (Sandweiss et al. 1996). The eastern and south-western islands of this region, such as Hawai'i, Cook Islands, New Zealand and Easter Island, were the last to receive Polynesian settlers possibly within the last 1200 cal yr BP, though the exact timing of this final expansion is a matter of debate (Anderson 1995).

Prehistoric human impacts on the environment of Pacific islands to the west of Easter Island have been well documented in palaeoecological and archaeological studies (Kirch 1996, Flenley and King 1984, Haberle 1996b, Parkes et al. 1992, Pimm et al. 1995, Weisler 1994), that include evidence for major forest clearance, increased erosion on hillsides and alluvial deposition in valley bottoms, increased burning, introduction of exotic species and extinction of native species. However, the timing and nature of disturbance induced by Polynesian occupation is open to some debate (Anderson 1995, Kirch and Ellison 1994) due to the difficulties of separating human from natural processes of disturbance in the palaeoecological and archaeological records.

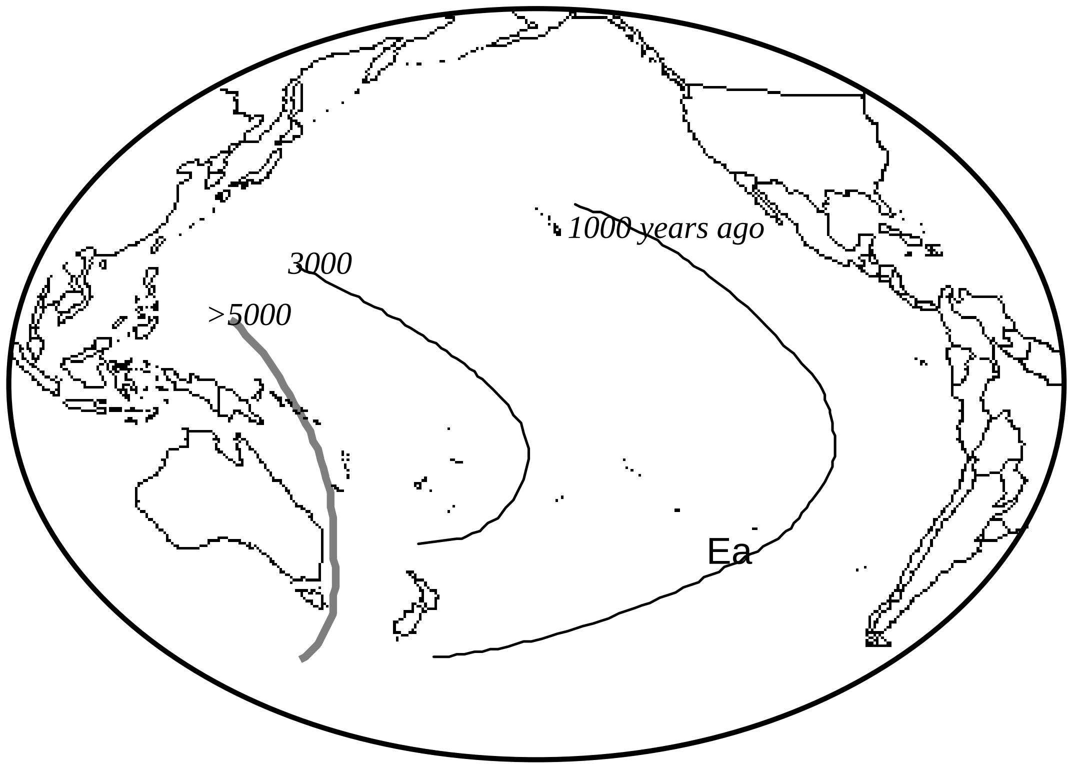


Figure 5. Location of Easter Island (Ea). The age of human colonisation eastwards into the Pacific Ocean is depicted by schematic lines of initial habitation from archaeological data.

In Fig. 6 the main trends of Easter Island ecological history are reduced to a few key proxy signals (after Figure 192 in Bahn and Flenley 1992), with the addition of two new proxy climate signals for the Pacific; a composite time series for the recurrence of El Niño events compared to the global air temperature changes since 950 cal yr BP (after Anderson 1992 and Gates 1993); and, known volcanic eruptions since 550 cal yr BP causing anomalous global[3] cooling of up to 1°C (Briffa et al. 1998). There is a striking correspondence between the period of statue building, the most resource demanding phase of human occupation, and the phase of low ENSO activity. Similarly, the cause of the ultimate collapse of the society that made these statues around 1770 appears to be closely linked to a period of intense ENSO activity, coupled with frequent volcanic disruption to global climate. Bahn and Flenley (1992) suggest that the impact of activities of the early human settlers was the major factor that led to the eventual collapse of island society around 180 cal yr BP (1770 AD). The island had certainly undergone substantial deforestation since initial settlement (Flenley and King 1984), but the alternative explanation may be that the environmental outcomes of a prolonged period of severe droughts and cooler global temperatures during the 17th century, may have been sufficient to topple the existing society, together with land degradation. However, this was clearly not the case on all Pacific islands. Kirch (1997) illustrates the results of prolonged environmental degradation on two other Pacific islands, Mangaia and Tikopia, in which the adaptations made by these two communities led to completely different outcomes; sustainable production on Tikopia and depopulation/warfare on Mangaia.

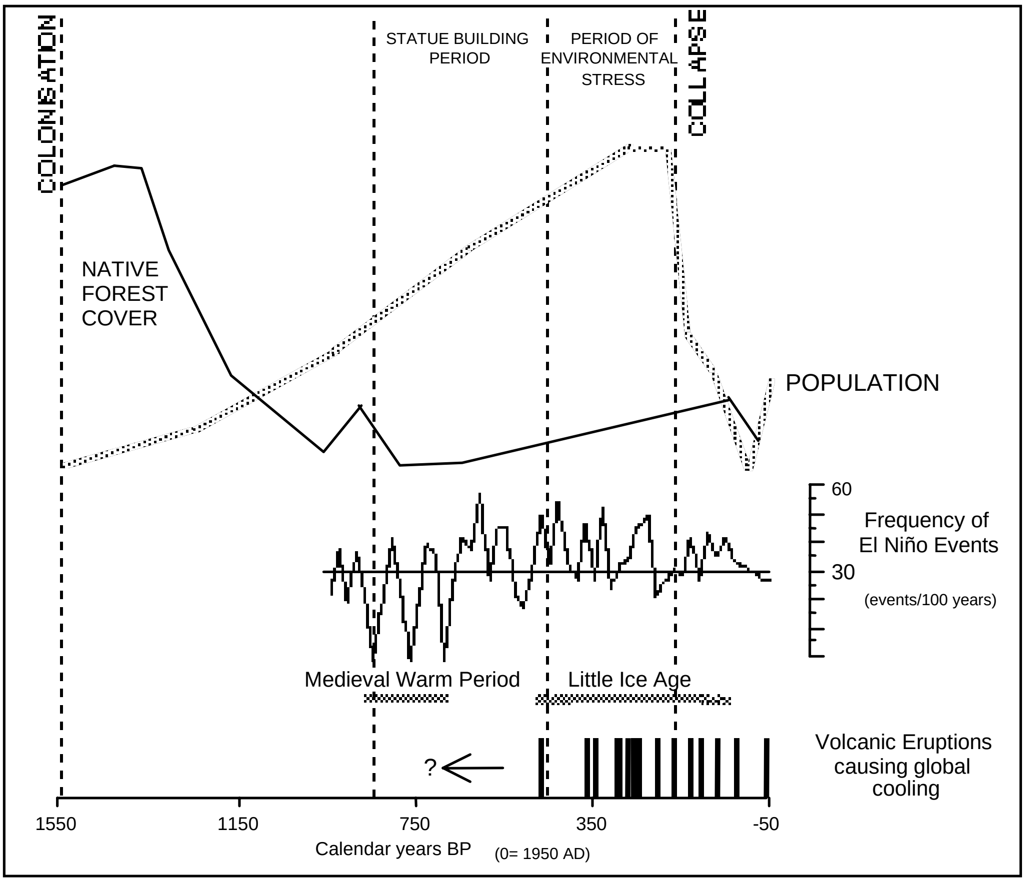


Figure 6. A diagrammatic model of some of the historical events and main trends in environmental change on Easter Island (after Bahn and Flenley 1992) compared with trends in climate change across the Pacific (time series for the recurrence of El Niño events since 1000 cal yr BP and the occurrence of the Little Ice Age and Medieval Warm Epoch, after Anderson 1992; volcanic eruptions of the last 550 cal yr BP causing global cooling, after Briffa et al. 1998).

3 The study (Briffa et al. 1998) uses only Northern Hemisphere temperature records, however, given that a number of the source volcanoes are located in the Southern Hemisphere, similar or greater temperature anomolies are assumed to be evident in the Southern Hemisphere as well.

Discussion

The evidence presented here of climate-culture interactions in several regions suggests a significant environmental component in human behaviour. Moreover there are numerous examples in the deep past of conflict over resources, episodes of environmental degradation, deforestation, soil erosion and extinctions. Around 10,000 years ago, something happened in at least three independent regions around the globe (China, Middle East, and highland New Guinea) that brought on a shift in plant resource exploitation that became agriculture. Similarly, around 1000-850 years ago in the tropics of the Americas and in the highlands of New Guinea, the breakdown of reliable wetland agricultural systems that had supported populations for centuries collapsed and resulted in a shift to dryland agriculture with a new agroforestry technology (*Casuarina* and *Alnus*) to alleviate nutrient depletion in the environment. A range of interrelated factors including population growth, environmental degradation, expanding exchange networks and increased inter-community warfare may have been implicated in the process, however, the recognition that the rapid climate changes recorded globally at these times provided the impetus or even the necessity to alter the way resources were managed. That these changes are not always synchronous around the globe may be explained in terms of the relative vulnerability of "marginal" populations to changes in climate.

Human cultures adapt to changing environmental conditions within a range of "normal" environmental variability. An important ecological question for *Homo sapien* is, at what point does the low frequency variations with larger amplitudes exceed the limits of human adaptability? That limits exist is illustrated in the examples given here, however, quantification of this remains unresolved and will require sophisticated population dynamics models that incorporate climatic variability as well as social factors. This question may best be answered in Pacific island ecosystems, where dispersed populations inhabiting islands with different resources are subject to similar environmental variability, namely, the ENSO phenomenon with its strongest signature located across the tropical Pacific ocean and which is one of the best understood and predictable components of the global climate system. The environmental stresses that led to the demise of Easter Island society around 200 years ago appear to have included a strong climate change component, though this change may have had different outcomes on other Pacific islands (Kirch 1997).

As to the implications of this kind of comparative research, Overpeck (1996) suggests that climate events of the type apparent in the present interglacial climate record may be our biggest concern in the years to come. Certainly, without the knowledge of natural long-term climate variations, no informed judgement can be made about the recent record of climatic changes, extremes of droughts, floods, storm frequencies, or changes in oceanic circulation. Extreme climatic events, by their infrequent nature, are difficult to evaluate or forecast unless pre-historical records are extended to reveal the frequency of prior occurrences. The historical ecology approach provides a means of tackling this question in across geographically and socially separate regions. This knowledge of climatic change can aid in planning for possible shifts in temperature and precipitation. This knowledge is vital for anticipating the extent and impact of global climate change on human society.

Acknowledgements

This paper was written while the author was a Visiting Fellow at the Department of Archaeology and Natural History, Research School of Pacific and Asian Studies, ANU. The initial paper was presented as a seminar in the Resource Management in Asia-Pacific Seminar Series in June 1998. The author would like to thank Jim Allen, Chris Ballard, Geoff Hope and Richard Grove for critical discussions and encouragement. Alex Chepstow-Lusty and Mark Maslin provided useful data on climate change. The author was funded by a joint Ranieri-Howard Grant.

References

Anderson, A. (1995) Current approaches in east Polynesia colonisation research. *The Journal of the Polynesian Society* 104: 110-132.

Anderson, R.Y. (1992) Long-term changes in the frequency of occurrence of El Niño events. *In* H.F. Diaz and V. Markgraf (eds.), *El Niño: Historical and Paleoclimatic Aspects of the Southern Oscillation*, pp 193-200. Cambridge University Press, Cambridge.

Bahn, P. and Flenley, J.R. (1992) *Easter Island Earth Island*. Thames and Hudson, London.

Bayliss-Smith, T. (1996) People-plant interactions in the New Guinea highlands: agricultural heartland or horticultural backwater? In D.R. Harris (ed.) *The Origins and Spread of Agriculture and Pastoralism in Eurasia*, University College London Press, London, pp. 499-523.

Bellwood, P., (1996) The origins and spread of agriculture in the Indo-Pacific region: gradualism and diffusion or revolution and colonization? In D.R. Harris (ed.) *The origins and spread of agriculture and pastoralism in Eurasia*, University College London Press, London, pp. 465-498.

Binford, M.W., Kolata, A.L., Brenner, M., Janusek, J.W., Seddon, M.T., Abbott, M. and Curtis, J.H. (1997) Climate variation and the rise and fall of an Andean civilisation. *Quaternary Research* 47: 235-248.

Blumler, M.A. and R. Byrne (1991) The ecological genetics of domestication and the origins of agriculture. *Current Anthropology*, 32: 23-54.

Bourke, R.M. ms. Altitudinal limits of 220 economic crop species in Papua New Guinea. In prep.

Briffa, K.R., Jones, P.D., Schweingruber, F.H. and Osborn, T.J. (1998) Influence of volcanic eruptions on Northern Hemisphere temperatur over the past 600 years. *Nature* 393: 450-455.

Brookfield, H.C. 1989 Frost and drought through time and space, Part III: What were conditions like when the high valleys were first settled? *Mountain Research and Development*, 9: 306-321.

Brown, M. and J.M. Powell 1974 Frost and drought in the highlands of Papua New Guinea. *Journal of Tropical Geography*, 38: 1-6.

Chepstow-Lusty, A.J., Bennett, K.D., FjeldsŒ, J., Kendall, A., Galiano, W., and Tupayachi Herrera, A. (1998) Tracing 4000 years of environmental history in the Cuzco area, Peru, from the pollen record. *Mountain Research and Development* 18, 159-172.

Crawford, G.W. 1992 Prehistoric plant cultivation in the Near East. In Cowan, C.W. and P.J. Watson (eds.) *The Origins of Agriculture: An International Perspective*, pp. 7-38. Smithsonian Institution Press, Washington.

Crumley, C.L., ed. (1994) *Historical Ecology: Cultural Knowledge and Changing Landscapes*. School of America Research Press, Santa Fe.

Daniels, J. and Daniels, C. (1993) Sugarcane in Prehistory. *Archaeology in Oceania*, 28: 1-8.

Diaz, B.E. (1992) Historical and prehistorical overview of El Niño/Southern Oscillation. In H.F. Diaz and V. Markgraf (eds.), *El Niño: Historical and Paleoclimatic Aspects of the Southern Oscillation*, pp 95-117. Cambridge University Press, Cambridge.

Enright, N.J., and Gosden, C., 1992. In J. Dodson (ed.), *The Naive Lands.* Longman Cheshire, Melbourne. pp. 160-198.

Fernandes, E.C.M. and Nair, P.K.R. (1987) An evaluation of the structure and function of tropical homegardens. *Agricultural Systems* 21: 279-310.

Flenley, J.R. and King, S.M. (1984) Late Quaternary pollen records from Easter Island. *Nature* 307, 47-50.

Gates, D.M. (1993) *Climate Change and its Biological Consequences*. Sinauer Associates Inc., Massachusetts.

Garrett-Jones, S.E. (1979) *Evidence for changes in Holocene vegetation and lake sedimentation in the Markham Valley, Papua New Guinea.* Unpublished Ph.D. Thesis, Australian National University, Canberra.

Golson, J. (1977) No room at the top: agricultural intensification in the New Guinea highlands. In *Sunda and Sahul: Prehistoric Studies in Southeast Asia, Melanesia and Australia*, Allen, J., J. Golson and R. Jones (eds.), pp. 601-638. Academic Press, London.

Golson, J. (1991a) The New Guinea Highlands on the eve of agriculture. In *Indo-Pacific Prehistory 1990*, Vol. 2, Bellwood, P. (ed.), pp. 82-91. Indo-Pacific Prehistory Association, Bulletin No. 11, Canberra.

Golson, J. (1991b) Bulmer Phase II: early agriculture in the New Guinea Highlands. In *Man and a Half: Essays in Pacific anthropology and ethnobiology in honour of Ralph Bulmer*, Pawley, A. (ed.), pp. 484-91. The Polynesian Society, Auckland.

Golson, J. and Gardner, D.S. (1990) Agriculture and sociopolitical organisation in New Guinea Highlands prehistory. *Annual Review in Anthropology,* 19: 395-417.

Golson, J. and Hughes, P. J. (1980) The appearance of plant and animal domestication in New Guinea. *Journal de la Société des Océanistes* 36: 294-303.

Gorecki, P.P. (1986) Human occupation and agricultural development in the Papua New Guinea highlands. *Mountain Research and Development*, 6: 159-166.

Groube, L. (1989) The taming of the rain forests: a model for Late Pleistocene forest exploitation in New Guinea. In Harris, D.R. and G.C. Hillman (eds.), *Foraging and Farming: the evolution of plant exploitation*, pp. 292-304. Unwin Hyman, London.

Haberle, S.G. (1991) *Ethnobotany of the Tari Basin, Southern Highlands Province, Papua New Guinea.* Department of Biogeography and Geomorphology, Research School of Pacific Studies, The Australian National University, Canberra.

Haberle, S.G. (1993) Pleistocene vegetation change and early human occupation of a tropical mountainous environment. In Smith, M.A., Spriggs M. and Fankhauser B. (eds.) *Sahul in Review: Pleistocene Archaeology in Australia, New Guinea and Island Melanesia*. Occasional Papers in Prehistory, No. 24, pp. 109-122. Australian National University, Canberra.

Haberle, S.G. (1995) The identification of cultivated *Pandanus* and *Colocasia* in pollen records and the implications for the study of early agriculture in New Guinea. *Vegetation History and Archaeobotany*, 4: 195-210.

Haberle, S.G. (1996a) Palaeoenvironmental changes in the eastern highlands of Papua New Guinea. *Archaeology in Oceania* 31: 1-11.

Haberle, S.G. (1996b) Explanations for palaeoecological changes on the northern plains of Guadalcanal, Solomon Islands: the last 3200 years. *The Holocene* 6: 333-338.

Haberle, S.G. (1998) Late Quaternary vegetation change in the Tari Basin, Papua New Guinea. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 137: 1-24.

Haberle, S.G. (in press) Dating the evidence for prehistoric agricultural change in the highlands of New Guinea: the last 2000 years. *Australian Archaeology*

Haberle, S.G., Hope, G.S. and DeFretes, Y. (1991) Environmental changes in the Baliem Valley, montane Irian Jaya, Republic of Indonesia. *Journal of Biogeography*, 18: 25-40.

Headland, T.N. (1997) Revisionism in ecological anthropology. *Current Anthropology* 38: 605-609.

Hoddel, D.A., Curtis, J.H. and Brenner, M. (1995) Possible role of climate in the collapse of Classic Maya civilisation. *Nature* 375: 391-394.

Hope, G.S. (1976) The vegetation history of Mt Wilhelm, Papua New Guinea. *Journal of Ecology*, 64: 627-664.

Hope, G.S. (1986) Development of present day biotic distributions in the New Guinea mountains. In Barlow, B.A. (ed.), *Flora and Fauna of Alpine Australasia: Ages and Origins*, pp. 129-145. CSIRO, Melbourne.

Hope, G.S. and Hope, J.H. (1976) Man on Mount Jaya. In Hope, G.S., J.A. Peterson, U. Radok and I. Allison (eds.), *The Equatorial Glaciers of New Guinea,* A.A. Balkema, Rotterdam pp. 225-240.

Hughes, P.J., Sullivan, M.E. and Yok, D. (1991) Human-induced erosion in a highlands catchment in Papua New Guinea: the prehistoric and contemporary records. *Zeitschrift für Geomorphologie* N.F., 83: 227-239.

Kirch, P.V. (1996) Late Holocene human-induced modifications to a central Polynesian island ecosystem. *Proceedings of the National Academy of Science USA* 93: 5296-5300.

Kirch, P.V. (1997) Microcosmic histories: Island perspectives on "global" change. *American Anthropologist* 99: 30-42.

Kirch, P.V., and Ellison, J. (1994) Palaeoenvironmental evidence for human colonisation of remote Oceanic islands. *Antiquity* 68: 310-321.

Leakey, R. and Lewin, R. (1992) *Origins Reconsidered*. London: Little, Brown and Company, pp.373.

Leakey, R. (1994) *The Origin of Humankind*. London: Weidenfeld and Nicolson, pp.171.

Leyden, B.W., M. Brenner and B.H. Dahlin (1998) Cultural and climatic history of Cobá, a lowland Maya city in Quintana Roo, Mexico. *Quaternary Research* 49: 111-122.

Maslin, M. (1996) Causes of Human Evolution. *The Bloomsbury Geographer*, 23: 55-62.

Matthews, P. (1991) A possible wildtype taro: *Colocasia esculenta* var. *aquatilis*. In Bellwood, P. (ed.), *Indo-Pacific prehistory 1990*, Vol. 2, pp. 69-81. Indo-Pacific Prehistory Association, Bulletin No. 11, Canberra.

McClung de Tapia, E. (1992) The origins of agriculture in Mesoamerica and Central America. In Cowan, C.W. and P.J. Watson (eds.), *The Origins of Agriculture: An International Perspective*, pp. 143-172. Smithsonian Institution Press, Washington.

McCorriston, J. and Hole, F. (1991) The ecology of seasonal stress and the origins of agriculture in the Near East. *American Anthropologist*, 93: 46-69.

McGlone, M.S., Kershaw, A.P. and Markgraf, V. (1992) El Niño/Southern Oscillation climatic variability in Australasia and South America palaeoenvironmental records. In H.F. Diaz and V. Markgraf (eds.) *El Niño: Historical and Paleoclimatic Aspects of the Southern Oscillation,* Cambridge University Press, Cambridge, pp 435-462.

Mountain, M.-J. (1991) Landscape use and environmental management of tropical rainforest by pre-agricultural hunter-gatherers in northern Sahulland. In Bellwood, P. (ed.), *Indo-Pacific prehistory 1990*, Vol. 2, Indo-Pacific Prehistory Association, Bulletin No. 11, Canberra, pp. 54-68.

Overpeck, J.T. (1996) Warm climate surprises. *Science* 271, pp1820-1821.

Parkes, A., Teller, J.T., and Flenley, J.R. 1992. Environmental history of the Lake Vaihiria drainage basin, Tahiti, French Polynesia. *Journal of Biogeography* 19, 431-447.

Pimm, S.L., Moulton, M.P. and Justice, L.J. (1995) Bird extinctions in the central Pacific. In J.H. Lawton and R.M May (eds.), *Extinction Rates,*. Oxford University Press, Oxford , pp. 75-87.

Powell, J.M. (1976) Ethnobotany. In Paijmans, K. (ed.), *New Guinea Vegetation*, Australian National University Press, Canberra, pp. 106-183.

Robinson, S.G. (1986) The Pleistocene palaeoclimatic record of North Atlantic deep sea sediments revealed by mineral magnetic measurements. *Physics Earth Planetary International*, 42, pp 22-47.

Sandweiss, D.H., Richardson III, J.B., Reitz, E.J., Rollins, H.B. and Maasch, K.A. (1996) Geoarchaeological evidence from Peru for a 5000 years B.P. onset of El Niño. *Science* 273: 1531-1533.

Sauer, C.O. (1952) *Agricultural origins and dispersals*. The American Geographic Society, New York.

Shulmeister, J. and Lees, B. (1995) Pollen evidence from tropical Australia for the onset of an ENSO-dominated climate at c. 4000 BP. *The Holocene* 5: 10-18.

Spriggs, M. (1997) *The Island Melanesians*. Blackwell Publishers, Sydney.

Thompson, L.G., Davis, M.E. and Mosley-Thompson, E. (1994) Glacial records of global climate: a 1500-year tropical ice core record of climate. *Human Ecology* 22: 83-95.

Thompson, L.G., Mosley-Thompson, E., Davis, M.E., Lin, P.-N., Henderson, K.A., Cole-Dai, J., Bolzan, J.F. and Liu, K.-B. (1995) Late Glacial Stage and Holocene tropical ice core records from Huascar‡n, Peru. *Science* 269: 46-50.

Tiedemann, R., Sarnthein, M., and Shackleton, N.J., (1994) Astronomic timescale for the Pliocene Atlantic $\delta^{18}O$ and dust flux records of ODP Site 659. *Paleoceanography*, 9: 619-638.

Vrba, E. (1985) Early Hominids in Southern Africa: Updated observations on chronological and ecological background. In Tobias P. V. (ed.) *Hominid Evolution: Past, present and future*, pp. 324-376. New York: Alan R. Liss.

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

Wickler, S. and Spriggs, M. (1988) Pleistocene human occupation of the Solomon Islands, Melanesia. *Antiquity* 62: 703-706.

Wood, B. (1993) Rift on the Record. *Nature*, 365: 789-790.

Yen, D.E. (1982) The history of cultivated plants. In May R.J. and H. Nelson (eds.), *Melanesia : Beyond Diversity*, pp. 281-295. Research School of Pacific Studies, Australian National University, Canberra.

Yen, D.E. (1991) Domestication: the lessons from New Guinea. In Pawley, A. (ed.), *Man and a Half: Essays in Pacific anthropology and Ethnobiology in honour of Ralph Bulmer,* pp. 558-569. Polynesian Society, Aukland.