CLIMATE CHANGE AND BIODIVERSITY IN MELANESIA

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Palaeoecology and Resilience in Melanesia: How can palaeoecology contribute to climate change response planning?

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Introduction

Information about the effects of changes experienced by biomes comes from the reconstruction of past vegetation and fauna based on biological fossils supported by dating. Records of environmental change are preserved in landforms and deposits such as lake, bog and cave sediments, alluvial and colluvial mantles and glacial moraines. Such information about past communities can contribute to climate change response planning by helping to define the amount and rate of change already experienced and hence the likely ability of ecosystems and species to endure change.

Based on studies of pollen and sediments in swamps and small lakes, a considerable amount is known about the changes over the past 60,000 years or so for Melanesian environments ranging from the lowlands to the high alpine zones of New Guinea and some Melanesian island groups such as New Caledonia and Fiji. The changes in the vertebrate fauna are sparsely known from archaeological sequences and cave and swamp deposits. There are also marine records of land pollen and charcoal to supplement ocean isotope and faunal data. While pollen, and to a lesser extent vertebrate fossils, are the main proxies that have been studied in Melanesia there is scope for work on invertebrates, opaline phytoliths, diatoms, and possibly tree rings. More recently, some decadal-scale studies have been carried out on lake sediments that point to current responses by the vegetation to climatic and anthropogenic impacts (Prentice et al 2005, Haberle 2007, Haberle unpublished).

These data can be interpreted to help with the following problems:

- Extent of previous stresses and recoveries as a measure of resilience.
- Identification of refugia that have been buffered against past climate change.
- Processes of community adjustment to climatic shifts.
- Fire histories and fire tolerance for management.
- Disturbance histories and recovery.

Extent of previous stresses and recoveries as a measure of resilience

Environmental stresses associated with climate change include thermal, precipitation, and radiation (associated with changes in cloud type and coverage) changes, as well as CO_2 concentration and sea level fluctuations. These are also the changes that will occur with future climate change, although the rapidity of current warming may exceed that experienced in the past. The particular impacts are unevenly experienced in Melanesia and hence the resilience of ecosystems can be expected to vary.

Thermal change

The average decrease of temperature with altitude (lapse rate) on the best measured altitudinal transect, (Mt Jaya, Papua) transect is 5.3° C/km reflecting very humid air (Prentice and Hope 2007). In New Guinea the strong correspondence between the lapse rate and important biophysical boundaries reflects the importance of thermal controls in the ever-wet climates. Elsewhere in Melanesia other important zonations are controlled by seasonal precipitation (Hope 1996a). Megathermal lowland environments have temperatures of 25-35° C throughout the year with a low diurnal range due to the high heat capacity of saturated air. At about 1,200-1,400 m, the mesothermal zone sees a reduction in tree leaf size and evapotranspiration is reduced. Above this zone, highland climates center around 18° C but have a greater diurnal range from 10-25 °C. Very rare frost can be experienced after periods of dry weather. Above 2,800 m asl, frost becomes more frequent leading to microtherm climates and a change to subalpine forests with microphyll and nanophyll leaves. The treeline, at about 3,900-4,200 m, marks a mean annual isotherm of 6° C and the tropic alpine zone (Barry 1978, Hnatiuk, Smith and McVean 1976). Daytime temperatures can reach 20° C, but at night frosts of -2 to -5° C are common. Because humidity remains high, the much colder night-time temperatures of other tropical mountains (-20° C) do not occur (Hastenrath 1991). Due to high snowfall, permanent snow builds up at about the +1° C isotherm which occurs around 4,650 m asl. Mountain peaks above this altitude are in the nival zone, where plant life is reduced to snow algae (Kol and Peterson 1976).

Figure 1. Meltwater pools on Mt Jaya, Papua. Water temperature is ca 4° due to heating of blue-green algae on the snow.

Changes in ice area are one of the clearest expressions of climate change, but in all of Melanesia, glaciation has affected only a tiny area of the New Guinea mountains. However, the effects of past changes in temperature are also seen in changes in the altitudes and nature of vegetation boundaries at lower altitudes. During the last glacial period, extensive glaciers covered ca 2,200 km^2 above 3,400m on the high mountains across the island (Prentice et al 2005). Tropical cooling seems to have coincided with the build up of large ice caps in the northern hemisphere but recent work by Tim Barrows on Mt Giluwe suggests that the last half million years has seen gradual warming in Papua New Guinea (PNG). Certainly recent warming of an estimated 1°C has seen the loss of ice caps since 1950 on Mt Trikora and Mt Idenberg and shrinkage of the Mt Jaya ice cap from 10.7 km^2 in 1935 to less than 3 km^2 in 2000 (Prentice and Hope 2007). Vegetation response since 1960 has included shrubby regrowth above the current treeline and the development of grasslands on former moraine.

Post-glacial warming after 17,700 cal yr BP (calibrated years before present) correlates with the invasion of the newly exposed landscapes by a high altitude scrub and *Cyathea* treeferns. The invasion seems to have been at a range of altitudes suggesting the availability of a wide zone with subalpine conditions which lasted until about 12,400 years ago. After this a more diverse forest slowly invades, suggesting that further temperature rise had finally allowed subalpine forest elements such as conifers (e.g., the podocarp *Dacrycarpus compactus*) to compete. The Holocene subalpine forest is fairly stable until human-controlled fire started to remove it widely, a process that commences at various times from >7000 years ago up to the last few centuries. This clearance has provided new subalpine habitat that has allowed the herb flora to expand from treeline refugia. The same disturbance also seems to be associated with increased range restriction or extinction of some native mammals resulting from Holocene hunting and the introduction of the dog (Hope and Haberle 2006, Haberle 2007).

From a range of sites in central PNG, the montane forest-subalpine grassland boundary at the height of the glaciation seems to have been at about 2,200 m altitude. Below this, *Nothofagus*-dominated forest seems to have been very common (Hope 1996a, b, Haberle 1998, Fairbairn et al 2006). From a consideration of all montane sites it seems that the boundary of mixed oak forest and beech forest rose about 700 m at the start of the Holocene, reflecting a temperature rise of 5-6°C.

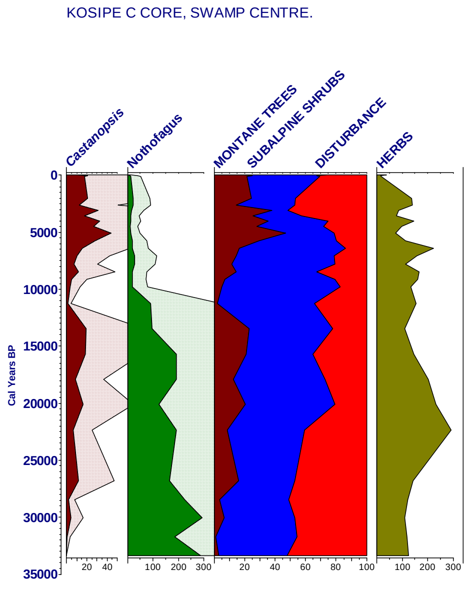

Figure 2. Beech decline around 12000 cal yr BP in SE PNG

However in southeastern New Guinea beech forest then became much less dominant (Figure 2), with retreats to patches and humid sites such as mountain ridge crests suggesting decreased cloudiness or increased seasonality, as this decline has not affected beech to the west in Papua so markedly. One interesting effect of this major shift in montane forests has been a very individualistic sorting of forest structure even on adjacent mountains, with quite different patterns of dominance despite a similar overall tree flora. The detailed composition of the forests is probably still adjusting. Frost and drought associated with recent El Niño events caused differential tree species death down to 2500 m (Brookfield 1989) suggesting that the limits for upper montane forest are adjusting not only to increased average temperature, but also to extreme events associated with increased climate variability.

Ongoing work by Simon Haberle at a range of sites below 1000 m in the ever-wet southern flank of New Guinea shows a more subdued response to thermal change across the Pleistocene-Holocene boundary. From lowland caves near Lake Ayamaru in the southern part of the Birds Head of Papua Aplin et al. (1999) record late Pleistocene faunas that include animals from higher altitude, suggesting a cooler climate and more varied vegetation within hunting range of the cave. Sea surface temperatures in Cenderawasih Bay, indicated by stable isotopes from foraminifera, show that temperatures 3–4° colder than present at 16000 yr BP (Prentice and Hope 2007). There are fluctuations of equivalent magnitude in the Holocene, suggesting rapid cooling in Cenderawasih Bay on several occasions. These changes are consistent with a vegetation record from the Cyclops Mountains where a rise in temperature of about 4°C at the end of the Pleistocene is inferred (Hope and Tulip 1994). The data extend back to Marine isotope Stage 4 and suggest that the Cyclops Mountains have been humid throughout the last glacial period and have always been well forested, indicating that the Western Pacific Warm Pool operates throughout the glacial cycle. There is an indication of renewed cooling in the early Holocene from this site.

Other Melanesian localities outside the equatorial region have limited evidence for thermal change, in concordance with marine core evidence that suggests a muted response to glacial cycles. The long core from Lake Xere Wapo in New Caledonia (220 m asl) is interpreted as showing less than 4°C change at the end of the Pleistocene, in agreement with a core from Fiji (Stevenson and Hope 2005). Nunn (2007) provides a comprehensive review of late Holocene thermal change and its effects in Melanesia (and elsewhere in the Pacific) and argues that thermal change of less than 2°C has occurred but still had significant effects. Minor sea level changes were seen as a more direct influence.

Arid-humid precipitation change

The southern lowlands of New Guinea and the Melanesian islands have a much more strongly seasonal rainfall pattern than the mountain ranges and northern New Guinea and are in some cases bounded by a shallow sea that withdrew at times of lower sea level. These areas are thought to have been drier during glacial times, based on the modern disjunction of eucalypt savanna in New Guinea (Hope and Haberle 2006) and theoretical models (e.g. Kershaw et al. 2003). There are as yet no Pleistocene lowland records from southern New Guinea, but the post-glacial migration of the rainforest boundary southwards has been identified on the Aru islands which were then part of the

New Guinea mainland (Hope and Aplin 2005). A faunal sequence starts about 20,000 yr BP and contains savanna fauna such as agile wallaby, but some rainforest elements such as possums are present in small numbers. Around 14,000 years ago the wallabies became rarer and rainforest taxa increased, suggesting that the boundary between closed forest and savanna had reached this site. It is assumed that the dry glacial period from ca 33-9000 cal yr BP identified in Northeast Queensland (estimated 30% of present rainfall) may also have occurred in Melanesia (Kershaw et al 2007). The windward side of New Caledonia has had periods of lower rainfall (Stevenson and Hope 2005) and the formation of calcretes, or hardpan, which is a hardened layer, in soils (Latham 1986) on the leeward side suggests that it also was more arid, although palaeoecological sites are lacking. Seasonality and tropical storm frequency may also have changed through time.

CO_2 Levels

A possible explanation for the relatively large depression of the limit of closed forest (ca 1800m) by comparison with the snowline depression (800-1000m) at Last Glacial Maximum (LGM) is that at high altitude woody growth was limited by low partial pressure of CO_2, adding a penalty to photosynthesis. This implies that the current CO_2 fertilisation effect will be pronounced at treeline and that rapid expansion of forest may be occurring. Observation suggests that this may be correct, but burning associated with anthropogenic forest modifications combined with El Niño events is actually removing subalpine forest on most mountains. In dry conditions mangrove forest may also be limited by CO_2 so some expansion of mangroves onto seasonal salt flats is possible. This effect will be dwarfed by sea level rise.

Sea level change

Changing sea levels have influenced climate as well as directly affecting available habitat and connectivity of lowland biota. In particular, the flooding of Arafura / Torres Strait and exposed barrier reefs correlates with increased coastal humidity and rainfall in southern New Guinea (Hope and Aplin 2005). All the coasts of Melanesia have changed with the rise of the sea after the LGM until it reached present levels around 6,000 years ago, a process that may have been very rapid at times (de Menocal et al 2000). The changes also broke up larger islands as in Fiji and increased the length of coastline. On some coasts the early open coastline is gradually cut off as coral growth creates reefs that slow down the wave energy, creating lagoons. The sediment yield may have risen due to increased rainfall and coastal erosion and together with the rapid growth of coral some of the area lost to sea level rise has been reclaimed. Where rivers discharge, land has built out onto the shelf for some kilometres creating freshwater swamp and lacustrine environments that have greatly expanded in the last 5,000 years or so.

Nunn (2007) has recently documented evidence for an abrupt fall in Pacific sea levels coincident with the “Little Ice Age” global cooling from 700-500 cal yr BP. He attributes loss of coral habitat and a contemporary increase in mangrove areas in shallowing bays to a “1500 AD event” which he claims caused increased erosion on land and deposition of sediment along coast lines. Current predictions of sea level rise due to warming and glacial melting will reverse successions such as that of the open sea-estuarine / lagoon and freshwater lake and swamp forest sequences by the saline flooding of large freshwater and tidal-influenced coastal flats. The effect will mirror that seen on the sinking coastline of southern Papua where mangroves, having been gradually replaced by swamp forest, have reinvaded within the past 1000 years (Ellison 2005). On the positive side rising seas can rejuvenate coral reef flats that have become emergent due to a fall in sea level.

Fire histories and fire tolerance for management

Charcoal studies (e.g. Haberle et al 2001, Kershaw et al 2002) suggest that fire has had a limited role in the wettest Melanesian areas prior to human arrival. The role of “natural” fire is probably tied to extreme climate events. Figure 4 (Hope, unpublished) shows charcoal concentrations from swamps from several Melanesian islands which were settled during the Lapita expansion around 3000 years ago. The expansion of fire after human settlement is also correlated with an expansion of dry forest and scrubs in the late Holocene with increased sediment yields postulated in Fiji (Nunn 2007). Likewise, the northward expansion of savanna over rainforest has occurred in New Guinea due to anthropogenic burning, possibly amplified by ENSO events. It is likely that continued anthropogenic modifications / burning, combined with increased climate variability, will enhance the potential for further northward shifts in the savanna-rainforest boundary in southern New Guinea.

At high altitudes fire has expanded subalpine habitat as well, providing ecological opportunities for some above-treeline taxa such as copper ringtail possums. Fire has been shown to be most damaging during El Niño-related drought (Ballard 2000). This has rewarded some generalists such as tree ferns and cycads that can survive low intensity fire (Figure 3).

Figure 3. Secondary vegetation at 3250m on Mt Wilhelm, PNG. This has developed from forest in the last few centuries.

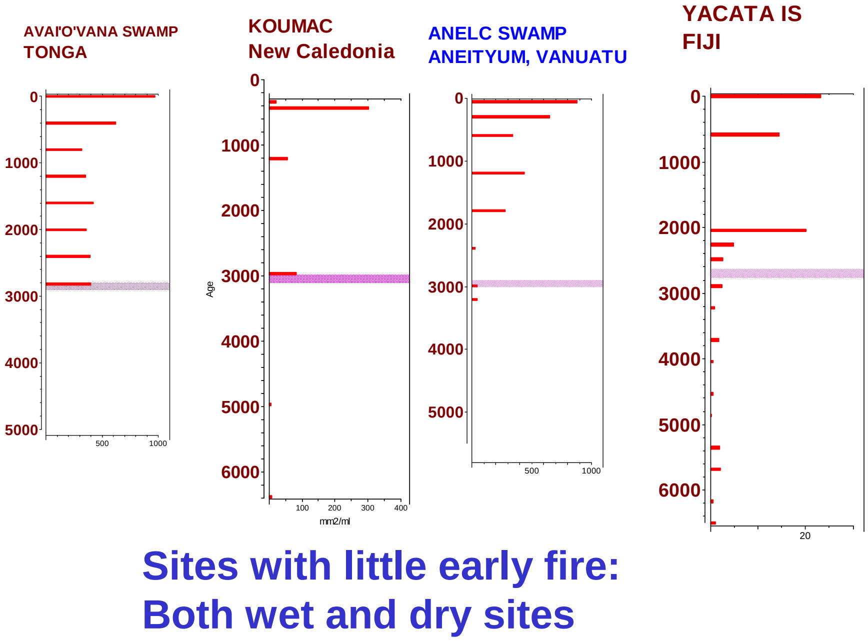

Figure 4. Charcoal concentration graphs from selected Melanesian islands. The cross hatched line indicates the earliest Lapita settlement. Some sites have a pre-human fire record.

Discussion

The Pleistocene-Holocene transition in Melanesia is quite dramatic and provides some reassurance that terrestrial biota have some measure of resilience to withstand or avoid substantial impacts on biodiversity resulting from future warming, precipitation, and sea level changes. It is important to note that although ecosystem resilience has been an important element in past environmental changes, the extent to which it can continue to operate in the future depends largely on the degree to which habitats and the ecosystem services they provide remain relatively healthy and intact.

Past environmental change has been most dramatic at the savanna-rainforest boundary and subalpine-alpine zone. While advances by savanna can be accommodated by rainforests, the alpine zone is very restricted and habitat for obligates such as the fern *Papuapteris linearis* and for successional communities on moraines may disappear.

Refugia that have been buffered against past climate change include the mountain flanks of New Guinea and the windward sides of the Melanesian islands. These have been climatically stable because orographic rain and clouds moderate temperature extremes and because these sites are less sensitive to ENSO variations. While New Guinea historically has been large enough to preserve large tracts of forest, many Melanesian islands have been stressed by human impact through burning of their seasonally dry areas. Because non-coastal lowland forest regions have for the most part not had large direct climate stresses, the ecological resilience of lowland New Guinea may be negatively impacted by significant forest modification or clearance. More specialised habitats, e.g. riparian and reef will also have lower resilience in the face of direct anthropogenic disturbance (overfishing, sedimentation, habitat destruction) as well as other environmental changes such as ocean acidification.

Palaeoecological research can thus provide baseline information on threatened plant and animal communities and the sensitivity to change of some of their individual species. It can contribute to vulnerability mapping and to planning for the maintenance or restoration of habitat connectivity. In specific cases it can provide a basis for attempts to reconstruct lost communities from completely altered island habitats. In the future high resolution studies of pollen, diatoms and geochemical proxies that link the Little Ice Age responses with current trends can provide a monitor of the on-ground effect of climate change.

Figure 5. Core sampling at Kosipe swamp 100km north of Port Moresby in Papua New Guinea.

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