

CHAPTER 9

HOLOCENE VEGETATION AND ENVIRONMENTAL CHANGE IN THE
MARKHAM VALLEY AND OTHER TROPICAL REGIONS

Palynological and stratigraphic evidence from the two lake sites studied reveals significant changes in both vegetation and sedimentary regime during the Holocene period.

Organic accumulation at the margin of the north-east bay of Lake Wanum commenced at about 9600 BP. The subsequent development of swamp vegetation in this area is interpreted as showing a general increase in water depth throughout the course of the Holocene. At Yanamugi, encroachment of swamp vegetation has taken place within the last few hundred years. The pollen sequence of dry-land taxa from Lake Wanum records the increasing influence of non-forest and grassland vegetation from about 8500 BP. Synchronous influx to the sediments of carbonised particles suggests that fire may play a role in the establishment or maintenance of such vegetation. Non-forest and grassland pollen taxa are present throughout the much younger deposits of Yanamugi.

DETERMINANTS OF ENVIRONMENTAL AND VEGETATIONAL CHANGE

It is apparent that most of these changes cannot have occurred under static environmental conditions. The evidence in favour of specific determinants of environmental changes is largely circumstantial, it being particularly difficult to discriminate between local causes and those of more widespread significance on the basis of the record of a single site. Only the pollen record from Lake Wanum core LW II covers the period from 9500 BP to c. 1500 BP. The poorly known chronology of the deposits at Yanamugi hinders correlation for the period when both sites preserve a pollen

record. Although the most recent 250 years is the best dated section at Yanamugi, no comparable pollen record exists for this time from Lake Wanum.

Environmental factors likely to produce vegetational changes fall into three major groups: geomorphic and hydrologic, climatic and anthropogenic. These determinants are almost never discrete, but impinge on each other in complex interaction. The positive identification of a single cause for any event is thus almost impossible. Probable determinants and their influence may, however, be evaluated in relation to evidence from the Markham Valley and other areas of New Guinea and tropical Australia.

Geomorphology and hydrology

Regional geological events, such as seismicity, or sea level fluctuation may influence local hydrology and thus lacustrine sedimentation. The study area is known to be tectonically active, the southern side of the Markham Valley less so than the Saruwaged Ranges to the north. Chappell (1973) has suggested that lakes and swamps in the vicinity of Lake Wanum may be fault impounded, but the extent of any movement during the Holocene remains speculative.

Of more direct impact on the sedimentation is the behaviour of local watercourses. At both Lake Wanum and Yanamugi influx of allochthonous grey clay is attributed, at least in part, to fluvial activity. Oomsis Creek directly affects the sedimentary regime of the southern and central sections of Lake Wanum. Given a lower water level, this influence may have extended to the northern margin of the basin also. Alluvial sediment is considered to be partially responsible for impounding of swamps and lakes adjoining the creek. At Yanamugi, an unidentified source, possibly Sina

Creek, appears to contribute to the influx of pollen, spores, and perhaps other detritus, from higher elevations into the lake. It thus becomes important to explore the causes and effects of probable changes in the morphology of these streams in relation to the sedimentary history of the two sites.

The post-glacial sea level rise is likely to have affected the drainage of the lower Markham area. At the last glacial maximum (*c.* 18 000 BP) the oceans surrounding the New Guinea region lay perhaps 140 m to 150 below their present level (Chappell, 1976). Due to isostatic effects, the lesser figure appears more applicable to areas such as the Huon Gulf that lack a broad submarine shelf. Subsequent rise in sea level is thought (Chappell and Thom, 1977) to follow a trend between that reconstructed for south-east Australia (Thom and Chappell, 1975) and for Micronesia (Bloom, 1970). The exact course in relation to any specific coast is modified by local tectonic movement as well as global isostatic and glacio-eustatic effects. Chappell (1976) estimates the regional eustatic sea level to be 40 m to 50 m below present at 10 000 BP. The smoothed sea level curve for south-east Australia (Chappell and Thom, 1977) shows a fairly constant rate of rise to about -18 m at 8500 BP. The rate then slows slightly until 7500 BP when sea level stood at about -10 m, the present level being reached by 6000 BP. Data from north-western Australia (Jennings, 1975) also suggest sea level to be within a few metres of its present position by 7400 BP to 6000 BP. In the oceanic islands of Micronesia sea level stood at around -5 m at 6000 BP slowly rising to the current level within the last few millennia (Bloom, 1970). The course of sea level relative to the Huon Gulf coast may parallel these estimates, although the local tectonic component is uncertain.

Rivers such as the Sepik, with steep offshore submarine contours and slight gradients, have been most affected by the rising sea level (Löffler, 1977). The Markham also has a nearshore submarine canyon although the river's gradient is relatively steep. The rapid rate of alluvial deposition in the valley may have prevented any substantial marine transgression. Aggradation of the river profile may have kept pace with the up to 20 mm yr^{-1} rise in sea level. Such aggradation would also have influenced the tributaries of the lower Markham, particularly those to the south of the valley where river gradients are less steep, such as the Wampit and Watut rivers. Oomsis Creek, a tributary of the Wampit River, may also have aggraded along its lower course and disrupted the drainage of the Lake Wanum basin. Initiation of organic accumulation in the basin occurred by 9600 BP against the background of a rapidly rising sea level. The rise in the water level of Lake Wanum between 9500 and about 7000 BP followed by a fairly static period until 5500 BP also parallels the trend of sea level. However, the most rapid increases in lake level, seen after this date, require an alternative explanation.

Geomorphic changes of a local nature include such phenomena as stream meandering, landslips, and floods. No major change in the course of Oomsis Creek is envisaged, as its valley is largely circumscribed by the topography of the surrounding granodiorite hills. The suspected fluvial influx at Yanamugi may, however, be due to changes in local hydrology. The channel of Sina Creek runs along the southern margin of the Markham floodplain and may be susceptible to the influence of movements in the major river. As the hydrology of the area is poorly known, this hypothesis is purely speculative.

Climatic change

The record of the earliest sediments at Lake Wanum coincides with the final phases of the global post-glacial amelioration of climate. Proxy data based on the evidence of glacial geomorphology and pollen analysis in the New Guinea highlands (reviewed by Bowler *et al.*, 1976) and the thermal implications of past marine planktonic assemblages (CLIMAP project members, 1976) provide a basis for reconstruction of the regional climate. Ambiguity exists in the interpretation of these data, although the major trends appear well defined.

Considerable refrigeration was experienced in the New Guinea highlands during the last glacial maximum, not only in the ice covered mountains above 3 400 m or 3 650 m, but as low as Sirunki (alt. 2 500 m). Lowering of the snow-line by 900 m to 1 200 m implies a mean annual temperature at least 6 °C lower than today, whilst pollen analytical data from Mt. Wilhelm and Sirunki suggest a temperature reduction at 17 000 BP of between 7 °C and 10 °C (Bowler *et al.*, 1976).

The refrigeration at sea level is likely to have been less dramatic. Nix and Kalma (1972) consider that the lapse rate of the drier, cooler air may have attenuated the temperature reduction to -3 °C or -4 °C. The CLIMAP reconstruction for 18 000 BP proposes a sea-surface temperature (SST) of 26 °C for the area, only 2 °C lower than present. Webster and Streten (1978) argue that the widely different temperature estimates from the marine and highland data are incompatible with even the most extreme probable lapse rates. If the highlands data are correct, these authors argue, then the SST of the western Pacific should be some 5 °C cooler than the CLIMAP estimate. The difference would be less if the reduction in freezing levels in the highlands were accomplished,

in part, by increased equatorward incursions of cold air from higher latitudes. However, this effect is considered unlikely to account for the demonstrated depression of the tree-line to below 2 500 m.

By 10 000 BP to 9000 BP, temperatures in the highlands ameliorated to within -1°C to -2.5°C below present (Bowler *et al.*, 1976). Temperature fluctuations later in the Holocene are likely to have been slight. Webster and Streten (1978) consider a 'hypsithermal' interval (*sensu* Deevey and Flint, 1957) to be 'well defined' by the palynological data from the New Guinea highlands and estimate temperature between 7000 BP and 4000 BP at between 1°C and 1.5°C higher than present. The pollen analytical evidence for such a thermal maximum comes from two areas. A number of organic deposits, some with discontinuous pollen records, have been studied from Mt. Carstensz, Irian Jaya by Hope and Peterson (1976) who consider too little to be yet known to infer temperature change over the period 10 000 BP to 3500 BP. Better understood are the pollen records of four sites on Mt. Wilhelm (Hope, 1976a). Here the period from about 8600 BP to 5000 BP is characterised by the highest extension of the tree-line, and the greatest development of forest and alpine shrubland seen in the post-glacial sequence. However, no substantial change in vegetation is observed during this period at the lowest altitude site on Mt. Wilhelm, Komanimambuno Mire, (2 740 m) or at Sirunki (Bowler *et al.*, 1976). The most cautious appraisal of high altitude vegetational evidence in favour of mid- and late-Holocene temperature fluctuations is thus required. As Hope (1976a) concludes,

'although climates probably induced changes in vegetation distribution until 8 500 yr BP the minor changes since that time are as likely to be due to human activity or other ecological factors as to climate, even though climatic change is known to have occurred.'

Thus, although the first millennium of sediment accumulation at Lake Wanum coincides with the final phase of climatic amelioration, the mean temperature at sea level is unlikely to have been significantly below that of today. Even allowing extrapolation at the current Lae lapse rate from the most extreme highland temperature estimates the decrease would be less than 1 °C in the lowlands at 10 000 BP. Minor thermal fluctuations since 8500 BP may be demonstrable in some montane areas, however their effect on lowland mean temperatures was probably negligible.

Palaeoclimatic inferences from New Guinea highlands data are usually couched in terms of thermal change, as temperature is the main control on vegetation in the highlands where rainfall is not usually limiting. As demonstrated, temperature fluctuations in the lowlands, especially during the Holocene, are likely to have been less intense than at higher altitudes. However, regional climatic change is also expressed by variation in both actual and effective precipitation. These effects are most likely to have been felt in areas, such as the Markham Valley, that now experience relatively low rainfall.

A theoretical reconstruction of the Australasian climate at the last glacial maximum (Nix and Kalma, 1972) suggests reduced precipitation due to the lesser area of warm oceanic-shelf water and lower SST. With rising temperatures from 14 000 BP, evaporation increases and dry conditions become accentuated. After the major sea level rise, but before Torres Strait flooded, temperature and rainfall higher than present are hypothesised, although evaporation remains similar to that of today. Nix and Kalma (1972) date this phase at 8000 BP, although using the data of Chappell and Thom (1977) their suggested sea level for this phase (-30 m) would reflect conditions closer to 9000 BP.

The rainfall component at least of this reconstruction is supported by pollen analytic and stratigraphic evidence from the Atherton Tableland, north-east Queensland (Kershaw, 1975). The progressive onset of organic accumulation at three sites (Bromfield Swamp, Lake Euramoo, and Quincan Crater) indicates increase in available moisture over the period from about 11 000 BP to 7000 BP. A change from sclerophyll vegetation to rainforest is recorded at these sites and in the deposits from Lynch's Crater (Kershaw, 1976) occurring across the tableland between 9500 BP and 6000 BP. The sequence of initiation of swamp conditions and transition to rainforest appears related to a precipitation threshold that parallels the present rainfall gradient across the area. Only the most humid site today (Lynch's Crater) shows organic accumulation during the late Pleistocene.

In view of these data it may be admissible to formulate a conservative climatic interpretation of sedimentological and ecological changes at Lake Wanum. Ignoring for the moment the effects of basin morphometry and swamp vegetation on absolute water level and evaporation, postulated fluctuations in water depth (Fig. 8.4) may be viewed as a response to climatic factors.

The onset of organic accumulation at 9600 BP in the north-east bay may reflect a climate favourable for the initiation of swamp conditions. It appears that only a slight excess of moisture was available until 8500 BP or 8200 BP, when permanent standing water may have become first established. This sequence suggests the possibility of an absolute increase in rainfall, especially so if temperatures were at all reduced during the beginning of the Holocene.

Since about 8200 BP a positive water balance has been maintained. The effective water depth apparently remained fairly static from about 8000 BP until a substantial rise at around 5000 BP. An increase in precipitation at this time cannot be ruled out, but is considered unlikely, unless the final flooding of Torres Strait produced an effect on the climate greater than is generally assumed. At Yanamugi, encroachment of swamp vegetation within the last few centuries is interpreted as due to increased local sedimentation, rather than a drop in the water level of the lake.

In contrast to the reconstructed swamp environment, the dry-land vegetation of Lake Wanum reveals no suggestion of climatic fluctuation. Even a 1 °C reduction in temperature for the basal sections of the pollen sequence might be reflected by increased representation by forest taxa, such as perhaps *Lithocarpus*, found 150 m above the site today. The increasing influence of non-forest and grassland vegetation in the pollen sequence and the evidence for fire frequency, if having any climatic significance, might suggest relative aridity or at least seasonality. Such an interpretation would run contrary to the evidence of the water depth record, were the latter climatically determined.

Thus the tentative climatic implications of evidence from Lake Wanum parallel those from the Atherton Tableland sites in identifying an increase in effective precipitation from at least 9600 BP to perhaps 8000 BP. However, no significant decrease in the effective precipitation is recorded at either Markham Valley site within the last few millennia, contrary to the suggestion by Kershaw (1974) for Lynch's Crater. Apart from the evidence of early Holocene aridity, climatic inferences from Lake Wanum are ambiguous.

Human impact

Man's occupation of the greater Australian region probably dates to at least 50 000 BP (White and O'Connell, 1979). The most ancient reliable evidence of human presence is a 33 000 BP radiocarbon date from the Mungo lunette, south-western New South Wales (Bowler *et al.*, 1972). The first indication of man in New Guinea comes from Kosipe swamp, at 2 000 m in the Owen Stanley Ranges, and is dated at 26 000 years ago (White *et al.*, 1970). Continent-wide occupation is shown by a number of sites within the period 20 000 BP to 30 000 BP (White and O'Connell, 1979).

The first evidence for agriculture in New Guinea is found at Kuk swamp (alt. 1 550 m) in the upper Wahgi Valley of the Western Highlands. Here phases of cultivation are implied by a series of artificial channels, presumably created for the purpose of water control. The oldest are dated (Golson, 1977a) at *c.* 9000 BP ('Phase 1') and 6000 BP to 5500 BP ('Phase 2'). Both agricultural episodes are short-lived and evidence for an intensive drainage system and prolonged use of the site is not found until 4000 BP. Pollen analysed sequences are available from two swamps in this area: Manton's (alt. 1 590 m) across the Wahgi Valley and Draepi, situated at 1 890 m at the base of Mt. Hagen (Powell *et al.*, 1975). Both indicate substantial forest clearance by 5200 BP, although this represents a minimum date as deposits of preceding millennia are absent.

Pollen analyses from contemporaneous deposits at higher elevations are less equivocal in showing human influence on the vegetation. These sites undoubtedly lie well above the altitudinal limit of extensive cultivation prior to the introduction of the sweet potato. Vegetation disturbance may account for the expansion

of forest ephemerals, and non-forest shrubs, herbs and grasses around Sirunki (2 500 m) from 4500 BP (Walker, 1970). Circumstantial evidence for human activity at even higher altitudes on the Saruwaged Plateau is given by Costin *et al.* (1977). Fossil leaf remains from Lake Mamsim (3 500 m) indicate local presence at 5700 BP of podocarp forest now found 500 m below the site. Human activity is invoked as the most probable cause of the subsequent deforestation, although minor climatic deterioration is also suggested.

Evidence for intensified forest clearance and cultivation is recorded at sites above 2 500 m within the last 1000 to 1500 years and particularly from about 300 BP (Hope, 1976a) possibly in response to the introduction of the sweet potato (*Ipomoea batatas*) into the New Guinea highlands by the later date.

The dry-land pollen record of both Markham Valley sites is strongly suggestive of human impact on the vegetation, even though there is no clear indication of reduced forest area. Whilst it is not permissible to equate increased PDR of certain non-forest taxa with a decrease in the forest cover, qualitative changes suggest that grassland has become more predominant during the upper Holocene. Corroborative, if circumstantial, evidence is provided by the record of carbonised particles that correlates closely with that of certain non-forest pollen taxa.

The first indication of, possibly anthropogenic, disturbance of the vegetation at Lake Wanum is seen between 8550 BP and 7850 BP in increased values for woody non-forest pollen taxa and influx of carbonised fragments. The occurrence of natural fires must be considered, although this period is supposed to be more humid than the preceding millennium, during which time no such

evidence is found. The second phase of vegetation disturbance, from 6950 BP to 6100 BP, is fairly similar in character to the earlier. From about 5350 BP, the dry-land pollen assemblages from Lake Wanum become dominated by woody non-forest and grassland taxa. A slight recovery of forest pollen taxa occurs from 3600 BP until 2300 BP, when a renewed phase of vegetation disturbance, continuing to the present day, is initiated. The dry-land pollen record of Yanamugi indicates presence of non-forest and grassland vegetation throughout the 1500 to 2000 year history of the sequence. Notably absent from either site is any indication of intensified agricultural activity several hundred years ago, such as is recorded in higher altitude sites. This period is, however, hardly represented in the Lake Wanum core LW II, although it is one of the better dated periods in Yanamugi's sedimentary history. It is unlikely that the introduction of the sweet potato had as great an effect on lowland agriculture, where it is not the staple crop today, as it did on the ceiling of cultivation in the highlands.

There is no clear evidence at either site for direct human impact on swamp vegetation. At Yanamugi it is possible that the sequence of clay and macrophytic detritus from 469 cm to 578 cm in core YAN 2 may reflect exploitation of the sago swamp, although this resource is not utilised today. Phases of considerable clay influx are recorded in the stratigraphy of both sites, some perhaps reflecting man-induced erosional events. A major clay band deposited between 6500 BP and 5000 BP at Lake Wanum overlaps two phases of suggested vegetation disturbance. It also precedes an increase in water level and diversification of the herbaceous swamp vegetation. It is possible to speculate that this horizon might reflect the erosional consequence of man's activity either in the lake basin, or

in the catchment of Oomsis Creek. A similar hypothesis, of indirect human impact on local hydrology, is proposed by Powell *et al.* (1975) to account for the initiation of organic accumulation at the Manton site and to explain clay deposition at nearby Draepi swamp. Later disturbance phases at Lake Wanum possibly associated with clearance activity appear synchronous with narrow clay bands, but as discussed in Chapter 8, no general correlation exists.

The interpretation of the pollen records of the Markham Valley sites as reflecting a substantial degree of human influence on the dry-land vegetation accords with the available palynological and archaeological evidence from the New Guinea highlands. With the proposal of complex agriculture at Kuk 9000 years ago (Golson, 1977b), the lack of unequivocal evidence for forest clearance at mid-altitude (1 500 m to 2 000 m) sites prior to 5000 BP appears due only to the absence of deposits suitable for analysis.

The most convincing evidence for vegetation disturbance and firing at Lake Wanum dates from 5350 BP although two distinct phases of increase in woody non-forest pollen taxa occur earlier in the sequence. Accepting the inference of human involvement, the episode commencing at 8550 BP represents the earliest pollen analytical evidence for vegetation clearance in New Guinea, although it is younger than the 'Phase 1' drainage channels at Kuk. In view of the suggested antiquity of highlands agriculture it is quite probable that cultivation in the lowlands pre-dates the base of the Lake Wanum core LW II (*c.* 9500 BP).

DETERMINANTS OF ENVIRONMENTAL AND VEGETATIONAL CHANGE IN THE MARKHAM VALLEY DURING THE HOLOCENE

With only one stratigraphic sequence spanning most of the Holocene period, the identification of regional changes and their causes is highly tentative and will undoubtedly be modified by future work.

The onset of swamp conditions in the north-east bay of Lake Wanum was probably facilitated by an increase in absolute precipitation during the period from 9600 BP to about 8000 BP. Increased humidity may reflect the progressive flooding of the Arafura Sea but is thought more likely due to more widespread changes concomitant with the global post-glacial climatic amelioration. The air masses of either the 'south-east' or 'north-west' circulations could have become more moist as increased rainfall from both would affect the Lake Wanum area. Local changes in hydrology as an indirect consequence of the rapidly rising sea level may also have had an influence on the water level of Lake Wanum during this period.

It is difficult to interpret the considerable increase in effective water depth in Lake Wanum subsequent to 8000 BP as a response to variation in precipitation. A period of clay influx from 6500 BP to 5000 BP may be associated with drainage disruption and an increase in the water depth of the lake. The clay deposition may result from local geomorphic change or might even have been triggered by man-induced erosion. A possibly analogous phase of clay influx at Yanamugi in more recent times may be anthropogenically caused, although again, natural hydrologic factors cannot be excluded.

No substantial desiccation is seen within the last 8000 years, although such an event would be recorded at Lake Wanum only if very severe. None of the palaeoecological evidence requires thermal change for its interpretation. If, as suggested by data from the New Guinea highlands, the mean temperature was lower during the early Holocene, this had a minimal effect on conditions at sea level.

Whilst the determinants of lake levels remain ambiguous, human impact can be identified as the major cause of changes in dry-land vegetation.

A Holocene vegetation history of the Markham region may be outlined thus. The altitudinal depression of montane vegetation associations influenced the lowland vegetation little, or at least, by 9000 BP, its effect was no longer felt. 'Alluvium' forest may have been more widespread in the vicinity of Lake Wanum during the early Holocene. Nix and Kalma (1972) postulate the Markham area to be too arid to support closed forest during the period 17 000 BP to 14 000 BP. It is suggested here that relative aridity was possibly maintained over much of the valley until about 8500 BP or 8200 BP. Taking into account the active geomorphic nature and poor soils of the valley floor it seems unlikely, therefore, that closed forest was much more widespread than present over the central valley prior to c. 8000 BP. Increased representation of 'alluvium' forest in the pollen record between 8000 BP and 6500 BP may reflect local conditions to the south of Lake Wanum, or of the lower Markham Valley. Although by perhaps 8000 BP the onset of more humid conditions is indicated, increasing human impact on the vegetation from this date may have contained the expansion of closed forest in the valley floor. Much of this area may have been occupied by

non-forest or open forest vegetation although, initially, open grassland was probably less widespread than today.

In contrast to the valley floor, the vegetation of the now grassed areas of the foothill slopes is likely to have resulted primarily from human activity. Rainfall is higher around the valley margin and soils are generally better developed and not susceptible to the unstable conditions of the valley floor. It is nonetheless notable that the larger tracts of grassland have developed on the thinner soils of the granodiorite and limestone areas. If the Lake Wanum area be typical of the valley margin, forest clearance may have started by 8500 BP, with a resulting expansion in grassland area. A pattern of vegetation distribution fairly similar to that found today had probably become established by 1500 to 2000 years ago.

LATE QUATERNARY ENVIRONMENTS OF THE TROPICAL LOWLANDS

Pan-continental correlations based on meagre and ambiguous data almost invariably prove in error. Bearing in mind Livingstone's admonition to 'beware of facile explanations not supported by evidence' (Livingstone, 1975) some wider implications of the present study may be sought by comparison with other tropical lowland areas.

The last glacial maximum is now generally considered a period of relative aridity in many tropical and sub-tropical areas (Rognon and Williams, 1977, Bowler, 1977). From about 11 000 BP to 8500 BP lake levels and vegetation in many regions reflect a change from arid to relatively humid conditions.

Morley (1976) reports the onset of organic accumulation at Danau Padang (alt. 950 m), Kerinci, Sumatra by 9800 BP. A transition from forest of an upper-montane to lower- or sub-montane affinity between 8600 BP and 8300 BP is interpreted as a response to a general increase in mean temperatures.

The considerable evidence for lake level fluctuations in Africa is summarised by Butzer *et al.* (1972) and Rognon and Williams (1977), whilst the course of climatic change is assessed by Livingstone (1975). A large number of dated sites, predominantly in east Africa, suggest progressively increasing humidity, particularly in the equatorial areas, from 12 000 BP to perhaps 7000 BP. The most informative sequence comes from Lake Victoria, on the equator at an altitude of 1 134 m. The lake level stood at 75 m below present 14 000 years ago (Livingstone, 1975). Kendall (1969) shows that the basin remained closed until 12 000 BP, indicating a climate drier than has prevailed since. From this date water level rises, although with a slight reversal at around 10 000 BP. Pollen analysis reveals a change from savanna vegetation to evergreen forest over the same period, the forest reaching its maximum extent by 8000 BP.

In Central America the onset of accumulation at the available lake sites is influenced either directly by rising sea-level, such as in the Gatun Basin of Panama (Bartlett and Barghoorn, 1973) or indirectly by the rising water-table as in the limestone area of the Yucatan peninsula (Deevey, 1978). Sedimentation in the Gatun Basin began around 11 300 BP, following an unconformity of over 20 000 years. Bartlett and Barghoorn (1973) interpret the pollen sequence from these sediments as indicating a temperature

reduction of 2.5 °C at this time, ameliorating to the present temperature by 8500 BP to 7300 BP.

The Lago de Valencia in Venezuela was essentially dry and surrounded by semi-arid vegetation from the base of a 13 000 year old sediment core until about 11 000 BP (Leyden and Whitehead, 1979). Between 9500 BP and 8500 BP the lake achieved its maximum Holocene level, and the modern pollen flora became established. Wijmstra and van der Hammen (1966) investigated lake deposits in present savanna areas of Guyana. Lake Moriru (alt. 110 m) in the Rupununi savanna records a change from mixed savanna woodland, dry-forest and open savanna to a less open vegetation of closed dry-forest or savanna woodland. The authors place this transition at about 10 000 BP, although only two younger radiocarbon dates support the chronology. Subsequent increase in open savanna vegetation dates from perhaps 7500 BP.

The last glacial maximum was arid not only in the continental tropical lowlands. The Galapagos islands, on the equator in the eastern Pacific, were also drier. A core from El Junco lake at c. 700 m on San Cristobal island (Colinvaux and Schofield, 1976a,b) spans over 48 000 years. Only the sediments of the last 10 000 years are lacustrine, the underlying strata having been deposited in an arid climate. The pollen record of the upper core (Colinvaux and Schofield, 1976a) shows the present vegetation to have become established early in the Holocene, with only minor change since that time.

No general synthesis of climatic fluctuations is possible for the latter part of the Holocene. It is clear that in most tropical lowland regions any such effects are expressed in terms of rainfall, rather than temperature. The influence of most changes

has been minor, compared to the events of the early Holocene. In many regions it becomes impossible to isolate the effects of minor climatic fluctuation from those of the progressively insistent human modification of the natural vegetation.

In Sumatra, Morley (1976) recognises two phases of vegetation disturbance. The first, interpreted as showing forest clearance, occurs between 4000 BP and 2500 BP, and is reflected by increase in the proportions of *Macaranga* and *Trema* pollen in the sediments. From 2500 BP until the present, higher frequencies of pollen of *Trema* and grasses apparently reflect sedentary agriculture.

Reduction in the PDR of forest trees in the pollen diagram from Lake Victoria is seen within the last 3000 to 3500 years, and may be attributed to human activity (Kendall, 1969).

Agriculture is well established by 3000 BP in the Yucatan lowlands, and forest clearance may date to 5000 BP (Deevey, 1978). Bartlett and Barghoorn (1973) identify maize pollen from sediments from the Gatun Basin dated at 6230 BP to 7300 BP, and increasing frequency of herb pollen and almost total disappearance of tree pollen is recorded within the last few millennia. Extension of the already extant Rupununi Savanna within the last 3000 years is attributed by Wijmstra and van der Hammen (1966) to man's activities.

Thus, the interpretation of the palaeoecological evidence from the Markham Valley accords, in broad detail with evidence from other tropical lowland or lower montane regions. Relative aridity during the late glacial period appears almost universal although the timing and regional expression of the early Holocene increase in humidity varies considerably. Many pollen records show the influence of human impact on the vegetation dating from 4000 BP or 5000

BP. At Lake Wanum, such effects appear well established by this date. Particularly interesting is comparison with the evidence from Sumatra (Morley, 1976). The palynological expression of human activity is very similar at Danau Padang and the Markham Valley sites. Man's destructive effect is however recorded at a much earlier date in Papua New Guinea lowlands.

In conclusion, the vegetation pattern of the Markham Valley has demonstrably not remained static during the Holocene. Both natural and anthropogenic environmental changes have been met by the ecological response of the plant communities.

PROSPECT

Despite its limitations the pollen analytical method is one of the most informative sources of evidence for vegetational and environmental change in the tropical lowlands. The expression of pollen occurrence in terms of annual depositional rates circumvents many of the inherent problems of dealing with the diverse pollen flora although calculation of such estimates requires a sound, independently derived, chronology that many sites cannot provide. Due to the relatively local nature of pollen deposition, no single site is likely to produce a vegetational history applicable to a wide area. Prospective palaeoecological study sites must therefore be chosen with specific aims in mind. It appears that lowland sites in New Guinea currently experiencing less than perhaps 1 800 mm rainfall per annum did not accumulate organic sediment during the late Pleistocene and early Holocene. Fuller Quaternary sequences undoubtedly exist in wetter or more elevated areas. Sites at altitudes of 800 m to 1 200 m may better reflect post-glacial thermal fluctuations, In addition areas less disturbed by man remain to be investigated.

This study thus barely scratches the surface of the polliniferous mud. Palynology's contribution to our comprehension of the complex tropical lowland rainforest ecosystem has hardly begun.