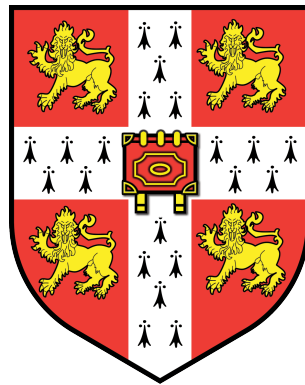


# **Human-rainforest interactions in Island Southeast Asia: Holocene vegetation history in Sarawak (Malaysian Borneo) and Palawan (western Philippines)**



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*This dissertation is submitted for the degree of Doctor of Philosophy*





*Dedicated to Henry Lagang*



## **Preface and acknowledgements**

### **Declaration**

This dissertation is the result of my own work and includes nothing which is the outcome of work done in collaboration except as declared in this Preface and specified in the text.

This dissertation is not substantially the same as any that I have submitted, or, is being concurrently submitted for a degree or diploma or other qualification at the University of Cambridge or any other University or similar institution except as declared in this Preface and specified in the text. I further state that no substantial part of my dissertation has already been submitted, or, is being concurrently submitted for any such degree, diploma or other qualification at the University of Cambridge or any other University or similar institution except as declared in this Preface and specified in the text.

This dissertation does not exceed the prescribed limit of 80,000 words for the Degree Committee of the Department of Archaeology and Anthropology within the Faculty of Human, Social, and Political Science.

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## **Usage**

### ***Latin nomenclature***

Botanical Latin names appear throughout this dissertation. Genus names and specific epithets are italicised; the initial letter of a given genus name is capitalised. The initial letter of a given plant family name is capitalised but not italicised. In pollen diagrams, plant family names that refer to pollen types which have been identified to family-level are written in ALL CAPS so as to signal coarse taxonomic resolution. The first time within a given section of text that a binomial is used, it is given as: [*Genus*] [*species*] [Authority Abbr.], [Family]. For example: *Macaranga tanarius* (L.) Müll.Arg., Euphorbiaceae. Within sentences that contain a list of Latin binomials, plant family names are placed in brackets so as to limit potentially confusing comma usage. Subsequent occurrences within a section are given as: [*G.*] [*species*]. Latin names of individual taxa that were

identified in the field to genus-level are given as: [*Genus*] sp.; similarly, Latin names of multiple congeneric taxa that were identified in the field to genus-level are given as a single entry as: [*Genus*] spp. Nomenclature and taxonomic placement of all plant taxa referred to in the text follow The Plant List (<http://www.theplantlist.org/>) and the Angiosperm Phylogeny Website ([www.mobot.org/MOBOT/research/APweb/welcome.html](http://www.mobot.org/MOBOT/research/APweb/welcome.html)), both accessed continuously through 1 September 2014. Authorities, author names, and abbreviations follow the International Plant Names Index (IPNI)(<http://www.ipni.org/>), also accessed continuously through 1 September 2014.

### ***Chronology***

Where possible, radiocarbon ages within the text are given as calibrated calendar years before present, with present taken to be the year 1950 CE, and given as: [2 $\sigma$  numeric age range] cal BP. In pollen diagrams, radiocarbon ages are presented in conventional radiocarbon years before present (1950 CE), and given as: [age] $\pm$ [1 $\sigma$  standard error] BP. When referenced within the text, both the conventional radiocarbon age that appears in the pollen diagram, as well as the calibrated radiocarbon age, are given for clarification and consistency.

Names and ages of geological time divisions referred to in the text follow the International Commission on Stratigraphy's (ICS)([www.stratigraphy.org](http://www.stratigraphy.org)) International Chronostratigraphic Chart v 2015/01 (Cohen *et al.*, 2013; updated).

### ***Abbreviations***

AMS	Accelerator Mass Spectrometry (isotope analytic method)
APG	Angiosperm Phylogeny Group (plant taxonomy working-group)
Ba	Barrio coring site of Jones (2012)
BIO-7	Barrio coring site of the present study
BP	Before Present, with present fixed at 1950 CE

BPG	Batu Patong / Pa' Buda coring site of Jones (2012)
<sup>14</sup> C	Radiocarbon, used in presentation of uncalibrated ages
cal	Calibrated/calendar years (in radiocarbon age notation)
CAP	Community Analysis Package (multi-variate statistics software)
CBD	Convention on Biological Diversity
CE	Current Era (alternative to AD, or <i>Anno Domini</i> )
CITES	Convention on International Trade in Endangered Species of Wild Fauna and Flora
CONISS	Constrained Incremental Sum of Squares (statistical method)
CRF	Cultured Rainforest Project
CTFS	Center for Tropical Forest Science
dbh	Diameter at breast height (tree width measurement)
DEFRA	Department of Environment, Food, and Rural Affairs (UK)
ENSO	<i>El Niño</i> —Southern Oscillation
FAO	United Nations Food and Agriculture Organisation
ForestGEO	Forest Global Earth Observatory
FOV	Fields of view (microscopy)
GSPC	Global Strategy for Plant Conservation
ICS	International Commission on Stratigraphy
ISEA	Island Southeast Asia
IUCN	International Union for the Conservation of Nature
ka	Kilo-annum (1000 years)

LGM	Last Glacial Maximum (global climatic period)
LMF	Lower montane forest (vegetation type)
LRF	Lowland Rainforest (a site name of the present study)
LOI	Loss-on-ignition (physical analysis of sediments)
Ma	Mega-annum (1,000,000 years)
NPCT	North Palawan Continental Terrane (tectonic feature)
OIS	Oxygen Isotope Stage (geochronology; also Marine Isotope Stage)
PCA	Principal Components Analysis (multi-variate statistics)
PDH	Pa' Dalih, prefix to coring site names of Jones (2012)
PIPRP	Palawan Island Palaeohistoric Research Project
QUB	Queen's University Belfast
sp.	Species (singular)
spp.	Multiple species of the same genus; congenetics
SPT	South Palawan Terrane (tectonic feature)
STRI	Smithsonian Tropical Research Institute
TCU	Top Crocker Unconformity (north Bornean stratigraphic feature)
TEEB	The Economics of Ecosystems and Biodiversity
UMF	Upper montane forest (vegetation type)
UNEP	United Nations Environment Programme
UN-REDD	Reducing Emissions from Deforestation and Forest Degradation
UP-ASP	Archaeological Studies Program, University of the Philippines



## Abstract

This research employs a modern analogue approach to examine relationships between pollen, vegetation change, and land use in the tropical environments of Island Southeast Asia over the past ~5000 years. Interpretation of fossil pollen data relies upon uniformitarian principles. Few modern pollen-vegetation studies from the region exist, and those that do have focused on climatic or ecological aims. Main contributions of this study are: the collection and analysis of modern botanical data and pollen assemblages from various human-modified and 'natural' vegetation types; and the comparison of this modern dataset with fossil pollen sequences in order to test hypotheses relating to signatures of past land use. Some fossil assemblages showed statistical similarity with those from modern 'cultured' landscapes, whilst others aligned more closely with those from natural vegetation. Cores from the northern Kelabit Highlands of Sarawak, Malaysian Borneo, contain assemblages from 1700 cal BP onwards that are similar to those produced by modern arboriculture; a core from the southern Highlands contains fossil assemblages as old as 2000 cal BP that align with those from modern wet rice paddies. These ages coincide with the earliest archaeological dates from nearby sites. Earlier vegetation changes appear to relate to edaphic development and climatic fluctuations. In northern Palawan, western Philippines, the first fossil pollen sequence from the island records post-5000 cal BP marine regression, hydrological fluctuations that are likely related to ENSO cyclicities, and persistence of open landscapes with minor evidence of closed forest after 2750 cal BP. This contrasts with existing proxy data that imply increasingly closed forest through the Holocene. In a region where direct archaeobotanical evidence is sparse, and little modern pollen-vegetation work has been done, this research contributes to clarifying modes and timings of changes in subsistence-related disturbance, as well as bolstering recent interpretations from other palaeoclimatic proxies for ENSO intensification from ~4000 cal BP. These results, and those from similar future studies, can provide baseline data for long-term monitoring and conservation initiatives.



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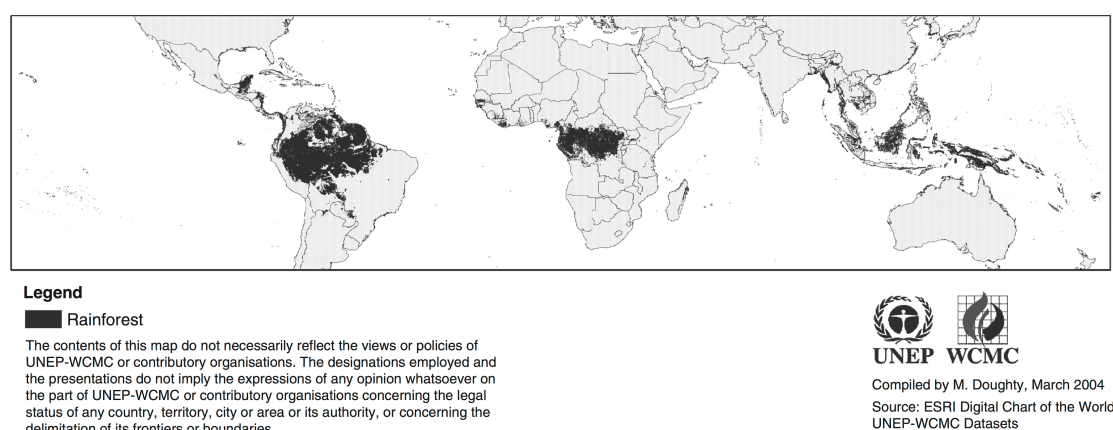
# 1 Introduction

This thesis is about the relationships between pollen, vegetation change, and land use within the tropical environments of Island Southeast Asia (ISEA), a region that modern humans have inhabited for at least 50,000 years (Barker *et al.*, 2007; Brothwell, 1960; Détroit *et al.*, 2004; Fox, 1970; Harrison, 1959b). The aim of this research is to advance our understanding of the histories of tropical vegetation and tropical subsistence. An approach that combines modern botany with fossil pollen analysis is applied within case studies of Holocene sequences from Malaysian Borneo and Palawan Island in the western Philippines. Across the subsequent chapters, results are situated within the context of ongoing dialogues about how we uncover and interpret tropical forest histories. Parallel discussions underscore the implications for conservation and future research.

Botanist A F W Schimper coined the term ‘tropical rainforest’ in his *Plant-Geography Upon a Physiological Basis* (1898; 1903 English translation from the original German). In it, his description of this term chimes with Western images of the prototypical equatorial vegetation:

*Rain-forest is evergreen, hygrophilous in character, at least thirty metres high, but usually much taller, rich in thick-stemmed lianes, and in woody as well as herbaceous epiphytes.* (Schimper, 1903: p. 260)

Globally, tropical forests that fit Schimper’s description occur today at low latitudes in three major regions and several additional minor ones. They are geographically separated by expanses of ocean and desert, and in places bounded and dissected by mountain ranges: in tropical Asia, sub-Saharan Africa, and the Neotropics that straddle both Americas (Figure 1.1) (Richards, 1996; Whitmore, 1998). Tropical forests are the most diverse and ecologically complex of all terrestrial biological communities (Myers, 1984). Whilst collectively occupying only seven per cent of the Earth’s land surface, they probably sustain



**Figure 1.1** Global distribution of lowland tropical rainforests. Source: Corlett and Primark (2008).

over half of the planet's life-forms (Wilson, 1988). They also provide habitats for people, containing “pharmacopoeias of irreplaceable products” (Laurance, 1999: p. 110) as well as sources of food, shelter, materials, livelihoods, and spiritual well-being. At scales greater than those of individual organisms and localised populations, tropical forests provide numerous ecosystem services in the forms of stabilisation of soils, river courses, and watersheds (Chin *et al.*, 1992); they help regulate regional climates and perpetuate rainfall through evapotranspiration (eg Brown, 1998; Hastenrath, 1997; Laurance, 1998; Salati & Vose, 1984; Spracklen *et al.*, 2012); they sequester carbon in plant biomass and in soil (Houghton & Skole, 1990); they make air breathable (eg Gregory *et al.*, 1986; Harriss, 1987; Hietz *et al.*, 2011) and water drinkable (eg Adeyinka *et al.*, 2014; Malmer *et al.*, 2010; Ojea & Martin-Ortega, 2015). At the molecular scale, the genetic diversity contained within tropical forests comprises the wild relatives of species of proven economic value such as rubber, coffee, mahogany, and cacao, and thus safeguards the future sustainment of many crops (Prance, 1991). That same genetic diversity is also a library that houses within each living cell tomes on the evolutionary histories and relationships of the constituent organisms (Avice, 2000; Stevens, 2001 onwards). These genetic libraries inform our understanding of how life on this planet evolved and is evolving. For all of these reasons, tropical forests connote biodiversity, and protecting biodiversity is widely accepted and understood to be in our self-interest (Secretariat of the Convention on Biological Diversity, 2010).



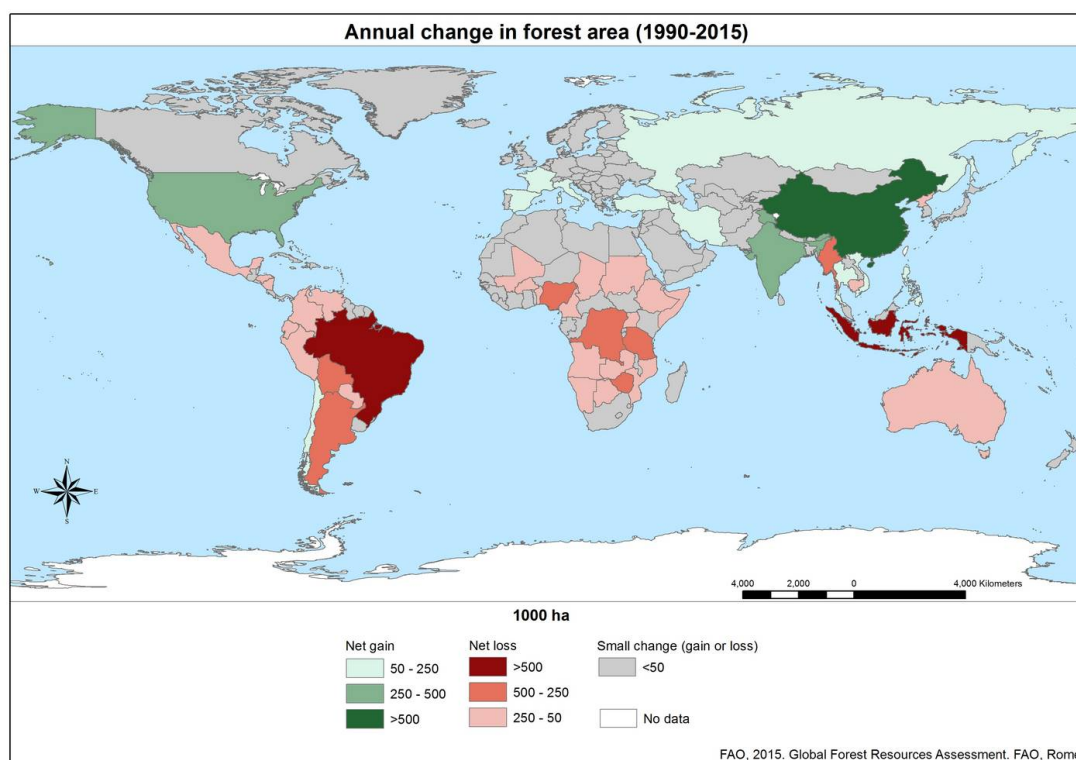
Yet despite the value of tropical forests, in most biological disciplines they remain under-studied (Janzen, 1986) and, at least botanically, under-collected (Prance *et al.*, 2000). Prance and colleagues (2000) allude to the legacy of the historical bias described in the following statement made in 1937 by the botanist of tropical Asia and initiator in 1948 of the ongoing *Flora Malesiana* project, Professor C G G J van Steenis:

*Most studies of vegetation have been carried out in Europe, and I am of the opinion that owing to a paucity of material these investigations have begun with an inverted viewpoint. When studying the manifold types of vegetation, comparing them and relating them to each other, one ought logically to start with the richest and to derive from it the less complicated, impoverished types which have arisen from it by selection. The richest type of vegetation in number of species, volume and density, is found in the tropics. It is not the impoverished anthropogenic vegetation of Europe which should be the starting-point of one's investigations.*  
(Richards, 1996: p. xxiii; translation of C G G J van Steenis, 1937)

The value of tropical forests, and the potential remaining for increasing our understanding of them, contrasts with current trends in their destruction. The United Nations Food and Agriculture Organisation (FAO, 1981) noted that by the late 1970s the humid tropics were losing forest cover at a rate estimated to have been around 75,000km<sup>2</sup> per year. The most recent FAO Global Forest Resources Assessment (FAO, 2015) shows that, although the rate of forest loss *globally* has slowed in the past 25 years to three per cent per year by area, *gains* in forest cover in temperate zones mask continued losses within the tropics (Figure 1.2) (Keenan *et al.*, 2015). More explicitly, in the same paper in which he introduced the term 'hotspot' to describe localities in tropical forests which feature "exceptional concentrations of species with exceptional levels of endemism, and that face exceptional degrees of threat" (Myers, 1988: p. 187), Norman Myers noted the many prognoses, even 30 years ago, of the impending, or, by some accounts, already underway, mass extinction of species centred on tropical forests (eg Ehrlich & Ehrlich, 1981; Myers, 1987; Western & Pearl, 1989;

Wilson, 1988). The following quote from that same 1988 paper underscores points made above:

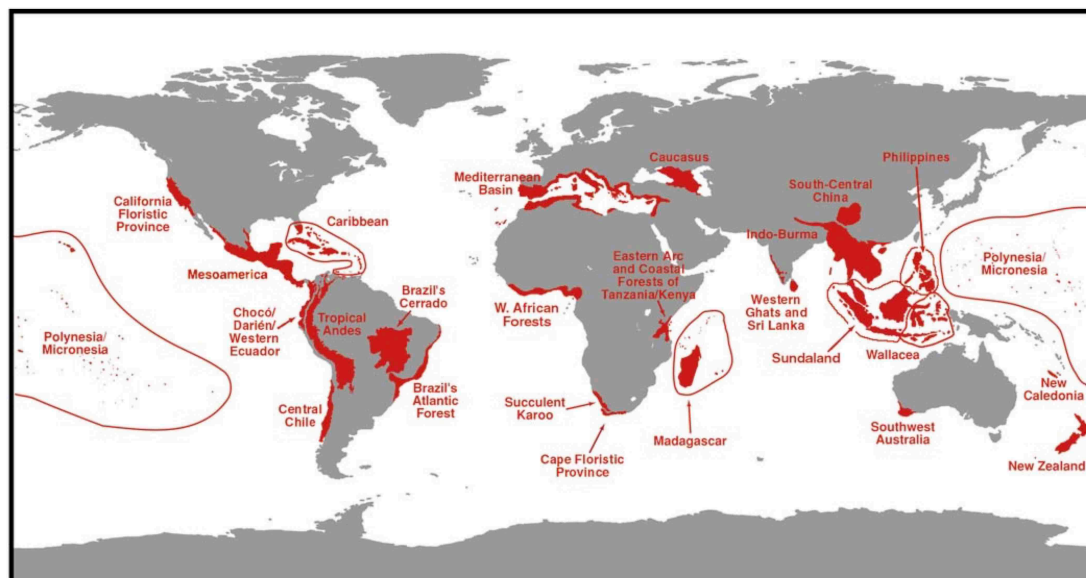
*These hotspot areas...total only 292,000km<sup>2</sup> (3.5 per cent) of a biome of 8.5 million km<sup>2</sup> of primary forest remaining. But they feature a large proportion, possibly a majority, of the 125,000 higher plant species, both local endemics and wide-distribution species, that exist in tropical forests overall...[and yet we are] bedevilled by lack of basic data. We know all too little about the numbers of species...Endemic species are extremely vulnerable to extinction when their localised habitats are deforested...The ecological specialisations of many tropical-forest species, such as sensitive positions in complex food webs, leave them subject to summary demise when their support ecosystems are merely destabilised through forest disturbance and degradation. (Myers, 1988: p. 187)*



**Figure 1.2** In global figures for forest cover change across 1990-2015, tropical forest losses were masked by gains in temperate forest. Source: FAO (2015).

Threats to tropical forest habitats inevitably extend to some species which people have not yet used but that have economic potential as medicines, foods, fibres, and other products (Prance, 1991).

Southeast Asia is one of the most biologically diverse regions on the planet for numerous different groups of organisms (Gower *et al.*, 2012a). The region houses three of Myers *et al.*'s (2000) 25 biodiversity hotspots: Sundaland, Wallacea, and the Philippines (see Figure 1.3), whilst also supporting some of the densest human populations on Earth with rapidly expanding economies. Recent and ongoing reduction in forest cover through logging of dipterocarp forests (Ashton, 2014) and conversion of lowland forest habitat to monocultures of non-native crop species such as the West African oil palm (*Elaeis guineensis* Jacq., Arecaceae) and the Brazilian rubber tree (*Hevea brasiliensis* (Willd. ex A.Juss.) Müll.Arg., Euphorbiaceae) have led to what Sodhi and Brook (2006) call 'biodiversity in crisis'. Synergisms between droughts, logging, and slash-and-burn farming have led to wildfires on a scale that lacks deep historical precedent, such as those that consumed over 20 million hectares in Southeast Asia as well as Amazonia during the 1982-83 and 1997-98 *El Niños* (Brown, 1998; Laurance, 1998). The pace of forest conversion is also causing displacement of indigenous peoples (Brosius, 2004) and erosion of rural livelihoods (Sodhi *et al.*, 2006).



**Figure 1.3** The 25 biodiversity hotspots. The Philippines, Sundaland, and Wallacea hotspots comprise the whole of Island Southeast Asia. Source: Myers *et al.* (2000).

Recognition and appreciation of the impact of these factors, combined with global environmental change, have generated conservation concerns and initiatives at scales ranging from the local to the global (Gower *et al.*, 2012b). Convening of the Rio Earth Summit in 1992 by the United Nations Environment Programme (UNEP) marked the global coalescence of a series of such international efforts over the preceding 20 years (Secretariat of the Convention on Biological Diversity, 2010). From the Earth Summit emerged the Convention on Biological Diversity (CBD), which signals the commitment of the 196 nations that are now Parties to the agreement to share in the responsibilities and benefits of the conservation and sustainable use of biodiversity. Related initiatives that have since sprouted and branched from the CBD include: *The Gran Canaria Declaration Calling for a Global Strategy for Plant Conservation (GSPC)* (2000), that led to the original GSPC (2002), followed up in 2010 by the Updated GSPC 2011-2020; The Economics of Ecosystems and Biodiversity (TEEB) study, conceived in 2007; the Reducing Emissions from Deforestation and Forest Degradation Programme (UN-REDD) that launched in 2008; the 20 Aichi Biodiversity Targets of the Strategic Plan for Biodiversity 2011-2020; the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES), established in 2012; and the recent 2015 Paris Agreement to the Framework Convention on Climate Change (UN-FCCC). These initiatives, amongst others, join the existing Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) agreement and the International Union for the Conservation of Nature (IUCN) in supporting and driving conservation efforts and research globally by state and non-state actors, and across the entire spectrum of scales.

These global multilateral conservation efforts mark a broadening over the past half century in the awareness of the roles that our species plays in ecological systems, as well as the impacts we are having upon them. Allocation of public funds for research has followed this growth in awareness, that is reflected in research agendas. Long-term monitoring of trends in ecological change is increasingly prioritised so as to improve future predictive capacities. This prioritisation is manifest, for example, in the expanding global network of sites



**Figure 1.4** CTFS-ForestGEO's 63 long-term plots spread across 24 countries. Source: [www.forestgeo.si.edu](http://www.forestgeo.si.edu).

since 1980 under the umbrella of the Center for Tropical Forest Science – Forest Global Earth Observatory (CTFS-ForestGEO) (Figure 1.4), that is maintained and periodically re-surveyed under the aegis of the Smithsonian Tropical Research Institute (STRI) (Ashton *et al.*, 1999).

Yet even in the context of long-term monitoring, most ecologists study organisms on a time scale of less than 100 years. This is a fraction of a single generation of many rainforest canopy trees (Ashton, 2014). Schoonmaker and Foster (1991) argue that a deeper temporal perspective is needed to better understand many natural patterns and processes. They argue that palaeoecology can provide such a perspective, and that the inter-relationships of modern ecology and palaeoecology are becoming more apparent.

*Palaeoecology can broaden the interpretation of issues that are specifically relevant to modern ecologists, e.g., the prevalence of stability versus rapid change in ecosystems, the concept of an integrated community, the importance of disturbance in regulating community organization, alternative explanations of species diversity, and refugia theory. (Schoonmaker & Foster, 1991: p. 205)*

Over the past 30 years, as ecologists began to expand the scales at which contemporary phenomena were addressed (eg Hubbell & Foster, 1986; Rickfels, 1987), palaeoecologists also contributed to ongoing discussions of ecological theory (eg Bennett, 1988; Prentice, 1988). Kathy Willis and colleagues have, over at least the past ten years, highlighted the potential of palaeoecology, and

particularly palynology, to extend back in time the temporal reach of long-term ecological monitoring and thus provide new baseline information for contemporary conservation (Froyd & Willis, 2008; Willis & Bhagwat, 2009, 2010; Willis & Birks, 2006; Willis *et al.*, 2005, 2007, 2010, 2013). Related research can also help to define ‘natural’ states of forests and thus inform and help set targets for modern and future restoration projects (eg Willis *et al.*, 2004). To which former state do we want to restore a particular ecosystem? Which climatic regimes, and types and degrees of human impact are considered natural and desirable restoration targets?

Whilst the synergies of palaeoecology and archaeology have been demonstrated since the early 1940s, more recently archaeologists such as Stahl (1996) and Troufflard (2013) argue that archaeology and anthropology have key roles to play in concert with palaeoecology in unravelling the ways in which human and natural histories are entwined. Such a perspective may yield insights into future management decisions that are driven by the recently adopted United Nations Sustainable Development Goals (General Assembly resolution 69/315, 2015).

In linking present processes with both the past and the future, palynology, as with archaeology, is rooted in the uniformitarian geology that, itself, sprang from the fertile soils of the Scottish Enlightenment at the end of the 18th and beginning of the 19th centuries (Hutton, 1795; Playfair, 1802; Lyell, 1830-1833). Whilst Nehemiah Grew in England and Marcello Malpighi in Italy were two of the first plant anatomists to examine pollen grains through Robert Hooke’s early compound microscopes in the 1660s (Manten, 1969), analysis of fossil pollen from sediments began with Lennart von Post’s (1916) first percentage pollen diagrams from peat swamps in Närke province west of Stockholm.

Johannes Iversen’s *Landnam* (1941) was the first demonstration of the use of palynological records as proxies for human activity and impact upon vegetation. Archaeologist Grahame Clark (1952) used Iversen’s *Landnam* thesis of human-induced vegetation changes to argue that:

*The best known exponents of the extensive, shifting agriculture of Neolithic times were the Danubian peasants who colonised the loess of central Europe...clearing small patches of forest, taking a few easy crops, and passing on to fresh ground. (Clark, 1952: pp. 95-96)*

Palynology was used later by Ian Simmons (1969) to show that human impact upon vegetation did not begin abruptly with Neolithic forest clearance following on from ecologically benign foragers, but rather that signs of forest manipulation during the Mesolithic of the English uplands are also visible in pollen records. In tandem, palynology and archaeology succeeded in uncovering nuances in the inter-relationships between human and vegetation histories in temperate Europe.

Ideas about tropical rainforest histories have also evolved. The impact of the grandeur of tropical forests upon first-time visitors from temperate climes led many Europeans throughout the centuries of colonialism in the equatorial regions to perpetuate a view of rainforests as primeval, ancient, and unchanging (eg Beccari, 1904; Low *et al.*, 2002). Botanist Lillian Gibbs' perceptions in 1909-1910 of the forests of Mount Kinabalu in what was then British North Borneo (now the East Malaysian state of Sabah) represent the opposite extreme. Foreshadowing a change to come in our understanding of rainforest histories, Gibbs wrote in 1914 not of the 'untrodden jungle' of the Victorians, but rather that:

*The whole country with its endless hill ranges, ranging from 3000-5000', is covered with what may be called well-worked secondary forest...Everywhere the forest is very well worked and has been so for generations...The true home of a jungle people is the jungle, which is to them what our agricultural and pasture land is to us. (Gibbs, 1914; pp. 9-10)*

However, the prospect of using palynology as a tool to reconstruct tropical forest histories, and directly interrogate such impressions as those of the early European colonials or of Ms Gibbs, met with initial pessimism (eg Faegri,

1966). Preconceptions about obstacles posed by the richness of the lowland tropical flora, the predominance there of animal pollination, and lack of wind beneath the rainforest canopy were self-fulfilling prophecies. Consequently, palynologists in the 1960s who were interested in the history of tropical vegetation focused their efforts on equatorial mountains where environmental parallels to the temperate zone are more widespread (eg Flenley, 1969; van der Hammen & Gonzalez, 1960; Livingstone, 1967).

In 1973, John Flenley began to challenge preconceptions with his study of modern pollen rain from lowland tropical rainforest at the Ulu Gombak Virgin Jungle Reserve in Selangor, West Malaysia (Flenley, 1973). His data suggested that, despite the peculiarities in tropical forest vegetation, palynology in the lowland and montane tropics could be used with reasonable reliability in much the same way that it had been in temperate Europe. This conclusion was supported by comparable studies in other tropical regions (Kershaw & Hyland, 1975; Salgado-Labouriau, 1978).

The increasing confidence in tropical palynology paved the way for acceptance of Flenley's landmark publication *The Equatorial Rain Forest: A Geological History* (1979a). This synthesis revealed the emerging picture of tropical forests as dynamic and subject to similar climatic drivers of change as were shown to influence the temperate forests of Europe and North America. The revolution in thinking about tropical forest history that this ushered in is embodied in the two quotes below by tropical ecologists of the day:

*The old notion of the stability of rainforests over long periods of time has been replaced by a dynamic concept of rainforests as kaleidoscopic mosaics continually reacting to climatic changes and human pressures.* Paul Richards (1996; p. xviii)

and by Iain Prance, Director of the Royal Botanic Gardens, Kew at the time:

*Historic data from palynology have shown that during the Pleistocene and Holocene, small changes in temperature and*



*rainfall greatly altered the distribution of tropical forests and savannah and of treeline level.* (Prance, 1991: p. 33)

Some of the earliest examples of links between records of past tropical vegetation changes and human activity came from Southeast Asia and Australasia. Whilst the ecological importance of fire, both natural and anthropogenic, had long been appreciated (eg reviews in Bird, 1995; Bowman, 1998; Clark, 1983), interpretations of palaeoecological and archaeological records were influenced by archaeologist Rhys Jones' coining of the phrase 'fire-stick farming' to describe indigenous land management techniques that involve intentional burning of the Australian vegetation to create habitat mosaics with a diversity of biological resources (Jones, 1969; cf Mellars, 1976). Two of John Flenley's PhD students in the late 1970s and early 1980s at the University of Hull, Bernard Maloney and Robert Morley, argued that pollen evidence of forest reduction and increases in the importance of fire in the early-mid Holocene of highland Sumatra were signs of forest clearance and burning by humans (Maloney, 1980 & 1985; Morley, 1982). Similar interpretations of pollen and charcoal records were put forth for tropical northern Australia (eg Kershaw, 1986) and New Guinea (eg Garrett-Jones, 1979; Hope & Tulip, 1994).

Direct evidence of manipulation of tropical Asian vegetation by humans in the deep past, however, has been slow to emerge. Whilst Chet Gorman's work at Spirit Cave in northern Thailand (Gorman, 1969; 1970; 1971) and Ian Glover's PhD research in East Timor (Glover, 1972) and later work in Sulawesi (Glover, 1976) initiated archaeobotanical enquiry in the region, systematic application of best archaeobotanical practices has until recently been wanting (Fairbairn, 2005; Paz, 2001). Jon Hather's edited volume *Tropical Archaeobotany* (1994), consisting of papers delivered at the Second World Archaeological Congress in Venezuela in 1990, highlights some of the methodological innovations that hold promise for redressing gaps in archaeological records of tropical subsistence. These gaps owe to peculiarities in the types of constituent crops used, as well as the way they preserve in tropical archaeological sediments. Growing application of these techniques is contributing to an emerging picture of prehistoric tropical subsistence in Island Southeast Asia (ISEA) that includes Pleistocene and early

Holocene indigenous forms of management of tree and root crops (eg Groube *et al.*, 1990; Hather, 1991; Latinis, 2000), as well as trajectories of subsistence changes that include development of hybrid foraging-farming economies, and even reversion from a focus on farming back to foraging (eg Barker, 2005; Barker *et al.*, 2011a; 2011b; Haberle *et al.*, 2012). Accounting for the complexities of these recent data challenges pre-existing archaeological narratives.

Research experiences and readings from my own master's degree at the Australian National University in 2009 provide the most proximal sources of my interest in tropical palynology as an archaeological tool to inform histories of tropical forest subsistence as well as contemporary conservation. In particular, exposure to the work and environment created by – and indeed meeting and working with – researchers involved with the archaeology and palaeoecology of New Guinea such as Jack Golson, Geoff Hope, Tim Denham, and Simon Haberle primed my curiosity. During the days that I spent peering down a microscope at pollen from Kuk Swamp, I recall reading papers from a 2007 special issue of the *Philosophical Transactions of the Royal Society B* entitled “Biodiversity hotspots through time: using the past to manage the future” (Volume 362, Issue 1478), edited by Kathy Willis, Lindsey Gillson, and Sandra Knapp. The papers in that issue, and in particular the article by Simon Haberle (2007) on prehistoric human impact upon rainforest biodiversity in New Guinea, shaped my curiosity to then pursue similar lines of enquiry at other sites within the region. This led me to the Cambridge-based work that Graeme Barker was directing on Borneo along with an international and interdisciplinary team of specialist collaborators, and eventually to the genesis of the present thesis.

## **1.1 Thesis aim and structure**

The aim of the research described in this thesis is to demonstrate the potential to sharpen the blunt tool of tropical palynology for contribution to current dialogues regarding the nature and extent of Holocene human impact upon rainforest vegetation. Northern Island Southeast Asia (ISEA) was selected as the geographical focus of this research due to recent and ongoing

archaeological projects in the region that continue to build upon a picture of Holocene human subsistence that challenges long-held narratives. In order to achieve the aim of this study, original and existing data are analysed via the modern analogue approach to vegetation reconstruction. The potential for this approach to push forward our understanding of the relative roles of humans and climate in driving vegetation change is highlighted across the following chapters.

In Chapter 2, regional background is provided by review of previous work in relevant sub-disciplines up to the time that the present study began.

From this review, current knowledge gaps are identified and defined at the start of Chapter 3. Specific questions designed to address these knowledge gaps are then posed that this research begins to answer. The approach taken to attempt to answer these questions, as well as introductions to the specific sites used as demonstrative case studies, are described, followed by a brief narrative of project development.

Chapter 4 describes in detail the specific field, laboratory, and desktop-based methods applied in material collection, processing, data production, and analyses.

In Chapter 5, results of the suite of botanical and palynological sampling across the modern landscapes of the Kelabit Highlands in the East Malaysian state of Sarawak on the island of Borneo are presented.

The modern analogue approach is then demonstrated in Chapter 6 by application of these results to five fossil pollen sequences from the Kelabit Highlands.

Chapter 7 presents the initial stages of application of the same approach within northern Palawan Island in the Republic of the Philippines.

Finally, Chapter 8 comprises a discussion of the results of this research in the context of current archaeological and palaeoecological dialogues. In so doing, the contributions of this research to the relevant bodies of knowledge are

assessed, implications for current and future conservation efforts are outlined, and future research directions are suggested.

## **2 Background and research context**

### **2.1 Introduction**

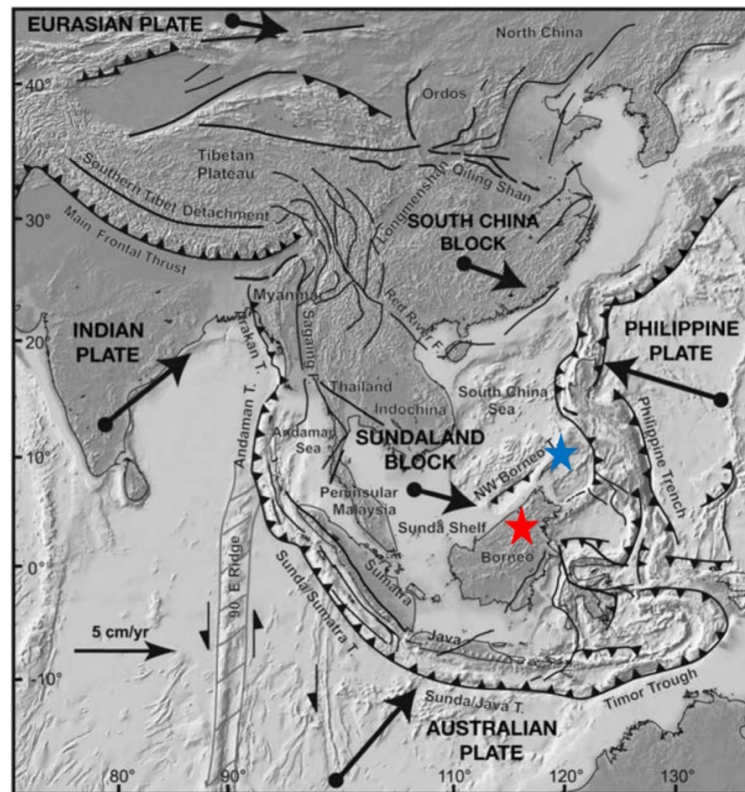
The focus of this thesis is the detection of signatures of human activity within Holocene sedimentary records of vegetation history in northern Island Southeast Asia. This chapter aims to provide an overview of the literature relevant to understanding the broader history of tropical Asian forests. This overview is multidisciplinary, and incorporates processes that were in motion well before the Holocene. Across the following sections, a sketch of the state of relevant knowledge at this project's inception is offered. This sketch is organised by discipline, whilst aiming to provide a holistic depiction. Geology ultimately underpins the geographic, climatic, biological, and human stories. An overview of the complex tectonic assembly of the region is offered first. This is followed by a description of how palaeogeography has shaped past climates, soils, and patterns of biological distributions. Within this context, key studies of the imprints of land use in palaeoecological records, and the archaeology of subsistence from Holocene sequences throughout the region are then discussed.

### **2.2 Regional tectonic setting, geologic history, and palaeogeography**

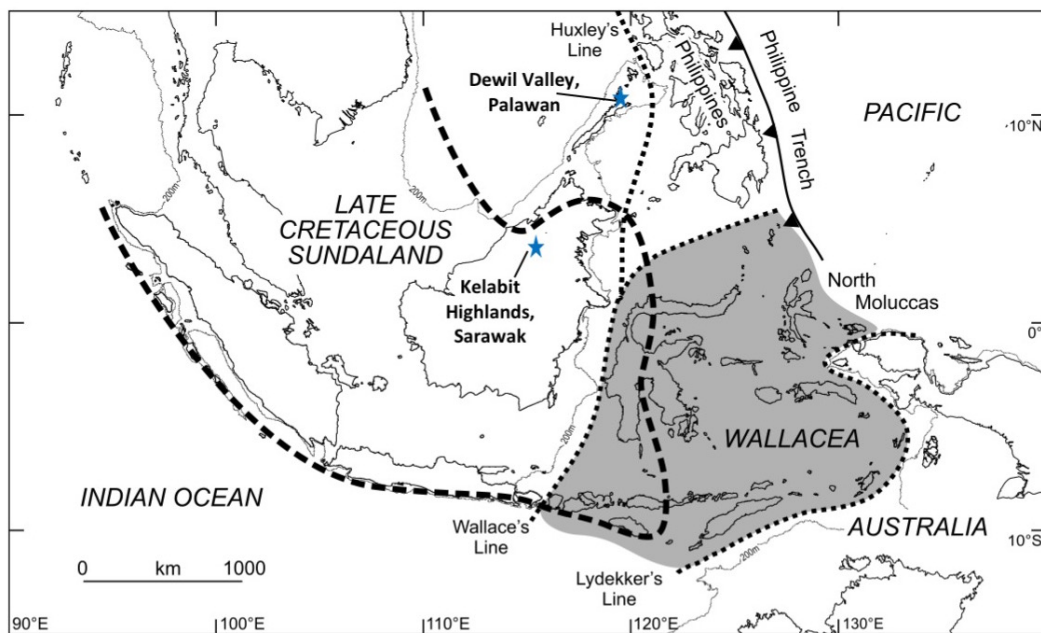
*The mountains of the Alpine-Himalayan belt descend southwards from the vast elevated plateau of Tibet into Indochina and terminate in an archipelago of continental crust and volcanic islands separated by small ocean basins: the Malay Archipelago of Alfred Russel Wallace (1869)...To the south, west, and east the region is surrounded by volcanic arcs where lithosphere of the Indian and Pacific Oceans is being subducted at high rates, accompanied by intense seismicity and abundant volcanism...The geology and palaeogeography of the region continue to change in a rapid way that has characterised most of the Cenozoic. (Hall, 2009: p. 148)*

Southeast Asia is one of the most tectonically dynamic regions on the planet today, and has been so since at least the middle of the Eocene epoch ~45 million years ago. This dynamism has had profound effects upon the distributions and connectivity of land and sea (Hall, 2001; 2002), patterns of ocean and atmospheric circulation (Hall *et al.*, 2011a&b; Morley, 2003; Sun & Wang, 2005), regional and possibly global climate (Cane & Molnar, 2001; Kudrass *et al.*, 1991; Lisiecki & Raymo, 2005; Morley, 2012; Zachos *et al.*, 2001), and the distribution and evolution of the biota (eg Gower *et al.*, 2012a; Wallace, 1860; Whitmore, 1981). Consequently, the environments encountered by the earliest human inhabitants of the region were the combined legacies of all of these processes. Geology and the tectonic evolution of the region thus underpin its biotic and human stories.

The Southeast Asian region today spans the boundaries of three major plates: Eurasia, India-Australia, and the Pacific-Philippine Sea plates (Figure 2.1). These plates consist of relatively ancient and stable cores, with younger and more dynamic blocks accreted along margins. They are in motion relative to one another, which, in their present positions and configurations, provides for some of the highest rates of convergence and subduction anywhere on the planet (Hall, 2009). Hall (2009) divides the region into four simplified tectonic parts (Figure 2.2): an early Mesozoic-late Cretaceous Sundaland continental core, forming a promontory that protrudes off the south-eastern margin of the Eurasian continent; the Australian continent to the south, moving northwards relative to Eurasia and colliding with the easternmost margin of Eurasia in eastern Indonesia; the Philippine Sea and Pacific oceanic plates to the east, moving westwards and colliding with and subducting beneath Eurasia at deep ocean trenches along the eastern margin of the region; and in the middle is Wallacea, the dynamic scattering of islands separated by deep and narrow seaways between the converging plates. Wallacea supports high floral, faunal, and marine biodiversity and endemism (Hall, 2009; Gower *et al.*, 2012a). It also houses the planet's only low-latitude inter-oceanic passage in the Indonesian Throughflow. This passage is geologically controlled, and globally important for



**Figure 2.1** Major plates within the Southeast Asian region, and directions of their relative motion. The South China Block and Sundaland Block were accreted onto the Eurasian Plate during the late Palaeozoic and early Mesozoic, and are now in motion eastwards together. The two case study areas of the present study are shown as coloured stars (Kelabit Highlands in red; Dewil Valley in blue), and both are located on the Sundaland Block. Source: Metcalfe (2011).



**Figure 2.2** Schematic simplification of the present Southeast Asian tectonic setting, showing the four constituent parts: the Sundaland core in the northwest; the Philippine Sea and Pacific plates in the northeast; the Australian continent in the southeast; and Wallacea at the nexus. The two case study areas for the present study are denoted by blue stars. Source: Hall (2012).

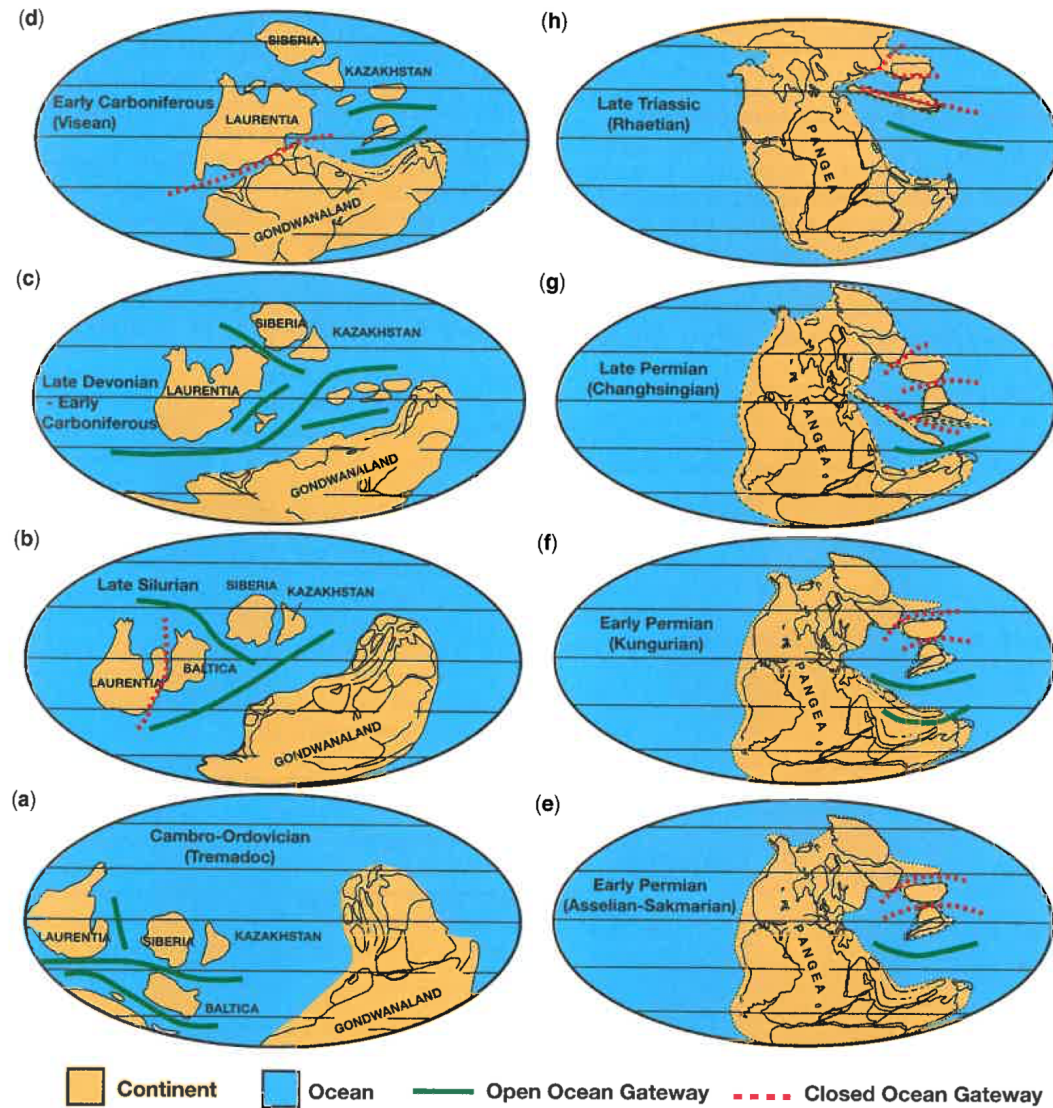
thermohaline circulation (Broecker, 1991; Godfrey, 1996; Gordon, 1986) and climate (Cane & Molnar, 2001; Lisiecki & Raymo, 2005).

### **2.2.1 Pre-Cenozoic geological overview: ~400 – 66 Ma**

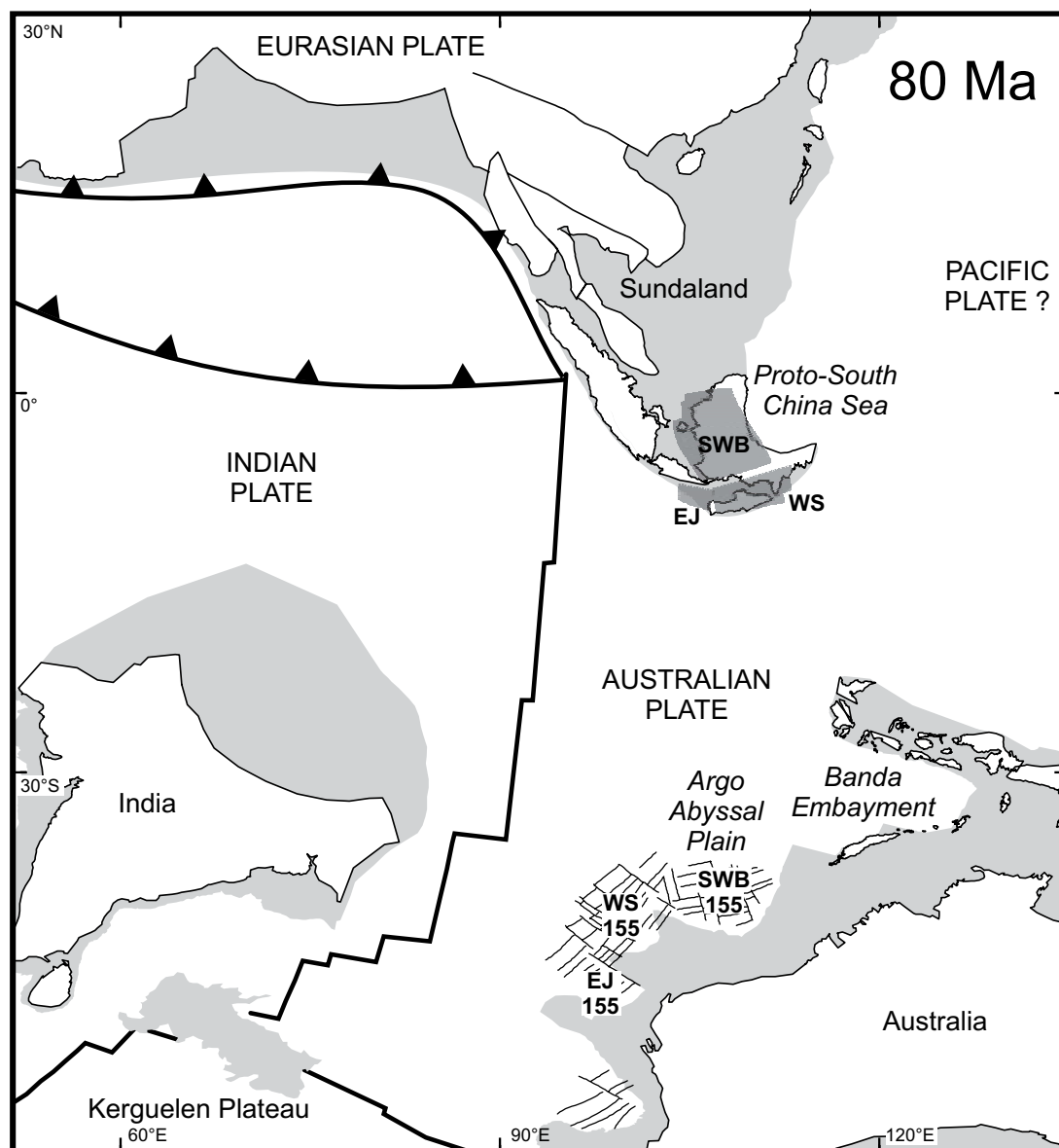
The South China and Sundaland Blocks, along with the microcontinental fragments that together comprise Indochina and Malaya sandwiched in between, derive from the northeast margin of the once-great southern supercontinent Gondwana. Metcalfe (2011) describes three successive continental strips or collages of terranes that separated from Gondwana in the middle Devonian (400-385 Ma), early Permian (290-280 Ma), and late Triassic-Jurassic (205-155 Ma). As these terranes moved successively northwards across the Tethys Ocean over a span of >200 Ma (Figure 2.3), they likely carried with them pre-angiosperm terrestrial biotas of ultimate Gondwanan derivation, and that would have further developed in relative isolation from one another. These terranes collided with and accreted onto East and Southeast Asia from the late Palaeozoic-late Mesozoic (295-85 Ma).

The last of these three terranes to arrive included microcontinental fragments that now underlie east Java, southwest Borneo, and west Sulawesi (Figure 2.4). Subduction-related magmatism and formation of granitic plutons accompanied the arrival of these terranes (van Hattum *et al.*, 2013). The most extensive of these late Cretaceous granites are manifest today in the now-uplifted and exhumed Schwaner Mountains of southwest Borneo (Hall *et al.*, 2008). To the south and west, the late Cretaceous witnessed the separation of Australia from Antarctica, as well as the rapid northward translation of India. By the close of the Cretaceous (66 Ma), India was centred at low southerly latitudes whilst Australia remained at mid-latitudes; both were still separated from the southern margins of Eurasia and the Sundaland promontory by the narrowing Tethys Ocean (Hall, 2012).





**Figure 2.3** Palaeozoic-early Mesozoic tectonic evolution and changing palaeogeography. In (c-h), successive strips of terranes are translated northward across the Tethyan embayment at the central-eastern margin of Pangea. Source: Metcalfe (2011).



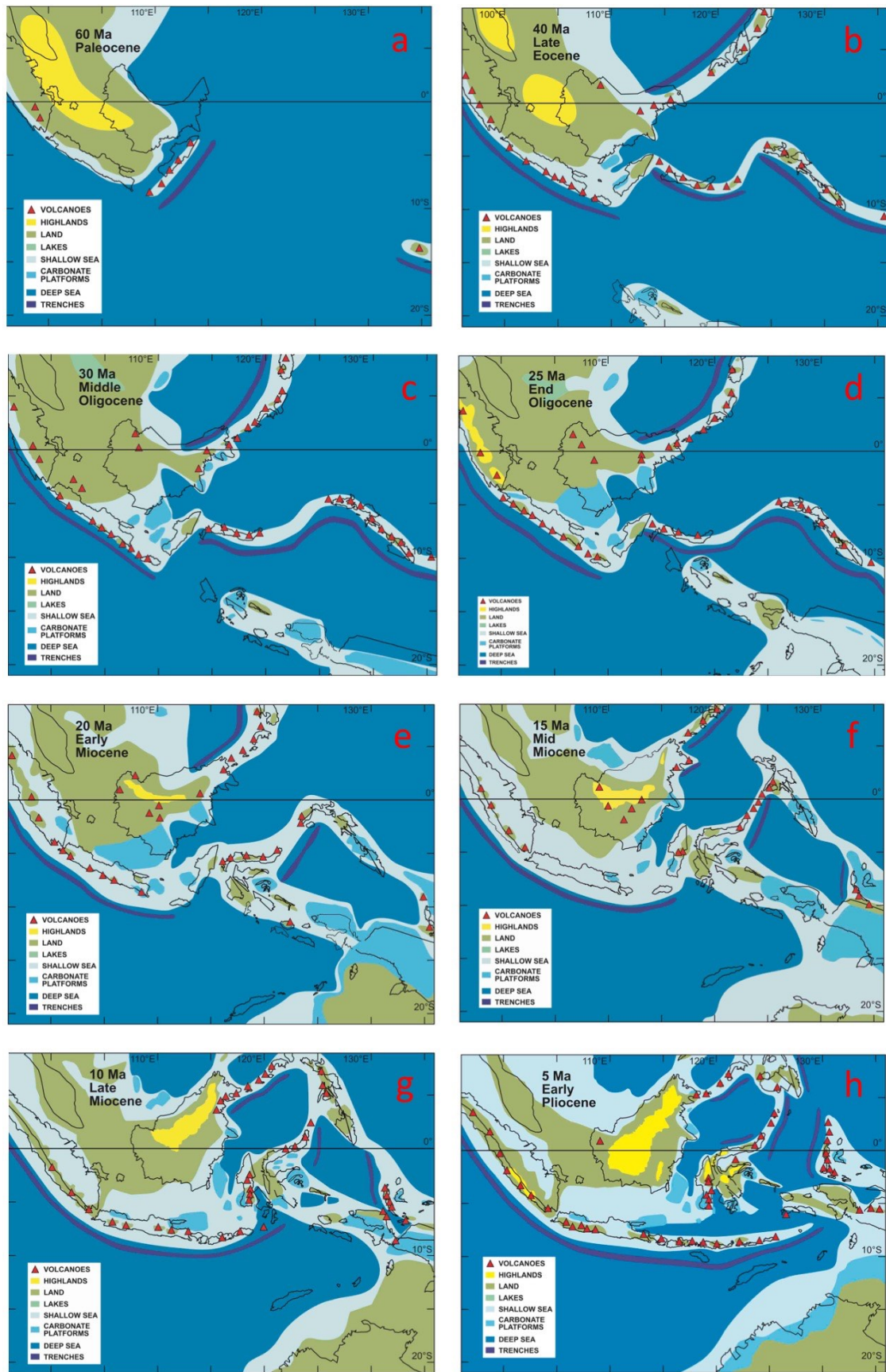
**Figure 2.4** Late Cretaceous (80 Ma) tectonics and palaeogeography, showing the configuration of Sundaland after the accretion of east Java (EJ), southwest Borneo (SWB), and west Sulawesi (WS). Note the source locations and timing (in Ma) of rifting from the northwest Australian margin of each of these fragments, as well as the location of Palawan as part of the eastern margin of the Eurasian Plate in South China. Source: Hall (2009).

### 2.2.2 Cenozoic geological development: 66 Ma – present

Hall (2009) stresses that the Cenozoic geology is the starting point for understanding Southeast Asian palaeoenvironments and the historical development of biogeographic patterns. However, Hall also notes that the geologic record of the region is incomplete and understudied in comparison with those of Europe and North America. It is clear from the presence of extensive

sutures and ophiolites, though, that the promontory comprising the Sundaland core grew incrementally throughout the Mesozoic by addition of continental fragments, rifted primarily from Australia and accreted onto the Sundaland margins via subduction. Sundaland is thus a composite continental core, not a stable and ancient craton (van Hattum *et al.*, 2013). Subduction along the southern and western margins of Sundaland appears to have ceased between ~85-45 Ma (eg Figure 2.5a). Much of the Sundaland core has remained a permanent land area since the Mesozoic (Abdullah, 2009), but its coastlines and topography are difficult to reconstruct due in large part to its emergent nature. Well-dated geologic and palaeogeographical reconstructions rely upon interpretations of and correlations between packages of marine sediments which contain isotopic and biostratigraphic markers (van Gorsel *et al.*, 2014; Hutchison, 2005; Zachos *et al.*, 2001). Such sediments of latest Cretaceous and earliest Cenozoic age in Sundaland are rare. The following account derives from reviews by Hall (2009; 2012), supplemented with other cited studies.

After India's northward translation was slowed by its eventual collision with Eurasia, several geologic processes were initiated across Southeast Asia. Estimates of the timing of the collision of India with the southern margin of Eurasia vary widely, ranging from the earliest-latest Eocene (55-34 Ma) (eg Aitchison *et al.*, 2007; Ali & Aitchison, 2005; Leech *et al.*, 2005; Peltzer & Tapponnier, 1998; Rowley, 1996; Tapponnier *et al.*, 1986). Northeast-directed compressional forces upon southern-central Eurasia associated with the collision led to extrusion of the Indochina and East Malaya microcontinental blocks in a southeast direction. Parallel faulting and the formation of horst and graben topographies accompanied this extrusion. These topographies guide the courses of many of the major river systems which flow across and drain the Southeast Asian mainland today. In Sundaland, extensional forces led to widespread subsidence, and the formation of bathymetrically shallow basins (Hall & Morley, 2004). Nearly coeval with this extrusion, extension, and subsidence, rifting along the South China margin led to south-eastward subduction of the proto-South China Sea beneath the northern margin



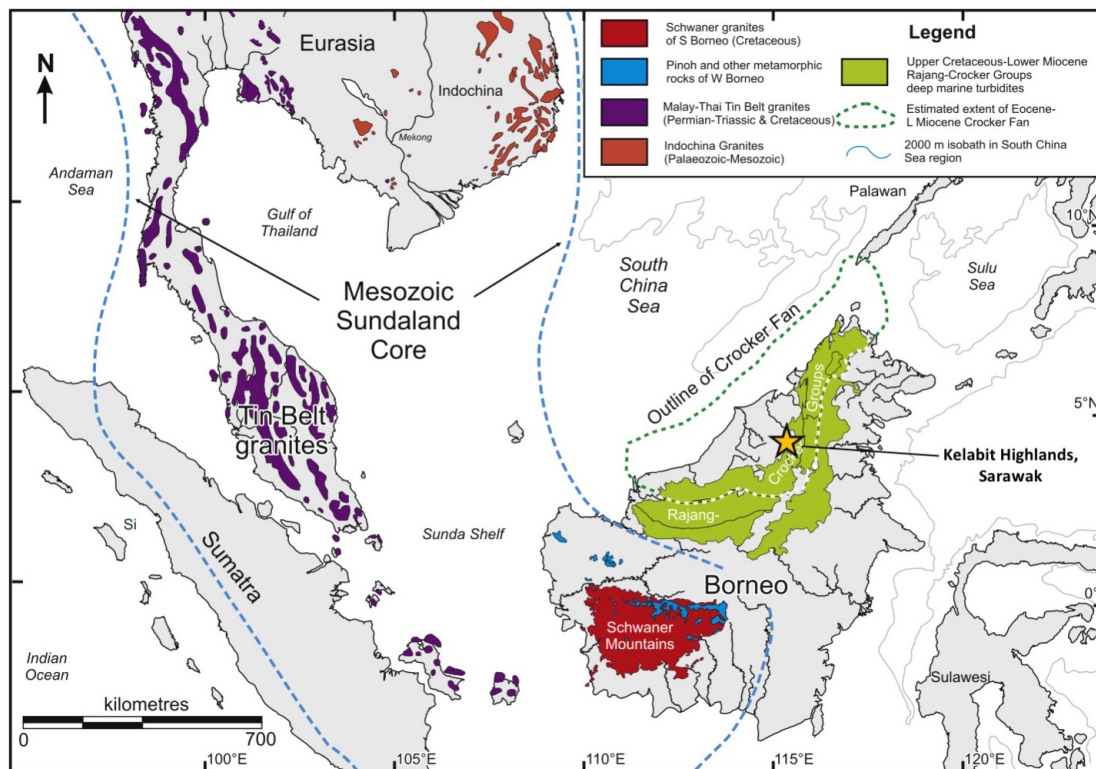
**Figure 2.5** Cenozoic palaeogeographical reconstructions of the Sundaland core and Wallacea. Source: adapted from Hall (2012).



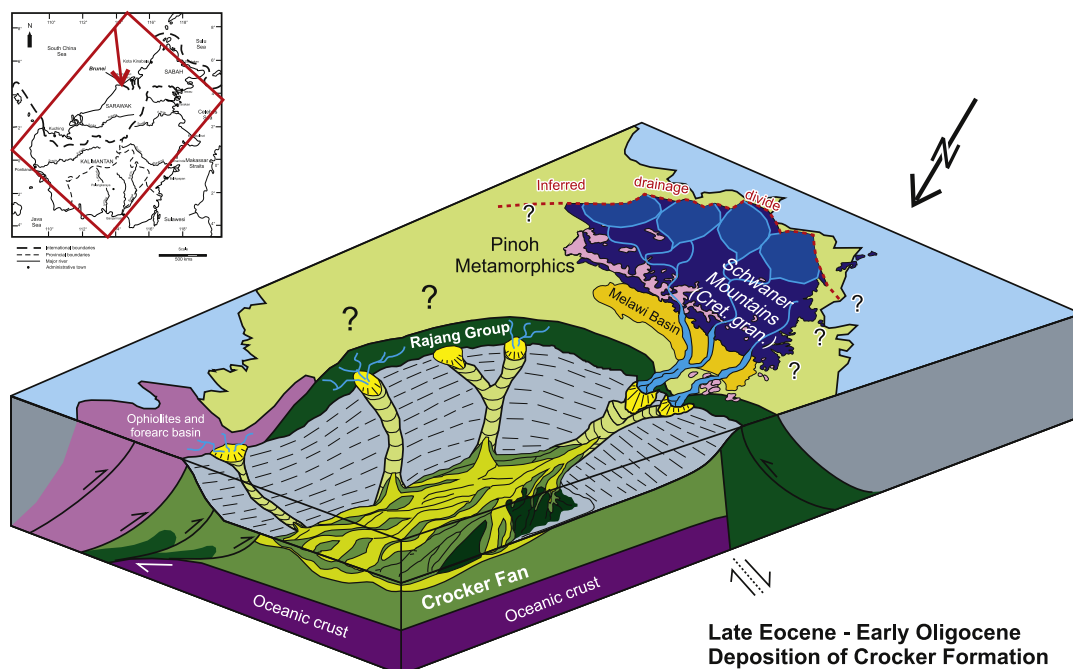
of the Sundaland promontory (Figure 2.5b-e). Additional rifting of West Sulawesi from the south-eastern Sundaland margin led to the opening of the Makassar Straits. In the south, Australia began to move more rapidly northward, which led to subduction along the southwestern margin of Sundaland and initiation of the Sunda Arc in Sumatra and Java, as well as anticlockwise rotation of Borneo. Hall (2009) and Metcalfe (2011) favour ~45 Ma for the timing of these events.

In what is today central Borneo, the Sarawak Orogeny in the mid Eocene (45-40 Ma) culminated in the uplift and emergence of the Rajang Group flysch that had accumulated in the foredeep off the previously submerged eastern margin of Sundaland (Hutchison, 1996). This episode of mountain-building across central and western Borneo is likely responsible for the exhumation and surficial erosion of the Schwaner granites, the formation of the Eocene Unconformity above the Rajang Group flysch, followed by the beginning of deposition of Crocker Fan sandstones in northern Borneo in the late Eocene-early Oligocene (~40-30 Ma). The Cretaceous Schwaner granites of southwest Borneo, and possibly the Permian-Triassic Tin Belt granites of the Thai-Malay Peninsula, comprise the likely source rocks for the Crocker Fan siliciclastic sandstones (Figures 2.6 & 2.7) (Hall, 2012; van Hattum *et al.*, 2013), though a source area as far afield as the eastern Himalayas has been suggested (eg Hutchison, 1996).

Subduction along the north coast of Borneo ceased in the early Miocene (~23 Ma) with the arrival at the subduction zone of microcontinental blocks that derived from the South China margin (Hall, 2012; van Hattum *et al.*, 2013). These blocks include the North Palawan Continental Terrane (NPCT), as well as the Reed Bank and Dangerous Grounds that today sit offshore Palawan and northwest Borneo, respectively. Following completion of subduction of the oceanic crust of the proto-South China Sea beneath Borneo, the collision of these microcontinental blocks with Sundaland likely drove the Sabah Orogeny in north Borneo, as well as uplift and deformation of the Eocene-lower Miocene Crocker Fan turbidites. This orogenic episode is manifest stratigraphically in part by the



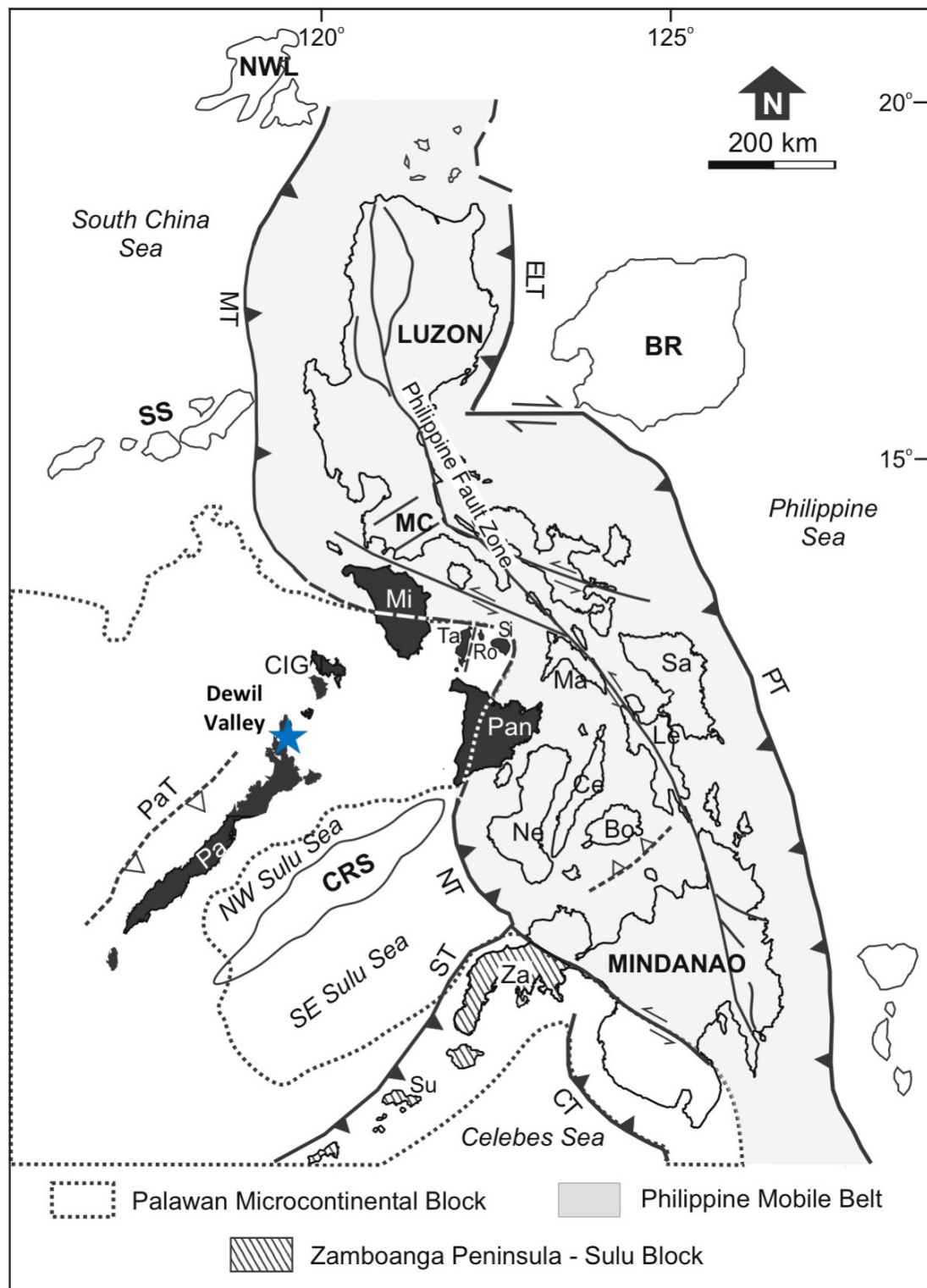
**Figure 2.6** Simplified regional geologic map of Borneo and surrounding areas of SE Asia. The Kelabit Highlands case study area appears as a yellow star; the Dewil Valley study area is at the northern tip of Palawan, which is underneath the legend in this map. Source: van Hattum *et al.* (2013).



**Figure 2.7** Diagrammatic representation of Crocker Fan deposition in the late Eocene – early Oligocene. Source: van Hattum *et al.* (2013).

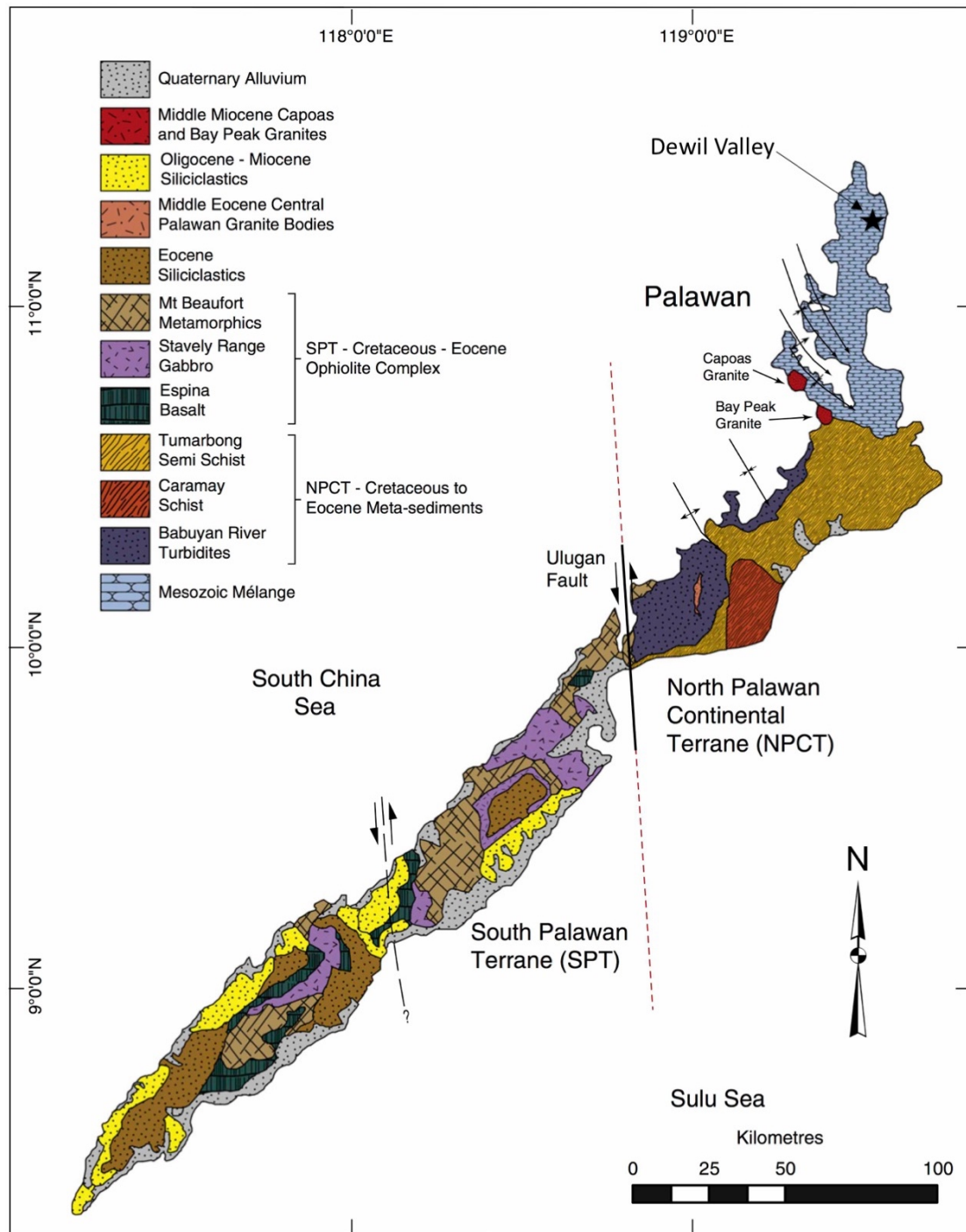
Top Crocker Unconformity (TCU) (van Hattum *et al.*, 2013). In northeast Sarawak and southwest Sabah, the TCU is overlain by the lower-mid Miocene siliciclastic sandstones of the Setap Shale and Meligan Formations. Van Hattum *et al.* (2013) note the similarity between these sandstones and those of the upper Cretaceous-lower Miocene Rajang and Crocker formations. The younger, overlying sandstones of the Setap Shale and Meligan Formations, though, are more mature in composition and texture (sorting and clast-rounding), and contain a higher proportion of quartzose minerals. Van Hattum *et al.* (2013) thus suggest that they are recycled from the uplifted and deformed Crocker and Rajang sandstones. The Setap Shale and Meligan Formation sandstones have, themselves, since been uplifted, deformed, and partially eroded, and today comprise many of the sandstone ridges and mountain ranges across interior north Borneo.

To the northeast of Borneo and the Sundaland core, the Philippines are made up of two major geologic blocks: the seismically active Philippine Mobile Belt that has been moving northwest ahead of the bow of the Australian Plate; and the aseismic Palawan microcontinental block (Figure 2.8) (Yumul *et al.*, 2009). The northeast-southwest trending Palawan is, itself, made up of two smaller terranes (Figure 2.9): the North Palawan Continental Terrane (NPCT), consisting of Eurasian continent-derived sedimentary and metamorphic rocks of Upper Palaeozoic-Palaeogene ages (>260-34 Ma); and the younger South Palawan Terrane (SPT), comprised of oceanic-derived rock formations such as the Palawan Ophiolite Complex (Mitchell, 1986) that are largely early Oligocene-early Miocene (34-22 Ma) in age. The oldest rock sequence reported in the Philippines is in the northernmost tip of Palawan Island and in the Calamian Island Group, a small archipelago off the northern tip of Palawan (Yumul *et al.*, 2009). This sequence consists of Upper Palaeozoic-Mesozoic turbidites, carbonates, chert, and quartz-rich sandstones that formed as accretionary complexes when Palawan was attached to the South China margin before rifting at ~45 Ma opened the South China Sea and initiated southward subduction of the proto-South China Sea (Suzuki *et al.*, 2000).



**Figure 2.8** Modern tectonics of the Philippines, consisting of two major tectonic regions: the Philippine Mobile Belt moving north and with active subduction at deep trenches along its eastern and western margins; and the Palawan Microcontinental Block indenter from the west, which rifted from the south China margin in the Eocene as the Proto-South China Sea subducted southwards and collided with the Mobile Belt in the early Miocene. The Dewil Valley case study area on Palawan Island appears as a blue star. Source: Yumul *et al.* (2009).





**Figure 2.9** Simplified geology and surface lithologies of Palawan. The Mesozoic Mélange in the north comprises a deep marine flysch sequence consisting of mudstones, shales and limestones, similar to the Rajang Formation of interior Borneo. Source: Suggate *et al.* (2014).

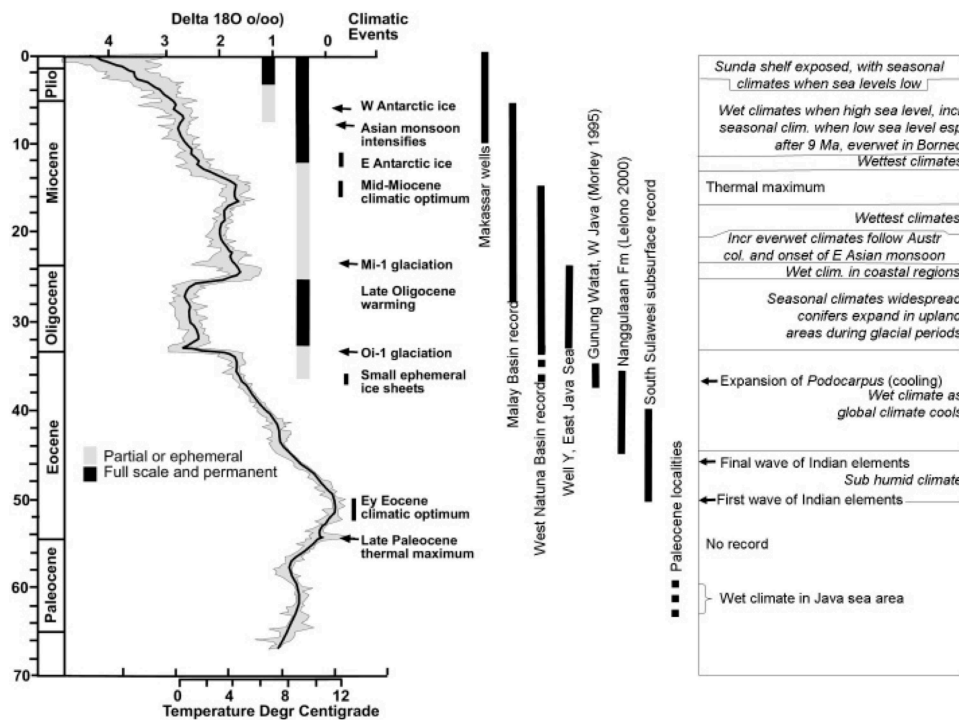
The Palawan microcontinental block collided with the Philippine Mobile Belt in the early Miocene (~23 Ma) (Hall, 2009). This is the same time that subduction of the proto-South China Sea ceased along the North Borneo Trench, as mentioned above. Minor south-eastward movement continued until Palawan was welded to the northeast margin of Sundaland by ~16 Ma (Hsu *et al.*, 2004).

Palawan is the only major Philippine island that is today tectonically part of Sundaland.

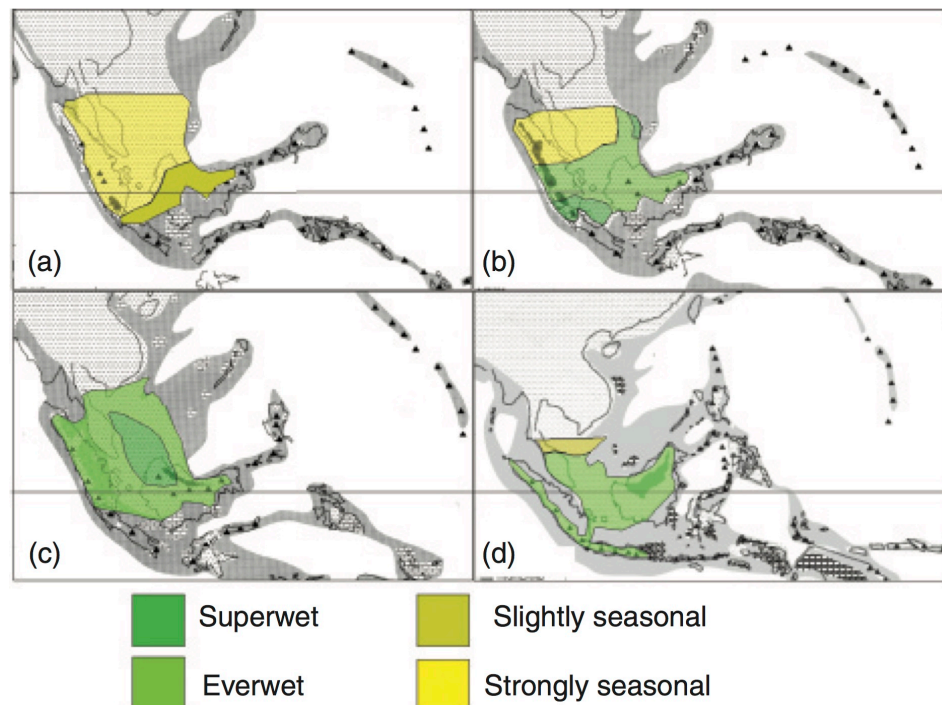
### **2.2.3 *Cenozoic palaeoclimates in relation to geology***

Island Southeast Asia's complex Cenozoic geological history has had a major impact upon the climatic development of the region and, thus, also upon its vegetation (Morley, 2012). Key events in this history were: the Eocene collision of India with Eurasia, followed by south-eastward extrusion of Indochina (Tapponnier *et al.*, 1986); closure of the Tethys Ocean, which affected ocean currents as well as the dispersal into the region of elements of the Indian flora (Morley, 2000); and the northward drift of Australasia leading to the Australian Plate's collision with Sundaland at the end of the Oligocene (~23 Ma). This final event resulted in development of the Indonesian Throughflow, and also facilitated limited interchange of floristic elements between Sundaland and Australasia (Morley 2002; 2003). These events coincide with widespread trends in climatic changes observed in Zachos *et al.*'s (2001) synthesis of deep-sea oxygen isotope records, reflecting the importance of the region to the global climate system (Figure 2.10).

The following narrative of climatic changes across the Cenozoic in Southeast Asia derives primarily from Morley (2012), which is inferred from fossil pollen and sediments. During the warm thermal optimum of the Palaeocene and early-mid Eocene epochs (66~45 Ma), a climatic gradient existed across the Southeast Asian region, with hot sub-humid climates in Sarawak, whilst Java was wetter at this time. As global temperature decreased into the mid Oligocene, climates across Sundaland were mainly sub-humid and seasonal (Figure 2.11a), with the development in the late Oligocene of wetter climates along the southern and eastern margins of the Sundaland core (Figure 2.11b). As the Australian Plate collided with Sundaland at the end of the Oligocene (~23 Ma), the subsequent constriction of the flow of warm equatorial waters from the Pacific to the Indian Oceans initiated the development of the complex patterns of inter-oceanic currents traversing the region that are referred to today as the



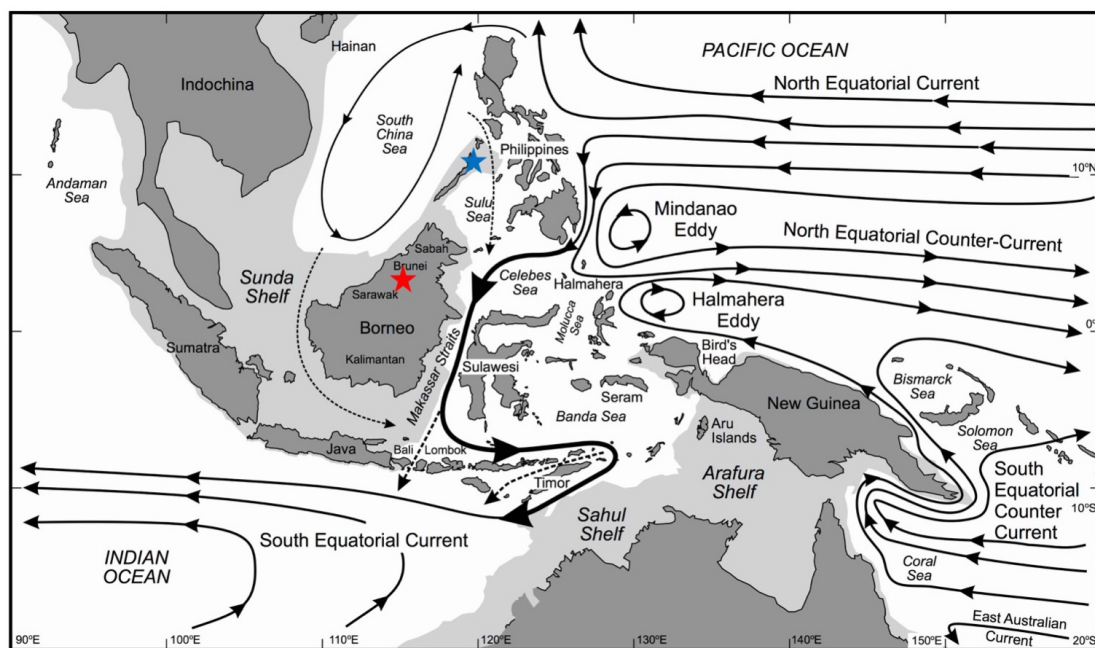
**Figure 2.10** Cenozoic global  $\delta^{18}\text{O}$  curve and major palaeoclimatic events from Zachos *et al.* (2001), compared with Southeast Asian palynological record and regional tectonic and climatic events. Time scale at left in millions of years ago. Source: Morley (2012).



**Figure 2.11** Mid-Cenozoic palaeo-rainfall reconstructions based upon palynological data: a) 28 Ma; b) 25 Ma; c) 20 Ma; d) 10 Ma. Source: Morley (2012).

Indonesian Throughflow (Figure 2.12). Moisture-laden air masses which overlaid the warm waters of the Indo-Pacific Warm Pool began to shed their precipitation on Sundaland from the early Miocene onward leading to the development and persistence of ever-wet climates in the Sundaland core (Morley, 2003) (Figure 2.11c&d).

The restriction of the flow of warm water and moist air from the equatorial west Pacific to the Indian Ocean since Australasia's collision with Sundaland ~23 Ma has been linked with the initiation of the East Asian (northeast) monsoon across the region (Sun & Wang, 2005). Global climate cooled through the late Miocene and Pliocene (~15-3 Ma) coincident with the expansion of northern hemisphere ice sheets. These processes were associated with the tectonic uplift of the Himalayas and the continued northward drift of the Australian continent into the southern hemisphere subtropical high pressure belt, which resulted in the initiation of the Australian (southwest) monsoon. Cane and Molnar (2001) link later stages of this process and continued restriction of the Indonesian Throughflow ~4-3 Ma to broader changes in the distributions of temperature and precipitation across the Indian Ocean, borne out in increasing aridification of East Africa.



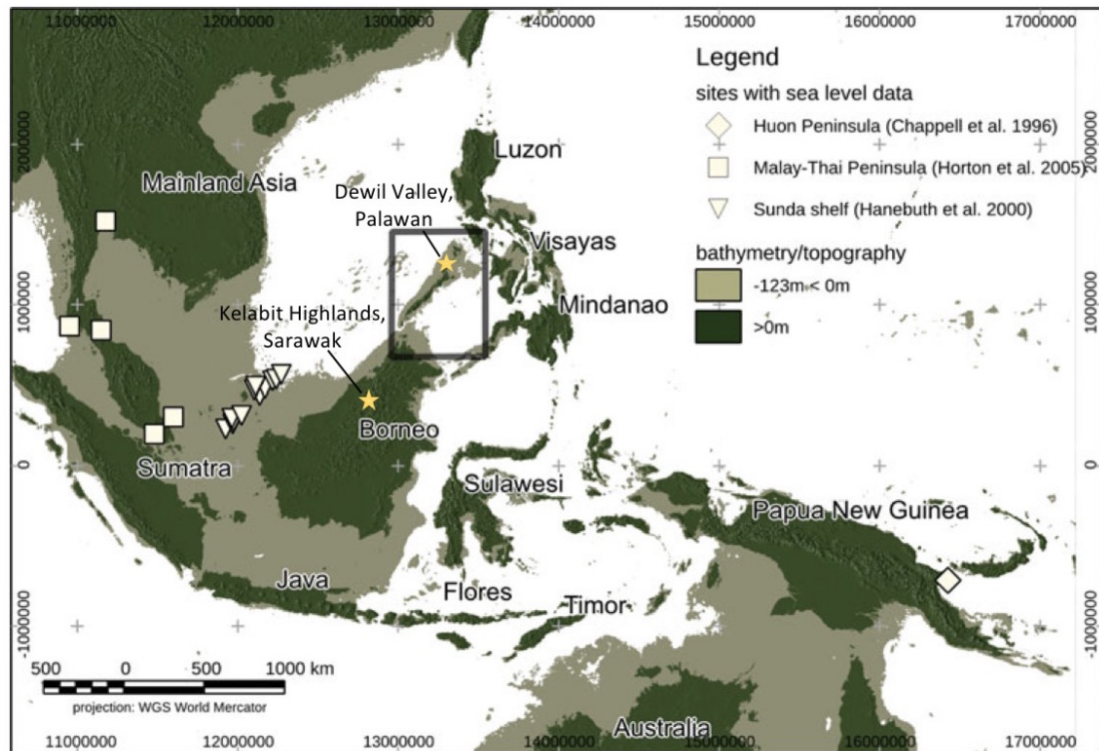
**Figure 2.12** Major modern ocean currents of the Southeast Asian Gateway, including the Indonesian Throughflow, the constriction of which has been linked to Miocene initiation of the Asian Monsoon and Pliocene aridification of East Africa. The two case study areas in the present study appear as coloured stars: Kelabit Highlands in red; Dewil Valley, Palawan in blue. Source: Hall (2009), after Godfrey (1996).

#### 2.2.4 Late Quaternary palaeoclimates and sea levels

Glacio-eustatic changes in sea-level throughout the Quaternary (~2.6 Ma – present) repeatedly drowned and exposed huge areas of the shallow Sunda and Sahul continental shelves within ISEA (Sathiamurthy & Voris, 2006; Voris, 2000). The exposure of the Sunda Shelf during glacial periods of lowered sea-level connected the large islands of Sumatra, Java, and Borneo with the Malay Peninsula, thus forming a contiguous extension of the Southeast Asian mainland referred to as Sundaland. Sea-level reconstructions and inferences from biogeographical distributions have often been in conflict regarding whether a land connection between Palawan and Borneo existed during the Last Glacial Maximum (cf Fox, 1970; Heaney, 1986; Reis & Garong, 2001), though there is agreement based upon the clear Sundaic affinities of the biota that a connection existed at some point during the Pleistocene. Using Geographic Information Systems based upon present-day bathymetry, Robles *et al.* (2015) argue that a lowering of sea-level by least 135m below that of the present-day is needed in order to expose a land connection between Palawan and Borneo, and this is likely to have occurred during the Pleistocene only during OIS 12 (~440 ka BP) and OIS 16 (~630 ka BP), with a shallow 15km-wide strait maintained during the LGM (Figure 2.13).

Fluctuations between cooler and drier, and warmer and wetter climates during OIS 3 after ~52 ka BP are reflected in the faunal and floral remains at Niah (Barker *et al.*, 2007; Hunt *et al.*, 2007; 2012). Periods of expansion and contraction of tall, closed rain forest are suggested, contemporary with the 'deep skull' (Barker *et al.*, 2007), as well as with the early human remains on Palawan at the Tabon Caves (Détroit *et al.*, 2004; Fox, 1970). Some authors argue that dispersal of large fauna, including humans, between parts of Sundaland that are now isolated islands covered primarily in rain forest was facilitated by a corridor of open, savanna-like vegetation (eg Heaney, 1991; Bird *et al.*, 2005). In contrast, palaeoenvironmental evidence also exists for the persistence of closed forest throughout even the coldest and driest glacial stages (eg Cannon *et al.*, 2009;

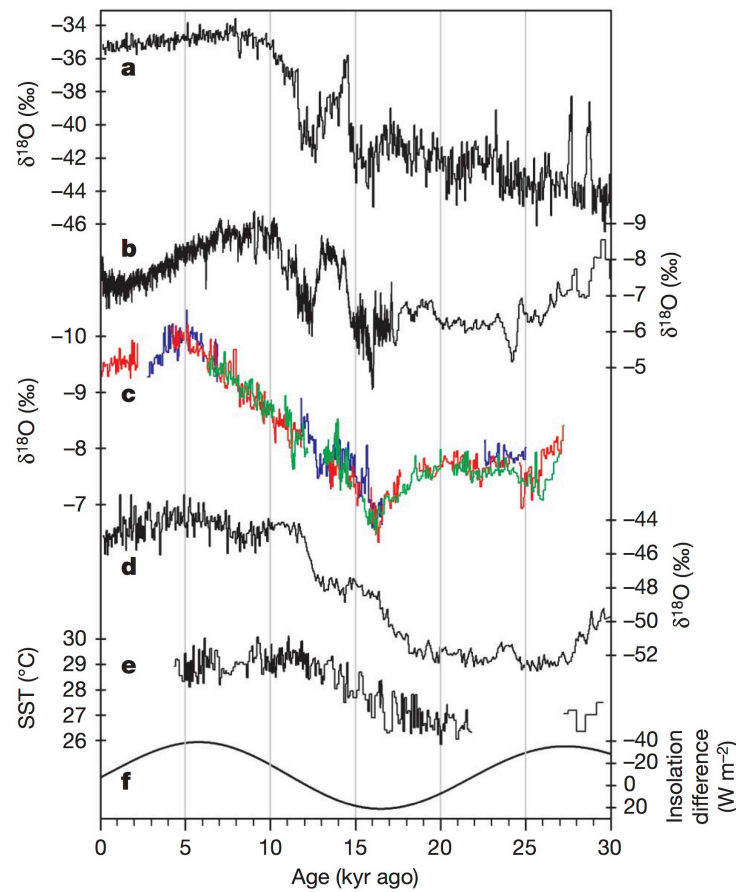




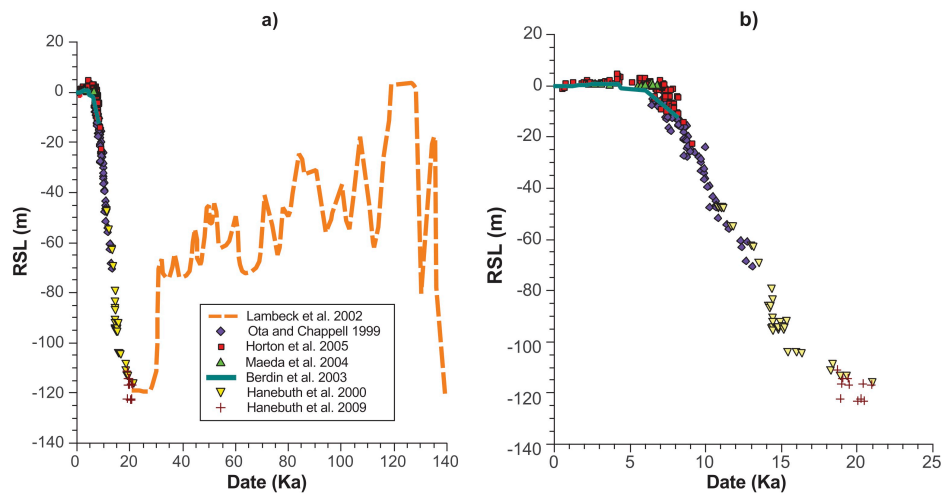
**Figure 2.13** Relief map of SE Asia showing present landmasses enclosed in dark green, and the -123 m bathymetric contour in grey-green, representing LGM coastlines. The two case study areas appear as yellow stars. The rectangle encloses Palawan, and is from the original publication. Source: Robles *et al.* (2015).

Wurster *et al.*, 2010). In any event, the archaeological record at Niah, with its evidence of novel hunting (eg Rabett, 2005) and plant processing techniques (Barton & Paz, 2007), shows that rain forest, had it persisted, would not have represented a significant barrier to human dispersal (Barker *et al.*, 2007).

Following dramatic decreases in temperature ~30-28 ka, sea-levels fell to their LGM low point of 123m below present levels (Hanebuth *et al.*, 2009) (Figure 2.13; 2.15a). Speleothem records from Borneo (Partin *et al.*, 2007) and Flores (Griffiths *et al.*, 2009) show correspondence between terminal Pleistocene climatic changes around the South China Sea, as well as southern Wallacea, with the northern hemisphere records of Meltwater Pulse 1A and the Bølling-Allerød stadial from 14.6-14.3 ka BP (Hanebuth & Stattegger, 2004) (Figure 2.14). Further pulses of sea-level rise occurred ~9-7 ka BP, and again in the mid-Holocene (eg Maeda *et al.*, 2004) (Figure 2.15), leading to expansion of mangrove forests (Fujimoto, 1997) and initiation of formation of many of the sub-coastal lowland peats, especially in Borneo (Anderson, 1964).



**Figure 2.14** Global comparison of northern Borneo (Gunung Buda NP, Sarawak) stalagmite  $\delta^{18}\text{O}$  records (c) with other late Quaternary palaeoclimate records. (a) Greenland (NGRIP) ice core  $\delta^{18}\text{O}$ ; (b) Hulu/Dongge caves (eastern China) stalagmite  $\delta^{18}\text{O}$ ; (d) Dronning Maud Land (Antarctica) ice core  $\delta^{18}\text{O}$ ; (e) Sulu Sea SST record from sediment core; (f) March minus September insolation at the equator. Source: Partin *et al.* (2007).



**Figure 2.15** Combined sea level curves from various Indo-Pacific sites for the past 140 ka (a) and 21 ka (b). Source: Robles *et al.* (2015).

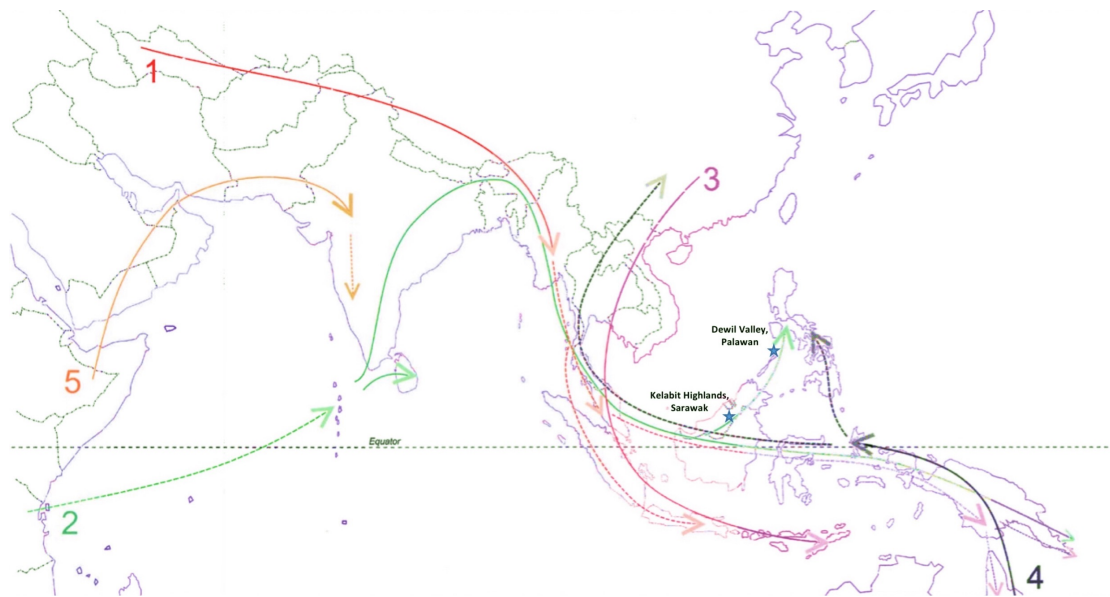
### 2.2.5 *Phytogeographic development*

The geologic and palaeoclimatic histories of ISEA just described have shaped opportunities for biotic dispersal into the region from adjacent areas. From a biogeographical perspective, two other regions that are often compared with ISEA when describing the development of biogeographic patterns, and in particular those related to dispersal across tectonic plate margins, are the Neotropics and southern Eurasia. The Cenozoic histories of all three of these regions are characterised by convergence of tectonic plates within low-latitude settings. The distinguishing difference regarding ISEA is that, whilst India collided with Eurasia in the Eocene, and the Isthmus of Panama became fully emergent and contiguous only in the Pliocene, narrow yet deep inter-oceanic seaways still flow between Sundaland and Australasia, forming significant barriers for some taxa (Richardson *et al.*, 2012).

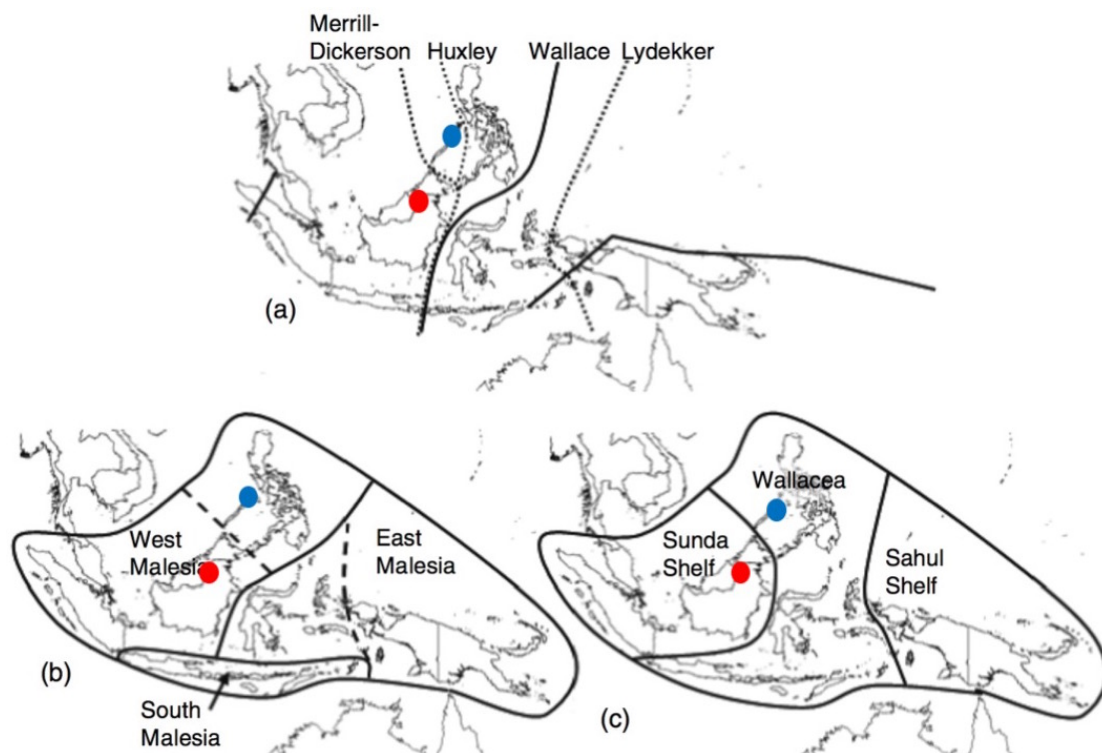
As early as Wallace (1869), the strong zoogeographic divide that traces the zone of convergence between the Sundaland microcontinental block and the Australian Plate was recognised. However, regarding his description of the region's significance for plant distributions, Wallace was more restrained. His phytogeographical inferences comprised the observation that temperate zone plant lineages inhabit montane elevations across ISEA. Phytogeographical distributions have indeed proven more complex than those of animals, with the significance of Wallace's Line for plants much diminished. This appears to be due to greater dispersal capacity of plants in comparison with that of animals, as recently demonstrated by Cody *et al.*'s (2010) re-examination of biogeographical patterns across the Isthmus of Panama using molecular phylogenetic methods.

The composition and distribution of the present flora of ISEA are aspects of the current states of ongoing processes which include, amongst others: geologically controlled opportunities for dispersal; climatically determined habitat suitability; and processes of community assembly and competition (Richardson *et al.*, 2012). Multiple major waves of dispersal into the region have occurred throughout the Cenozoic, following a few primary routes (Figure 2.16).





**Figure 2.16** Immigration tracks of flowering plants into tropical Asia, numbered in sequence across geological time: 1) pre-Eocene (before 50 Ma) immigration of limited angiosperm families from Eurasia; 2) Eocene rafting of Gondwanic elements such as dipterocarps on the Indian 'Noah's Ark'; 3) Oligocene (34-23 Ma) arrival of temperate eastern Laurasian conifers and magnoliids; 4) early Miocene dispersal of Australasian elements such as *Dacrydium* and *Casuarina*, and later Plio-Pleistocene immigrants *Dacrycarpus* and *Phyllocladus*; 5) post-Miocene dry elements from Africa into India. The two case study areas appear as blue stars. Source: Ashton (2014).



**Figure 2.17** ISEA biogeographical demarcations: a) zoogeographical divisions; b) van Steenis' (1950) original boundaries and internal divisions of the Malesian phytogeographical region; c) van Welzen *et al.*'s (2005) phytogeographical divisions of Malesia. In all three maps, the Kelabit Highlands case study area is shown as a red dot; the Dewil Valley study area is shown as a blue dot. Source: Richardson *et al.* (2012).

Overlain during the last three million years by the effects of repeated drowning and exposure of the shallow continental shelves described in the previous section, these processes have led to creation of a floristic region named Malesia

(*sensu* Zollinger, and van Steenis), that has consistently been subdivided into three sub-regions (Figure 2.17): 'West Malesia', 'East Malesia', and 'South Malesia' of van Steenis (1950), or roughly corresponding to the 'Sunda Shelf', 'Sahul Shelf', and 'Wallacea' of van Welzen *et al.* (2005). The boundaries of these subdivisions vary from study to study depending upon the methods used and the taxonomic level of analysis.

In general, greater dispersal across the region has occurred from west to east than in the opposite direction, though examples of the latter do exist (ie many Podocarpaceae and Myrtaceae). Morley (2003) likens the sub-region of Wallacea to a filter, exemplified by the ecologically and economically significant Dipterocarpaceae which are well represented west of the Wallace Line but poorly represented to the east. Thirteen plant families have an exclusively Sundaic distribution; eight are exclusively Sahulian; many clades within the palm family, Arecaceae, exhibit bi-centric and disjunct distributions with dual foci on Borneo and New Guinea (Baker *et al.*, 1998; Baker & Couvreur, 2012; Dransfield *et al.*, 2008). The Australasian elements that did successfully disperse into and take root within Sundaland are concentrated in habitats where competition has been reduced due to: temperature, as is the case with many of the montane conifers, and myrtaceous shrubs and treelets of higher elevations; or, due to edaphic limitation on nutrient or water availability, as with the extensive *kerangas*, *kerapah*, and peat communities of Borneo (Ashton, 2014).

## **2.3 Modern forest types and distributions**

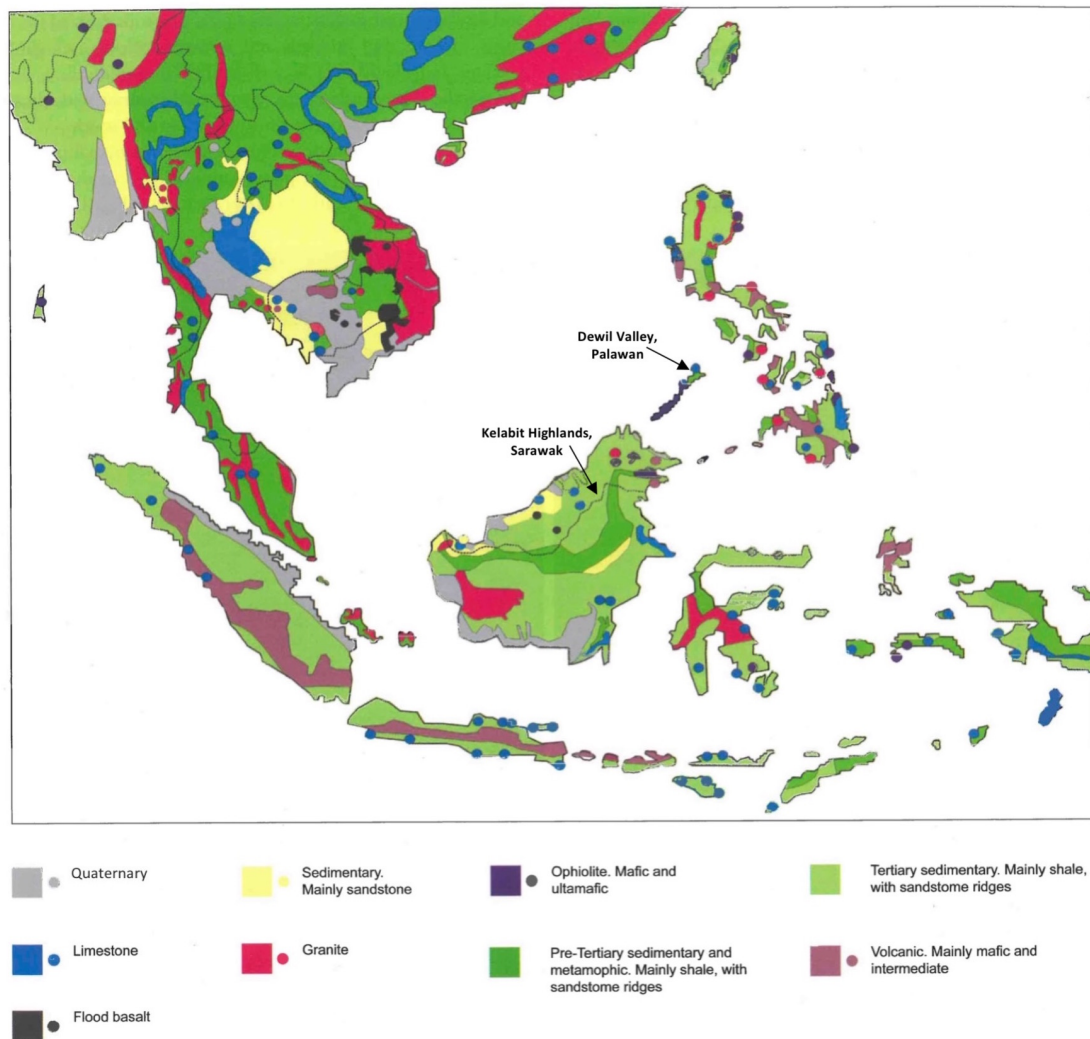
### **2.3.1 Forest formations in relation to soil, climate, and disturbance**

At a gross scale, Southeast Asian forests have commonly been classified into three broad climatic types: ever-wet tropical rain forest; drought-adapted tropical moist forest, or monsoon forest; and montane forest (van Steenis, 1950; Whitmore, 1984). Ever-wet tropical rain forest is restricted to climatic settings defined by >1750mm of rain spread evenly across the year (mean monthly rainfall exceeds estimated mean evapotranspiration, ie >100mm per month); monsoon forests occur within climates distinguished by <1250mm of seasonal rain, with a predictable multi-month period of low rainfall or drought; and

montane forests generally occur within the attitudinally depressed temperatures above ~1000m, though this elevation varies locally depending upon geography, ie continentality, localised diurnal cloud base, slope, aspect, and exposure (Richardson *et al.*, 2012).

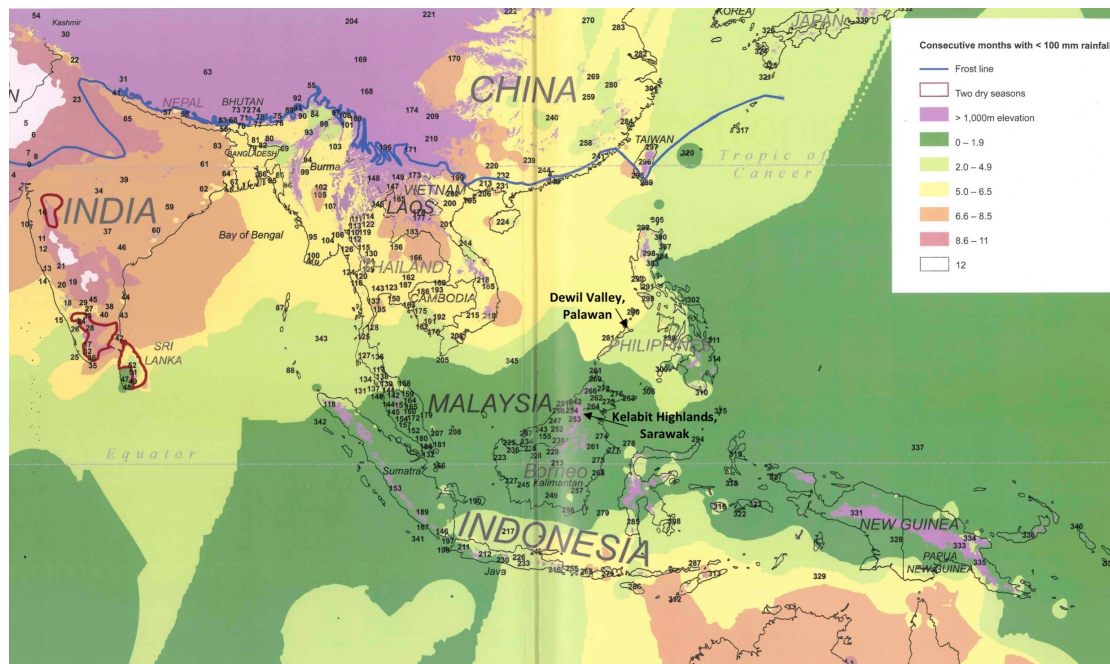
Ashton (1995; 2014) accounts for the various localised edaphic and physiographic modifiers to these climatically defined forest types. Ashton's classification emphasises forest formations or common floristic associations that occur within given envelopes delimited by the interplay between climate, soils, and disturbance. As such, the ever-wet tropical rain forest of van Steenis and Whitmore is further subdivided into mixed dipterocarp forest, and various edaphically or hydrologically controlled types such as *kerangas* (heath forest), *kerapah* (peat forest), limestone forests, ultramafic (ophiolitic) forests, riparian (riverine) forests, and mangroves. Within monsoonal climates, seasonal evergreen forests, and semi-evergreen forests occur. Montane forests are subdivided into lower montane and upper montane zones.

Distributions of soil parent material and mineral substrate (Figure 2.18), as well as patterns of rainfall seasonality (Figure 2.19), have been shaped by the geologic evolution described in the preceding sections. Distributions of major vegetation types across the region closely track patterns in rainfall seasonality (Figure 2.20), which are further modified by soil type. Detailed accounts of the floristic compositions of these forest types are beyond the scope of this chapter, though more in-depth treatment of floras local to the two case study areas in highland north-eastern Sarawak and lowland, sub-coastal northern Palawan appear in Chapters 3, 5, and 7. Below are some general descriptions, and comments about distributions of some of the notable forest types relevant to the present study.

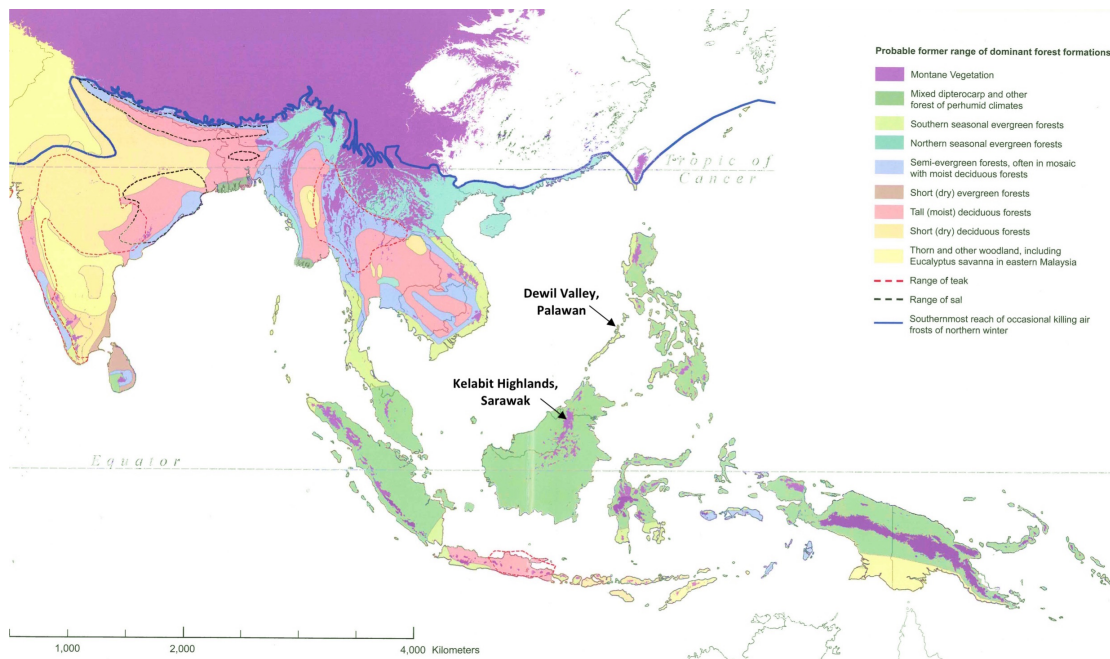


**Figure 2.18** Surface lithologies and soil parent materials across SE Asia, showing the two case study areas of the present study. Source: Ashton (2014).

Mixed Dipterocarp Forest (MDF) is the primary lowland vegetation type within ever-wet western Malesia, centred on northwest Borneo, peninsular Malaysia, and Sumatra. This is the iconic lowland rain forest of ISEA, with 80m tall emergent dipterocarps, abundant buttressed bases of main stems, large woody lianes, and multi-strata architecture. A structurally similar but floristically distinct type extends to the perhumid regions of the Philippines, Sulawesi, Moluccas, and New Guinea. The canopy layer of this forest type is dominated not by any single species, but by many, overwhelmingly in the family Dipterocarpaceae within western Malesia, whilst dipterocarps are poorly represented in eastern Malesia. Dipterocarps decline in both abundance and species diversity with altitude in a continuous manner up to ~ 700m. This forest type predominates on freely draining soils in lowland and ever-wet climates.



**Figure 2.19** Distribution of average seasonality in rainfall across tropical Asia. Note the ever-wet central Sundaland core encompassing Borneo (on which the Kelabit Highlands case study area is located), peninsular Malaysia and Sumatra, and the surrounding areas of increasingly seasonal rainfall (including the case study area of the Dewil Valley, Palawan). Source: inside front cover of Ashton (2014).



**Figure 2.20** Distribution of major vegetation formations across tropical Asia, displaying a close relationship to the distribution of rainfall seasonality. Montane vegetation (purple) is the dominant vegetation type across the Kelabit Highlands, whilst seasonal evergreen forest (light green) covers most of Palawan, including the Dewil Valley case study area. Source: inside back cover of Ashton (2014).

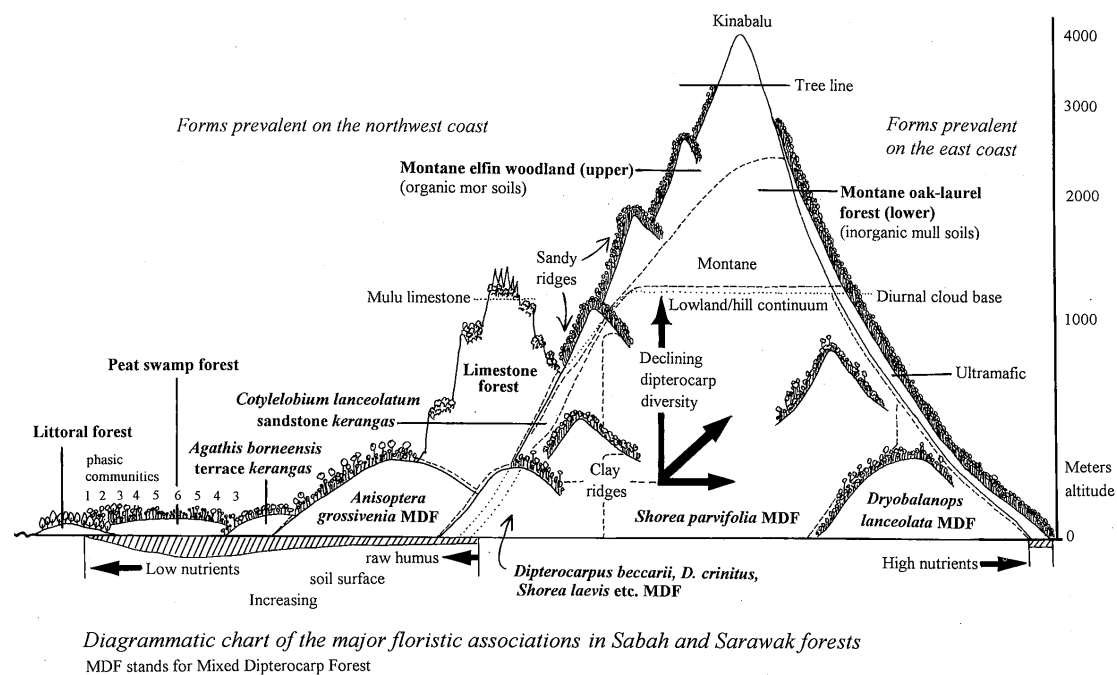


*Kerangas* is forest of low stature, composed of pole-sized trees, and confined to white sand soils. The term *kerangas* originates from Borneo, and refers to land unsuitable for rice cultivation (Ashton, 2014) due to the low soil nutrient availability and drought-prone freely draining mineral substrate. Leaf sizes are small (notophyll-microphyll), and canopies are relatively open, facilitating penetration of diffuse light. These communities occur on deep podzols of raised Pleistocene beach terraces, and on shallower podzols of sandstone ridges and montane plateaux. Plant families that are particularly well-represented within *kerangas* are Myrtaceae, Theaceae, Podocarpaceae, Ericaceae, Clusiaceae, and Ebenaceae, with conspicuous occurrence of the pitcher plants of Nepenthaceae.

*Kerapah* is the swamp analogue of *kerangas*, which occurs on deep peats. Anderson (1964) recognised six phasic communities that change in structure and composition, and are distributed in concentric bands across the large peat domes common along the coastal alluvial plains of northwest Borneo. Species diversity in *kerapah* is reduced, and there is a tendency toward canopy dominance of *Shorea albida* Symington (Dipterocarpaceae). The proportion of taxa endemic to the *kerapah* flora is small, with many peat swamp elements also found in *kerangas* or surrounding mixed dipterocarp forest.

Mangrove forests are woody vegetation types restricted to the tidal zone and occupying marine or brackish environments in the tropics and sub-tropics (Giesen *et al.*, 2006). Notable physiological features common in many taxa of mangroves are stilt roots and pneumatophores, which represent adaptations to the saline and regularly inundated habitat. Taxa of the family Rhizophoraceae are dominant elements, whilst *Avicennia* L. (Acanthaceae), *Sonneratia* L.f. (Lythraceae), *Nypa fruticans* Wurmb (Arecaceae), and *Acrostichum* L. (Pteridaceae) are common in Southeast Asian mangroves, which are globally the most extensive and diverse of this vegetation type.

Regarding altitudinal zonation of forest types, Ashton (1995) provides a diagrammatic chart of the major floristic associations that occur across the sharp and diverse topographies of Sabah and Sarawak (Figure 2.21). Additionally,



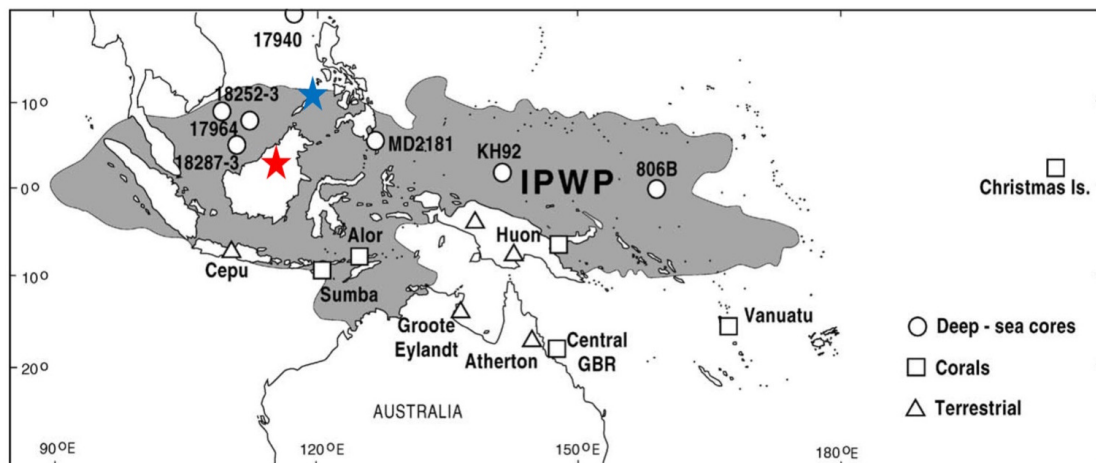
**Figure 2.21** Diagrammatic example of relationships between major floristic associations, elevation and substrate in Sarawak and Sabah, taken as representative of Sundaland forests. Source: Ashton (1995).

Kitayama (1992) looks more specifically at the flora at different elevations on Mount Kinabalu, whilst van Steenis (1984) summarises floristic altitudinal zones across the Malesian region. Montane forests occur above the local diurnal cloud base. In northwest Borneo, lower montane forest occurs from ~900-1800m, passing into the upper montane zone above this elevation. Lower montane forests in Southeast Asia are frequently referred to as oak-laurel forests due to the abundance and diversity of taxa within the families Fagaceae and Lauraceae. Canopy height of lower montane forest is generally 25-30m, with tree diameters at breast height ~60-90cm (Lim, 2006). Upper montane ('elvin') forest is much shorter in stature, ~8-10m, with epiphytic orchids, mosses, and bryophytes cloaking trunks and branches. Dominant families are Myrtaceae, Fagaceae, Clusiaceae, Theaceae, and Araucariaceae. Soils supporting these upper montane forests are thin or non-existent, with the substrate composed of raw humus and mats of tangled rootlets.

### 2.3.2 ENSO and supra-annual cyclicities

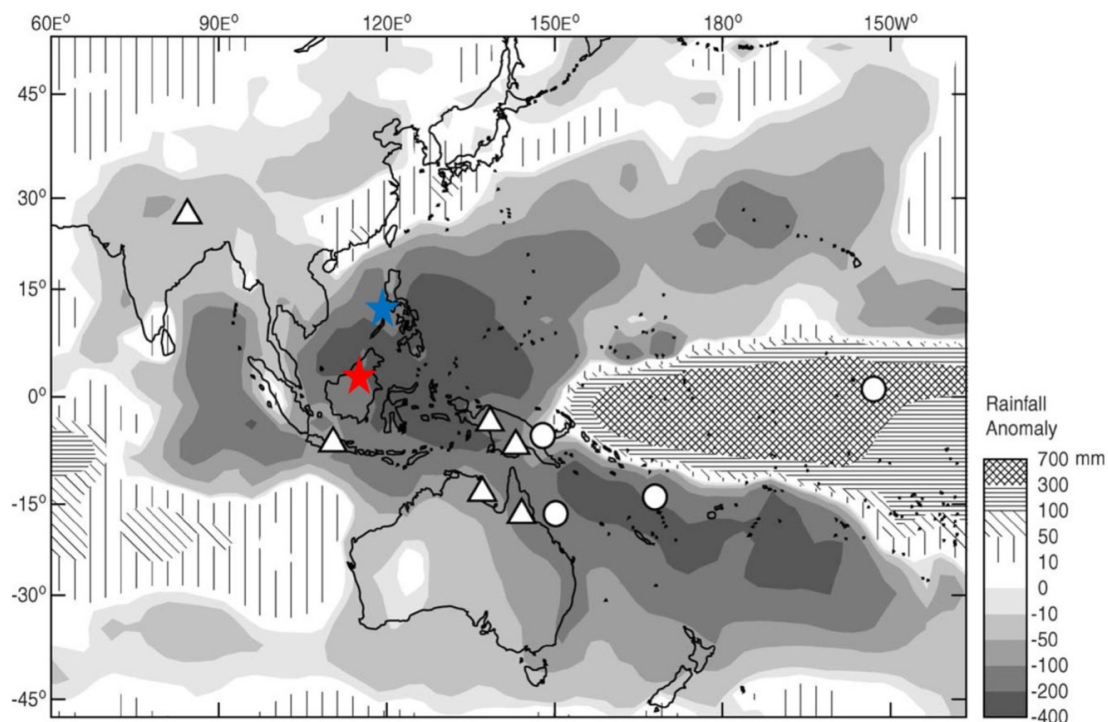
The Indo-Pacific Warm Pool (IPWP; Figure 2.22) is the largest contiguous expanse of warm surface seawater in excess of 28°C anywhere on Earth. This pool of warm equatorial water drives atmospheric convection currents in moist overlying air masses, leading to localised precipitation surpluses over evaporation in excess of 2m (Oberhuber, 1988). This thin skin of solar-heated surface waters is variable from year to year in size, temperature, and positioning, with implications for global climate (Cane & Clement, 1999; Clement *et al.*, 2001). This variable influence operates on time scales spanning the inter-annual (El Niño-Southern Oscillation; ENSO) to millennial (Cane & Clement, 1999). The formation of the IPWP has been linked to the constriction of the Indonesian Throughflow as Australia has come into closer contact with the Eurasian continent in eastern Indonesia since the lower Miocene (~23 Ma) (Hall *et al.*, 2011b).

The strong *El Niño* conditions (periodic, inter-annual eastward displacement of the warm surface waters of the IPWP into the central tropical Pacific, driven by temporary failure of the easterly trade winds and leading to decreased convective rainfall over ISEA) (Figure 2.23) in 1982-83 and 1997-98



**Figure 2.22** Spatial extent of the Indo-Pacific Warm Pool, consisting of a thin skin of relatively warm, fresh, buoyant water in excess of 28°C. This pool of solar-heated surface water is an integral element of the global coupled ocean-atmosphere system, and drives vigorous convection of overlying moist air leading to 2m surplus in precipitation. The two case study areas of the present study are shown as coloured stars: the Kelabit Highlands, Sarawak in red; the Dewil Valley, Palawan in blue. Source: Gagan *et al.* (2004).



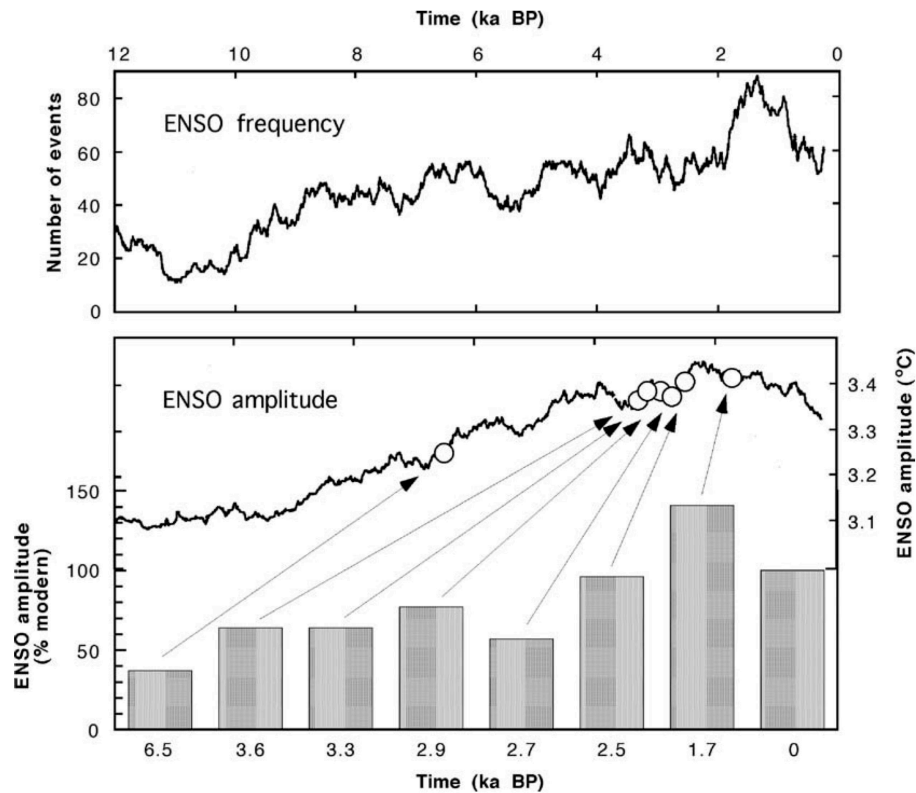


**Figure 2.23** Rainfall anomalies across the Indo-Pacific during modern *El Niño* events from 1900-1998, as compiled from rain gauge records and satellite estimates. The two case study areas in the present study are shown as coloured stars: the Kelabit Highlands, Sarawak in red; the Dewil Valley, Palawan in blue. Source: Gagan *et al.* (2004).

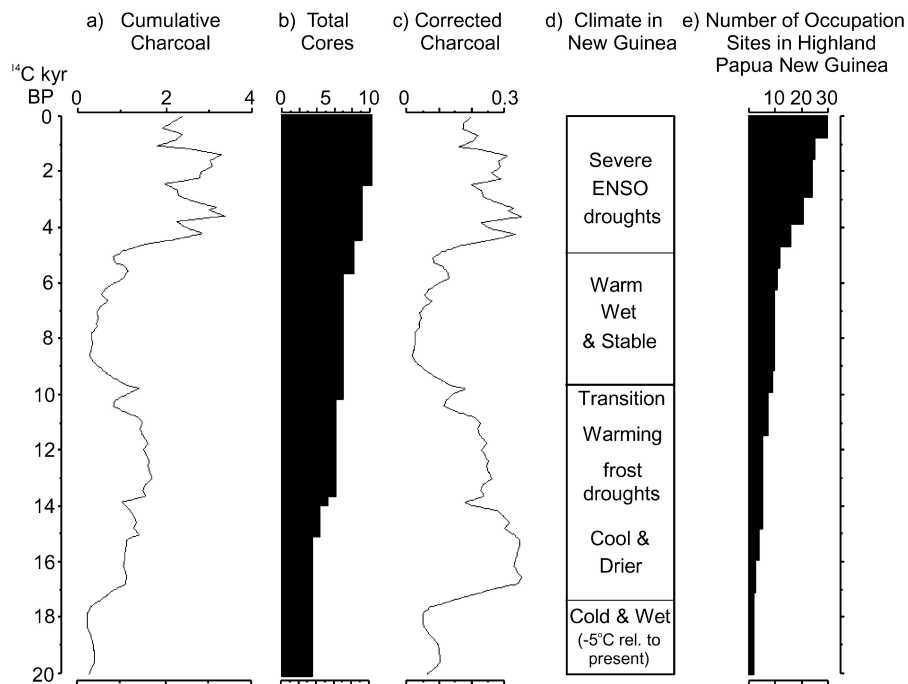
caused severe drought and extensive fires across large areas of ISEA (Siegert *et al.*, 2001), which destroyed vast tracts of normally wet tropical forest. These events provided impetus to increase study of ENSO dynamics and history. Subsequent marine palaeothermometry studies using foraminiferal Mg/Ca and alkenone unsaturation ratios from deep-sea sediment cores from different parts of the IPWP (eg Kienast *et al.*, 2001; Lea *et al.*, 2000; Stott *et al.*, 2002) have led to the development of detailed histories for the post-glacial evolution of sea surface temperature across ISEA. During the Last Glacial Maximum (LGM), sea surface temperatures in the IPWP were  $\sim 3^{\circ}\text{C}$  cooler than at present. In the centre of the IPWP north of New Guinea, the rapid post-glacial rise in sea surface temperature led northern hemisphere deglaciation by  $\sim 3000$  years (Lea *et al.*, 2000; Stott *et al.*, 2002). In contrast, records from the Sulu and South China Seas (Figure 2.14e) (Kienast *et al.*, 2001) are synchronous with well-dated northern hemisphere post-glacial palaeoclimatic features such as the Bølling-Allerød and Younger Dryas events.

The state of the ENSO phenomenon in the equatorial Pacific is central to the inter-annual variability in the global climate system (Gagan *et al.*, 2004). The

location of IPWP waters and associated convective rainfall is tied to the state of the ENSO. During *El Niño* events, temporary failure of the easterly trade winds leads to an eastward shift of the IPWP out into the central tropical Pacific. This, in turn, changes the distribution of precipitation, fuelling drought in the western Pacific and increased rainfall in the eastern Pacific. Palaeohistoric records of *El Niño* events from both sides of the tropical Pacific track an increase in frequency and development of modern modalities from ~5000 BP, with a peak in intensity ~3000-1700 BP (Figure 2.24) (Donders *et al.*, 2007; Gagan *et al.*, 2004; Goldammer and Seibert, 1989; Haberle and Chepstow-Lusty, 2000; Haberle and Ledru, 2001; Haberle *et al.*, 2001; Markgraf *et al.*, 1992; Mooney *et al.*, 2011; Partin *et al.*, 2007; Power *et al.*, 2008). It is expected that sedimentary charcoal curves, in their utility as proxy records of past regional fire (Patterson *et al.*, 1987), would mirror *El Niño* indices from the Indo-Pacific region. Haberle *et al.* (2001) compared records of post-glacial ENSO development with a cumulative charcoal curve from ten pollen cores from New Guinea and Indonesia (Figure 2.25) to test this expectation. Their results appear to show that, whilst people have inhabited the region since before the LGM (eg Summerhayes *et al.*, 2010), regional burning closely tracks climatic variability.



**Figure 2.24** Summary of reconstructed and insolation model estimates of Holocene evolution of ENSO frequency (top) and amplitude (bottom). Source: Gagan *et al.* (2004).

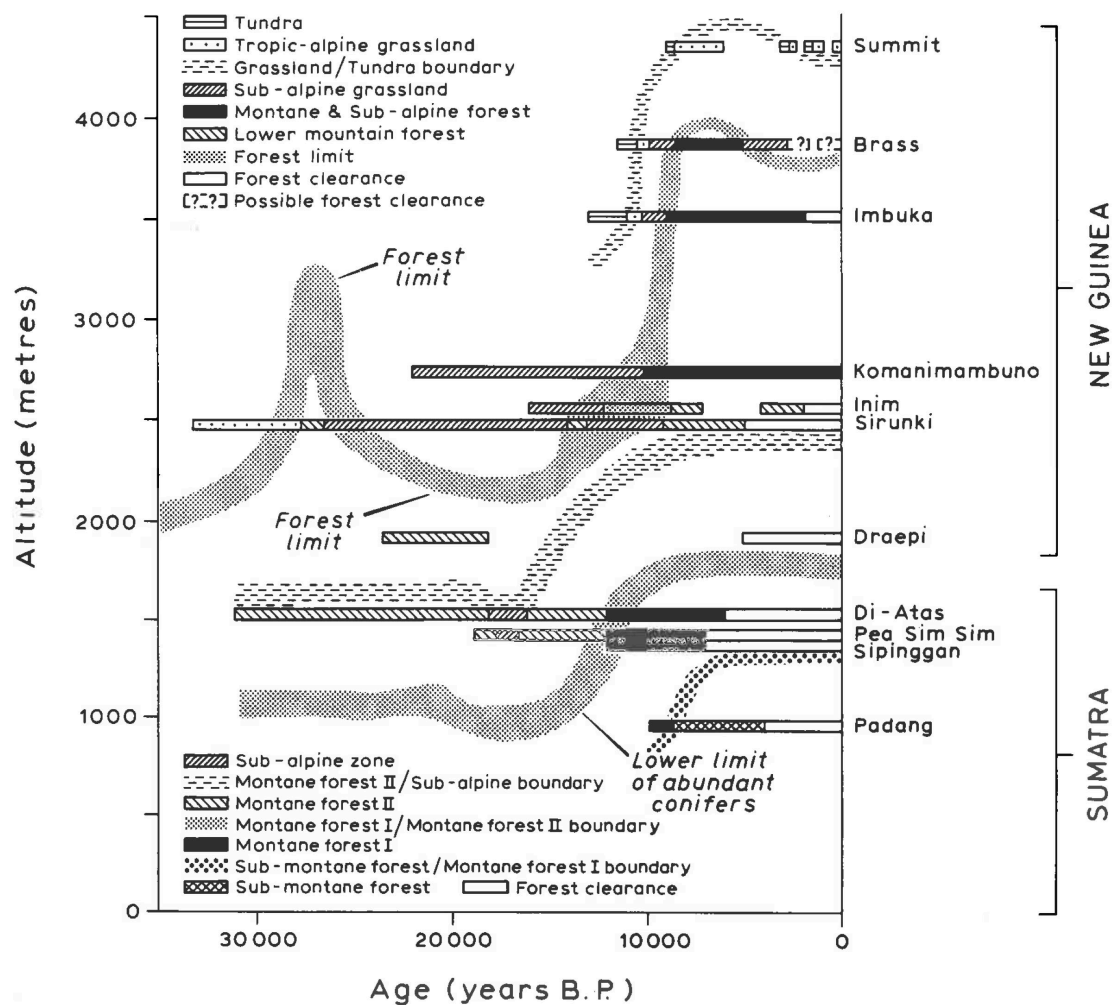


**Figure 2.25** Comparison of cumulative charcoal curve from ten records across New Guinea and Indonesia (synthesised in Haberle & Ledru, 2001) with IPWP records of post-glacial climatic evolution. Source: Haberle *et al.* (2001).

## 2.4 Palaeoecology and land use

During the late 1960s through 1980s, pollen studies with regional implications across ISEA were concentrated in montane environments above 1000m elevation, whilst early records from the lowlands came from peat swamps which showed predominantly localised hydroseral vegetation changes (eg Anderson and Müller, 1975; Haseldonckx, 1977; Morley, 1981a&b; Müller, 1965). The large, mountainous islands of Sumatra in the Sundaic west of the region and New Guinea in the Sahulian east were two broad spatial foci of early montane studies (eg Flenley, 1967; Hope, 1973 & 1976; Maloney, 1979; Morley, 1976; Morley, 1982; Newsome, 1988; Powell, 1970; Walker, 1970; Walker & Flenley, 1979). Flenley's (1979a&b; 1984) syntheses of these records played a role in the re-shaping of thinking surrounding tropical forest histories that was referred to in Chapter 1. These early studies have since been built upon with records from other islands (eg Anshari *et al.*, 2001; 2004; Dam *et al.*, 2001a; Hope, 2001; Hope *et al.*, 2005; van der Kaars & Dam, 1995; Stuijts *et al.*, 1988), and syntheses have repeatedly been refined (eg Flenley, 1998; Haberle & David, 2004; Haberle *et al.*, 2001; Haberle & David, 2004; Hope *et al.*, 2004).

Quaternary glacial periods were characterised by more open vegetation than that of interglacials, which was a result of both cooler and drier conditions (Hope *et al.*, 2004). Regionally, montane temperatures may have been depressed by as much as 5-7°C at the Last Glacial Maximum (Haberle & David, 2004), though records from the Indo-Pacific Warm Pool suggest less of a temperature reduction (eg Lea *et al.*, 2000; Stott *et al.*, 2002). As mentioned above in section 2.2.5, there is evidence in Sundaland for a 'savanna corridor' at the LGM (Bird *et al.*, 2005; Heaney, 1991), as well as evidence for a mosaic of drier vegetation types with persistent yet restricted distribution of moist, lowland forest at this time (Wurster *et al.*, 2010). After the Late Glacial and terminal Pleistocene, montane pollen diagrams from the region (Figure 2.26) show a shift upslope of

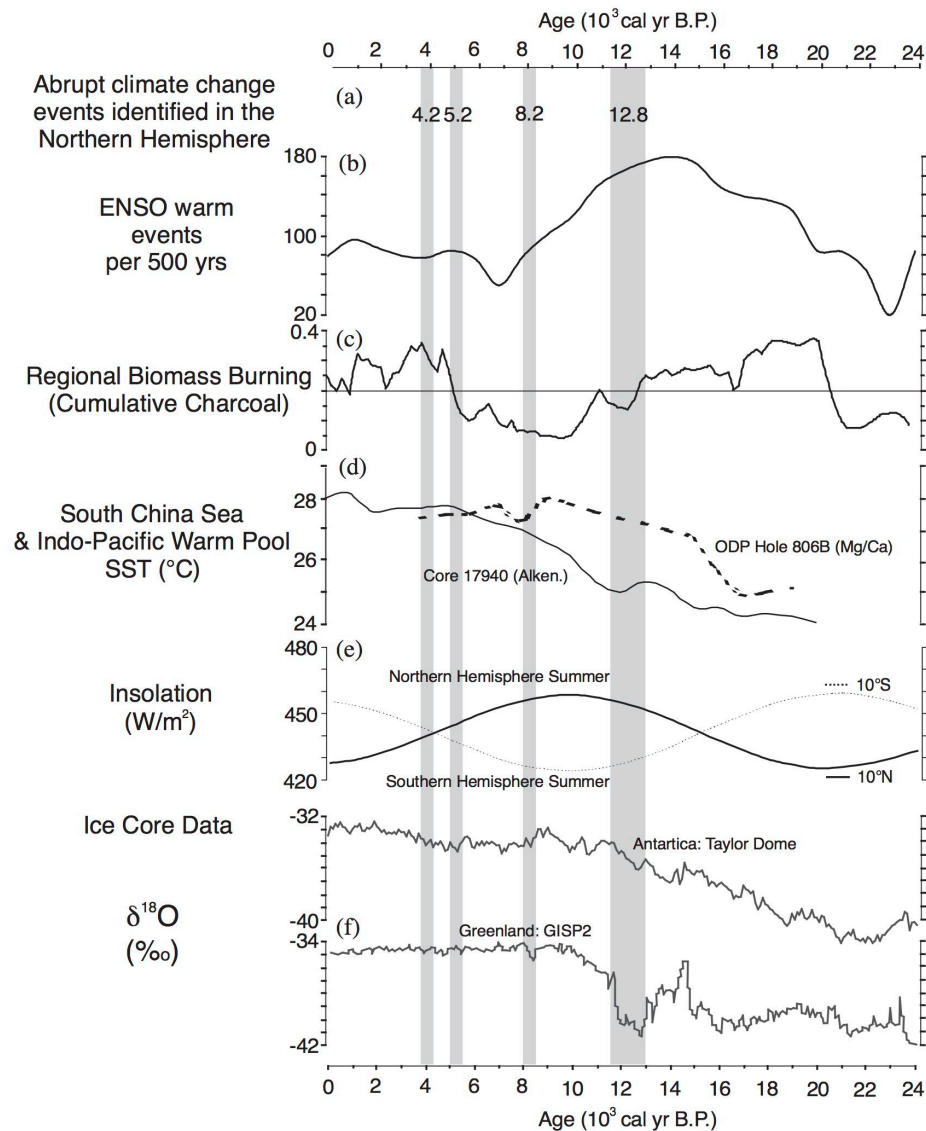


**Figure 2.26** Summary of inferred changes in altitudinal vegetation zones from early pollen diagrams from New Guinea and Sumatra. The New Guinean records generally come from higher elevations nearer to the present tropic-alpine zone, so inferences regarding forest limits derive primarily from New Guinea whereas most of the Sumatran sites are located within the present montane forest bands. Source: Flenley (1984).

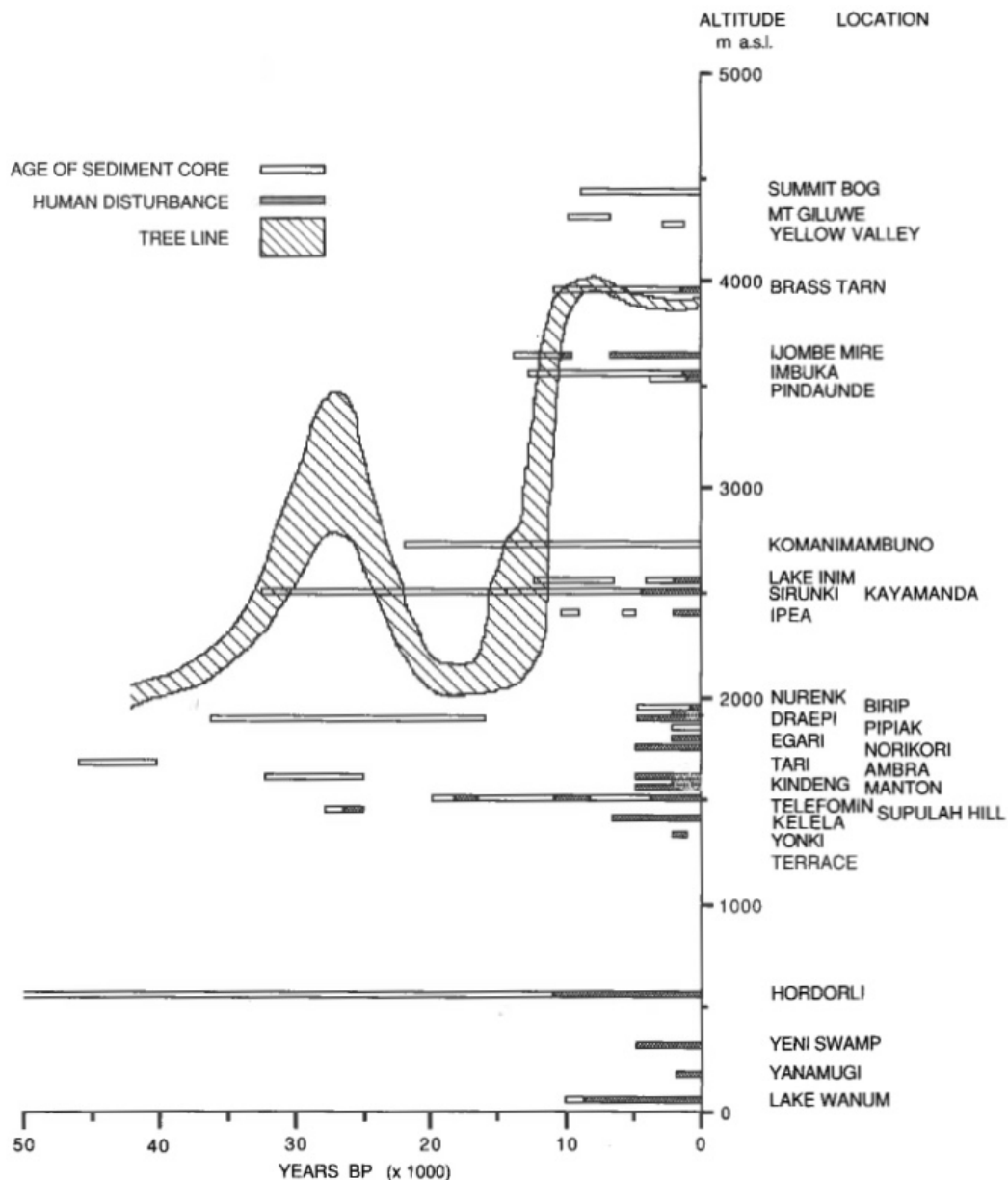
altitudinal vegetation zones with the warming and climatic amelioration of the early Holocene. However, Quaternary climatic changes across glacial-interglacial cycles in ISEA seem to be represented differently in the highlands and lowlands (Hope *et al.*, 2004). Temperature is the variable that most influenced montane vegetation, whereas moisture availability has had the major effect upon lowland environments. The alternate drowning and exposure of the Sunda and Sahul continental shelves throughout the Quaternary as a result of glacio-eustatic fluctuations has also had marked influence upon lowland vegetation due to the effect on weather systems associated with localised changes in continentality (Partin *et al.*, 2007).

Post-glacial palaeoclimatic development across ISEA appears spatially heterogeneous at a regional scale. This is possibly due to the role of the marginal seas. The onset of moister conditions and increases in moist forest cover seem to have been locally delayed until the shelf areas had been inundated (Hope *et al.*, 2004). Sea surface temperature reconstruction from the South China Sea for the last glacial transition (~17,000-9000 BP) mirrors the northern hemisphere climatic changes (encompassing the warming of the Bølling-Allerød interstadial at 14,600 BP and the cooling of the Younger Dryas stadial at 12,800 BP) inferred from proxy records from Greenland (Kienast *et al.*, 2001). In contrast, these same temperature reversals are not recorded in the centre of the Indo-Pacific Warm Pool (IPWP) north of New Guinea (Stott *et al.*, 2002). Later episodes of inferred aridity in northern hemisphere records at 8200, 5200, and 4200 BP are similarly paralleled in Southeast Asia in records from outside of the IPWP (eg Gagan *et al.*, 2004) (Figure 2.27). Local climate dynamics associated with the Indo-Pacific Warm Pool seem to have overshadowed influences from deglaciation in the northern hemisphere (Haberle & David, 2004). This spatial heterogeneity in distributions of palaeoclimatic changes across the region has bearing on interpretations of drivers of changes inferred from other proxy palaeoenvironmental records.

The strongest cases for signs of human impact in Holocene palaeoecological records from ISEA come from New Guinea. Numerous well-dated palynological and archaeological sequences have been published over the past 50 years, primarily from the inter-montane valleys of the Central Cordillera and higher elevations (eg reviews in Fairbairn *et al.*, 2006; Haberle, 1994; Haberle & David, 2004; Haberle *et al.*, 2001; Hope *et al.*, 1983; 2004; Hope & Haberle, 2005), though important lowland pollen cores also exist (eg Hope & Tulip, 1994; Garrett-Jones, 1979). These records have been synthesised by Flenley (1979a), and modified by Haberle (1994) to include suggested signs of human impact (Figure 2.28). Whilst initial interpretations of pollen and charcoal records from areas of the highlands such as the Baliem Valley and Tari Basin attributed increases in fire-related disturbance at 32,500 and 20,000 BP, respectively, to human influence (eg Haberle *et al.*, 1991; Haberle, 1998b; Hope,



**Figure 2.27** Comparison of equatorial Indo-Australasian and global climate proxies: (a) abrupt climate change events identified in the Northern Hemisphere (Weiss, 2000); (b) modelled number of ENSO warm events per 500 years (Clement *et al.*, 2000); (c) regional burning curve derived from records from New Guinea and Indonesia (Haberle *et al.*, 2001); (d) sea surface temperature reconstructions from ODP Hole 806B on the Ontong Java Plateau (Lea *et al.*, 2000) and Core 17940 in the South China Sea (after Pelejero *et al.*, 1999); (e) low-latitude summer insolation (Berger & Loutre, 1991); (f) δ<sup>18</sup>O ice-core data from Antarctica (Broecker, 1998) and Greenland (Grootes *et al.*, 1993). Source: Haberle & David (2004).



**Figure 2.28** New Guinea pollen records interpreted to show human disturbance. Sites Draepi, Ambra and Manton within the cluster of sites between 1000-2000 m are located in the same catchment as the Kuk Swamp archaeological site. Source: reproduced and modified in Haberle (1994), after Flenley (1979a).

1998), the severe ENSO-induced drought and fires of 1997-98 across ISEA, and the subsequent palaeothermometry studies mentioned above, appear to have influenced thinking on the relative importances of climate and people in driving past vegetation changes (Goldammer, 2007). Subsequently, Haberle *et al.*'s (2001) summary of pollen records from New Guinea and Indonesia suggests widespread forest clearance as early as only 7800 BP and intensifying through to the present. In parallel, Haberle *et al.* (2001) attribute the dramatic increase shown in the regional burning curve after 6000 BP, and peaking between 4500



and 1000 BP, to increased climatic variability associated with severe ENSO-induced droughts (Figure 2.27b&c). Within the last ~1000 years, the innovation of *Casuarina* silviculture as a source of fuel and timber, and as a means of soil nitrogen replenishment, appears widespread across the highlands of New Guinea (Haberle, 2007).

Haberle and Ledru (2001) argue that increases in *El Niño* strength and frequency from the mid-Holocene (see Figures 2.24 and 2.27b&c) are a potential cause of vegetation shifts across the Southeast Asian region towards more secondary forest and increased burning from this time. For example, Maxwell's (2001) record from Kara Lake in northeast Cambodia, to the north of the Sundaland core, implies a strengthened summer monsoon from 8400-5300 BP. This is followed by evidence for drier climates marked by more frequent fires and successional taxa after 5300 BP. Recovery of moist forest is suggested in the last 2400 years. To the east of Sundaland, in north-western Luzon, Stevenson *et al.*'s (2010) record from sub-coastal Paoay Lake shows a sustained increase in charcoal between 6500-5000 BP. The authors also note evidence of disturbance in extra-local submontane forests, as inferred from the wind-dispersed pollen of elements of *Pinus*-dominated communities. Apparent recovery of these pine forests occurs after 1000 BP. To the south of the Sundaland core, records from west Java (Stuijts, 1993) and South Kalimantan (Sémah and Sémah, 2012) suggest increased seasonality and evidence of drying from 6000 BP. In central Java, Sémah *et al.* (2004) record forest recession and development of grasslands at ~4000 BP, with what they see as unequivocal human impact only from ~1500 BP. Frequency analyses of drier rain forest and sclerophyll components, and charcoal in marine cores from the region also reveal mid-late Holocene tropical monsoon and ENSO influences (Hope *et al.*, 2004).

Holocene pollen records from the large island of Borneo in the centre of Sundaland are mixed regarding interpretations of potential signs of human impact. Charcoal and microfossil assemblages with secondary taxa have been identified in both Pleistocene (Anshari *et al.*, 2001; 2004) and Holocene (Hope *et al.*, 2005) portions of pollen records from Kalimantan. Anshari *et al.* (2001; 2004) present discontinuous pollen sequences from the Lake Sentarum region of

West Kalimantan which show changes in climate and vegetation, as well as increasing charcoal abundances throughout the records from 30,000 BP. The authors argue that the inferred fires are anthropogenic throughout, with highest human impact within the last ~1400 years. In contrast, in their study of 95 cores distributed along transects across areas of the Kutai peatlands of East Kalimantan, Hope *et al.* (2005) note that whilst charcoal from rainforests in East Kalimantan has been dated to the Pleistocene through to the Holocene (Goldammer & Seibert, 1989), these authors argue that anthropogenic burning is not evident until ~3000 BP with appreciable increases after 1500 BP. If this is correct, this may be a greater reflection of past human populations' aversion to peat swamps than evidence of their broader minimal impact.

Within Sarawak in Borneo's northwest, along the South China Sea coast and adjacent to the Sunda Shelf, Anderson and Müller (1975) present a Holocene record from a large peat dome, which shows seral changes through time that parallel the different phasic communities recorded in the modern vegetation related to distance from the edge of the dome and depth of the underlying peat. These authors do not attribute changes observed in the Holocene peats to human activity. In contrast, more recent pollen records from Sarawak, at Loagan Bunut (Hunt & Premathilake, 2012), Gan Kira and Kampong Irang (Hunt & Rushworth, 2005), and from the Great Cave at Niah (Hunt *et al.*, 2007; 2012) are argued to show climatic fluctuations and human impact in the form of burning, clearance, and translocation and exploitation of various plants from before the LGM through the Holocene to the present. Many of these interpretations are corroborated by the extensive archaeological record from the numerous caves of the Gunung Subis at Niah spanning more than 50,000 years (ie Barker, 2013; archaeology briefly discussed in the following section).

In the Sumatran Rift Valley, within the Sundaland core just west of Borneo, and where the archaeological record provides less corroborative evidence than at Niah or in New Guinea, Flenley and Butler (2001) suggest five different disturbance mechanisms to which the Sumatran vegetation has been subject throughout the late Quaternary. These suggested mechanisms, the processes involved, and the expected sedimentary signature that each might

leave are summarised in Table 2.1. From this attempt to define an objective framework within which to infer causal mechanisms behind the early Holocene increases in charcoal and pollen of secondary taxa present in many highland Sumatran records (eg Maloney, 1979; 1980; 1985; Morley, 1982; Newsome & Flenley, 1988), Flenley and Butler (2001) arrive at the conclusion that it “may be possible to distinguish different types of disturbance by the record they leave in sediments” (p 290). However, these authors use identical wording to describe the expected sedimentary signatures of anthropogenic disturbance, and disturbance owing to natural fires (Table 2.1). Indeed, the second of their three bullet-pointed conclusions regarding interpretation of the pollen sequence they present for Sikijang Swamp in the Kerinci Valley states that:

*The forest began to be disturbed around 7000 years BP. The likely cause of this disturbance is slash and burn agriculture, but natural firing is also a possibility.* Flenley and Butler (2001: p. 305)

Despite best efforts, this attempt at distinguishing natural from anthropogenic disturbance proved equivocal, and reflects the challenges faced by all pollen analysts working in ISEA where people, droughts, and fires all have long histories.

Multiple recent review papers that summarise current palaeoecological

**Table 2.1** Summary of Flenley and Butler’s (2001) suggested five types of disturbances to which Sumatran vegetation has been subject during the late Quaternary.

<b>Flenley and Butler's (2001) vegetation disturbances</b>		
<b>Disturbance type</b>	<b>Processes</b>	<b>Expected sedimentary signature</b>
<b>Tectonics</b>	Landslips; erosion	In-washed soil; microfossil assemblages with secondary taxa
<b>Volcanism</b>	Fire; ashfall	Tephra; charcoal; microfossil assemblages with secondary taxa
<b>Anthropogenic</b>	Burning; clearance	Charcoal; microfossil assemblages with secondary taxa; possibly in-washed soil
<b>Natural fire</b>	Lightning; drought	Charcoal; microfossil assemblages with secondary taxa; possibly in-washed soil
<b>Storms</b>	Wind-throw; gap dynamics	Microfossil assemblages with minor representation of secondary taxa

understanding across ISEA highlight the ongoing dialogue within the palaeoecological community about the interpretations of signatures of human impact in proxy palaeoenvironmental records (eg Haberle, 2007; Haberle *et al.*, 2001; Haberle & David, 2004; Hope *et al.*, 2004; Hunt & Rabett, 2014; Sémah & Sémah, 2012). Haberle (2007), Sémah and Sémah (2012), and Hunt and Rabett (2014) all note that increases in microscopic charcoal in pollen cores have often been argued as evidence of anthropogenic influence upon vegetation, without due consideration to the problem of equifinality in assigning a causal mechanism to proxy records of fire from ISEA. Signs in sedimentary records of anthropogenic burning are nearly indistinguishable from natural fire, especially in a region affected by periodic but frequent and severe ENSO-induced droughts. As a corollary, and further complicating the interpretation of charcoal increases in pollen cores, is Hunt and Rabett's (2014) observation that "selective vegetation modification by fire does not necessarily require big extensive fires" (p 25).

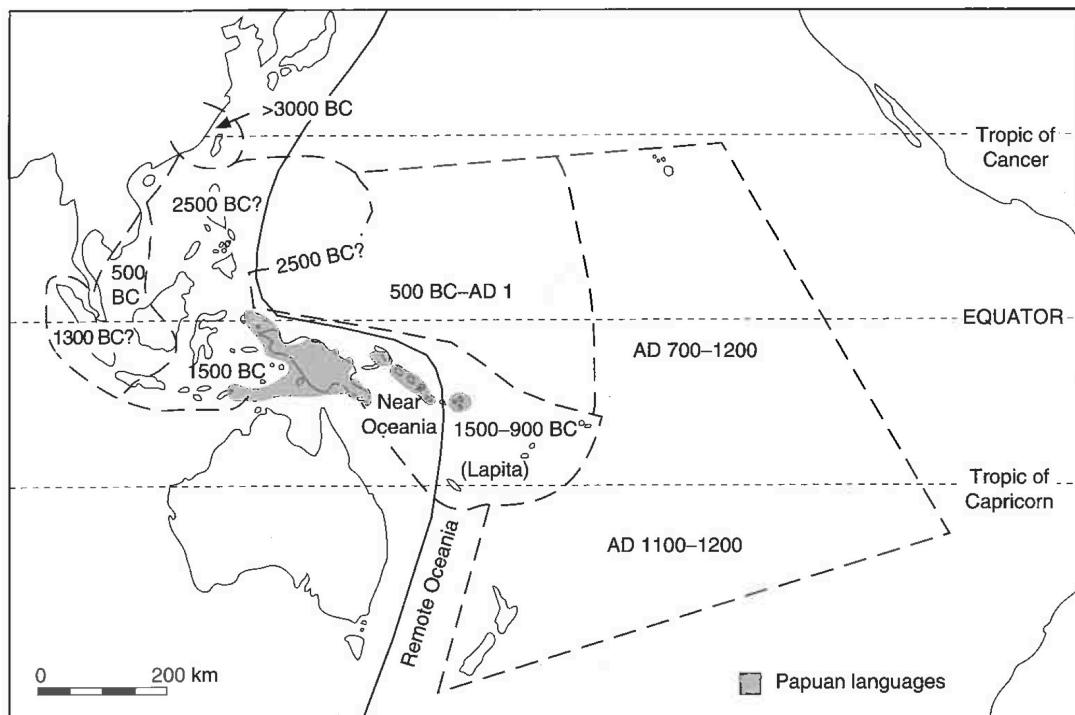
Sémah and Sémah (2012) propose that, in order to address the seemingly subjective interpretations of anthropogenic opening of forest structure when clear proxies of deforestation or cultivation are lacking, pollen analysts might examine whether fossil records show vegetational succession following signs of disturbance, or whether natural seral processes appear to be arrested. They argue that human maintenance of open landscapes might manifest in this manner, and that this approach can provide a more objective assessment of signs of human impact in sedimentary records. Hunt and Rabett (2014) have revisited many of the published pollen records from ISEA using this approach (Table 2.2). This approach appears to be potentially useful for sequences that have been, or will be in the future, subsampled and analysed at high temporal resolution. However, the inter-annual or inter-decadal vegetation successions, such as those in the region that have been studied and are ecologically understood (eg Flenley & Richards, 1982; Primack & Lee, 1991; Slik *et al.*, 2003a), might be missed or conflated in fossil records in which high-resolution subsampling was not part of the original study design, as is commonly the case.

**Table 2.2** Pollen evidence of early Holocene human activity in Sundaland in relation to signatures of interrupted vegetational successions. Source: Hunt & Rabett (2014).

Location	Citation	Background	Holocene ecology	Succession present/not present
Nong Thalee Son Hong, South Thailand	Maloney 1999; Kealhofer 2003	Lowland lake	Lowland rainforest with disturbance indicators from the base of the Holocene	No succession present, intermittent burning, open areas maintained until ~7.2 ka
Lake Kumphawapi, Northeast Thailand	Kealhofer and Penny 1998; Penny 1999, 2001; Kealhofer 2002, Burke 2014	Lowland lake	Holocene grassland and woody vegetation replacing Pleistocene savannah with regular fires. Disturbance indicators present throughout	Holocene succession of temperate and then tropical woodland taxa but woody vegetation is a minor component of vegetation. Intermittent burning through early-mid Holocene. Penny suggests intensification of burning ~7.4 ka. Succession disrupted through Holocene. Strong clearance and agriculture from 0.4 ka.
Rawa Danau, West Java	van der Kaars et al., 2001	Lowland swamp/lake	Open grassy vegetation with much evidence for fire from 15.7 ka succeeded by Lowland forest with high proportion of disturbance indicators in Early Holocene	No succession apparent. Poorly dated and possibly discontinuous sequences.
Niah Cave, Sarawak	Hunt et al., 2012	Karst tower on coastal plain	Lowland forest with disturbance indicators rapidly replaces Late Pleistocene open dryland forest	Not present.
Loagan Bunut, Sarawak	Hunt and Premathilake 2012	Back estuary	Lowland forest and mangroves from ~11.2 ka: disturbance indicators and charred material frequent	Succession disrupted very early in the Holocene; intermittent disturbance thereafter.
Danau Padang, Mt Kerenici, Sumatra	Morley, 1982	Lake in upland valley	Lower Montane and swamp forest with prominent disturbance indicators from early in Holocene. Major canopy opening after ~9.6 ka	Succession disrupted ~10.5 ka, then intermittent disturbance, diminishing ~5 ka. Charcoal intermittently present
Tao Sipinggan, Toba Uplands, Sumatra	Maloney 1996	Lake in Toba Uplands	Lower Montane forest with disturbance indicators from ~10.5 ka	Clearance and canopy opening 1.6 ka
ND1, Son Hong (Red River) Delta, Vietnam	Li et al., 2006	Back estuary	Lowland forest and mangroves: succession from semi-open, through temperate to subtropical forest ~11.6–9.4 ka. Disturbance ~10.4 ka	Succession present but interrupted by peak of herbs ~10.4 ka.
Ranca Upas, West Java	Stuijts, 1993	Upland lake	Lower Montane rainforest with disturbance indicators from ~10 to ~7.5 ka and from ~4 ka–recent	Succession disrupted ~10–7.5 ka, charcoal present
Danau di-Atas, Sumatra	Newsome and Flenley, 1988	Lake in Sumatra Uplands	Lower Montane forest with disturbance from ~9.6 ka	Succession disrupted
Batulicin, Kalimantan	Yulianto et al., 2005	Coastal mangroves	Coastal mangroves from ~9.1 ka, transitioning to peat swamp. Strong representation of disturbance indicators throughout.	No dryland succession apparent.
Pea Sim–Sim, Toba Uplands, Sumatra	Maloney, 1980	Lake in Toba Uplands	Lower Montane and swamp forest with prominent disturbance indicators from early in Holocene. Major canopy opening after ~8.2 ka	No succession apparent.
Rawang Sikiang, Mt. Kerenici, Sumatra	Flenley and Butler, 2001	Swamp in upland valley	Submontane forest with disturbance indicators from base of Holocene. Clearance with grassy patches from ~8 ka	No succession present.
Pea Bullok, Toba Uplands, Sumatra	Maloney and McCormack, 1996; Maloney, 1996	Lake in Toba Uplands	Lower Montane and swamp forest with disturbance indicators from base of Holocene. Major canopy opening after ~7.5 ka	Succession shows replacement of <i>Dacrydium</i> , <i>Eugenia</i> , then <i>Castanopsis</i> , then <i>Quercus</i> before major disruption of vegetation and development of scrub ~7.5 ka.
Laguna de Bay, Luzon	Ward and Bulalacao, 1999	Coastal lagoon	Coastal savannah progressively replacing dry lowland forest. Record starts ~7 ka	No succession apparent. Climate dries 5 ka
Paoay Lake, Luzon	Stevenson et al., 2010	Coastal lagoon	Coastal savanna with montane pine forest upslope. Record from ~6.5 ka shows disturbance indicators from base. Burning of woody biomass replaced by burning of grasses at 5 ka. Disturbance indicators become more common 3.7 ka	No succession apparent. Climate dries ~5 ka
Kampong Irang and Gan Kira, Niah, Sarawak	Hunt and Rushworth, 2005			Back mangrove succession to freshwater disrupted by burning and possible cultivation.

## 2.5 Archaeologies of subsistence

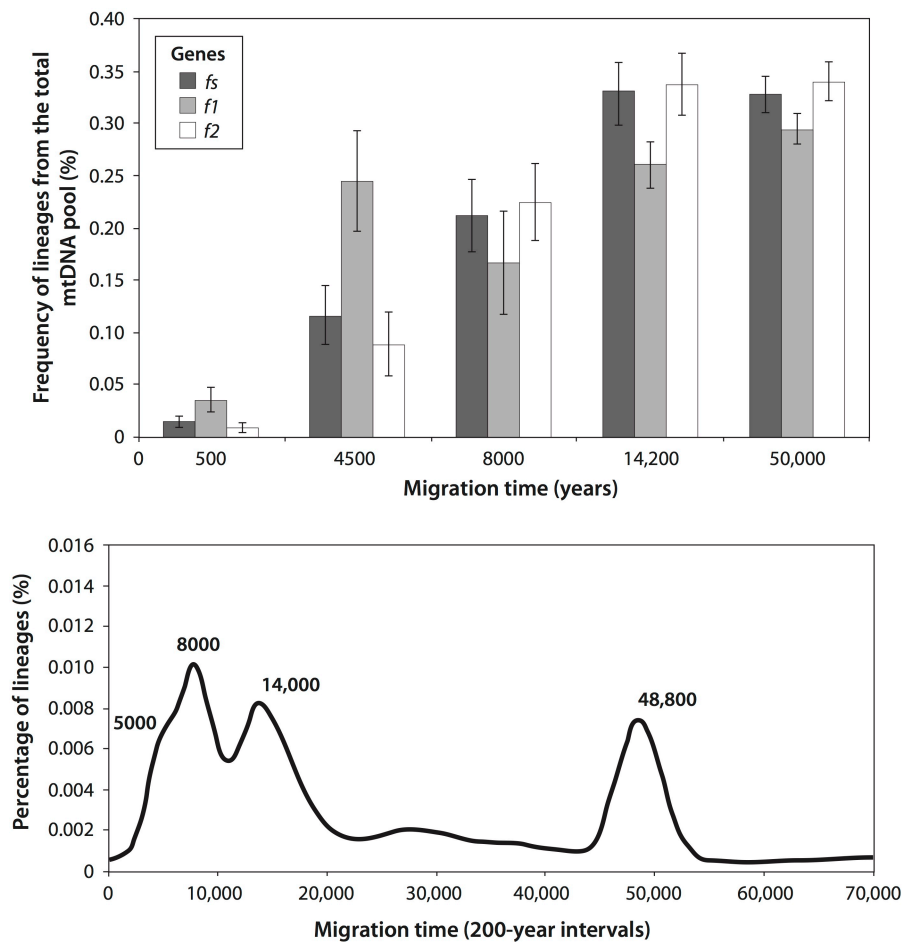
Since the 1980s, the dominant narrative of Holocene human histories across Island Southeast Asia (ISEA) has been a regional adaptation of Colin Renfrew’s farming-language hypothesis (Renfrew, 1987). This ‘Austronesian hypothesis’ has been most prolifically argued by Peter Bellwood (1987; 2005; 2006; 2007), with early linguistic support from Robert Blust (eg 1984/1985). These authors promote the interpretation of linkages between the spread of Austronesian languages with intrusive, expansionist rice-farmers that left Taiwan around four thousand years ago, and replaced or absorbed indigenous foragers on their way to rapidly colonising ISEA to the south, then Near and Remote Oceania to the east, and Madagascar to the west (Figure 2.29). In this model, these Austronesian-speakers brought with them a package of Neolithic material culture (eg red-slipped pottery with dentate stamping; spindle whorls; clay ear-rings; and polished quadrangular adzes), and domestic plants and



**Figure 2.29** Peter Bellwood's model for the expansion of Austronesian-speaking farmers across ISEA and the Pacific. Source: Barker (2006), after Bellwood (2007, revised) and Pawley (2002).

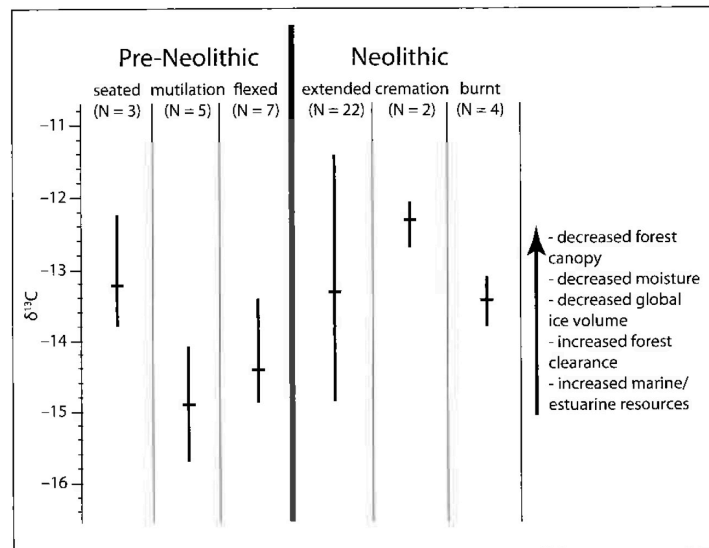
animals (namely rice, replaced further south and east by tree and root crops, along with pigs, dogs, and chickens). This narrative has explanatory power in correlating the vast geographic range across which are distributed people who today speak Austronesian languages with the expansion in ISEA after 4000 BP of elements of the material culture and economic bases just mentioned.

This narrative is increasingly challenged, however, by data from a suite of more recent studies employing various techniques in archaeological science. Soares *et al.*'s (2008) study of modern mitochondrial DNA lineages provides evidence for major human population expansions across ISEA that appear coincident with the punctuated, rapid rises in global sea level at the end of the Pleistocene and beginning of the Holocene (Figure 2.30). These expansions predate the suggested chronology of the Austronesian expansion. As such, these authors argue that global climatic change and regional flooding of the Sunda Shelf following the end of the most recent Ice Age, and the human movements initiated by the subsequent fragmentation of land areas, have shaped the distribution of modern human genetic diversity across ISEA, rather than a Neolithic demic diffusion fuelled by agricultural expansion (Soares *et al.*, 2008).



**Figure 2.30** The chronology of early human dispersal reconstructed from the analysis of mitochondrial DNA in present-day populations of Island Southeast Asia. Source: Barton *et al.* (2013), after Soares *et al.* (2008).

In the West Mouth of the Great Cave at Niah in Sarawak near the coast in northwest Borneo, studies of the cranial and dental morphologies (Manser, 2005; Lloyd-Smith *et al.*, 2013) and mortuary practices (Barker & Lloyd-Smith, 2013) in human burials that span portions of the >50,000-year occupation chronology at the site demonstrate continuity between the pre-Neolithic and Neolithic human populations. This is contrary to what one would expect to find had a Neolithic demic intrusion occurred. However, examination of the isotopic compositions of tooth enamel from these burials, which can be indicative of broad dietary changes, shows that the people who were buried at Niah during the Neolithic were consuming resources from a more open landscape as compared with the environmental isotopic signatures of the pre-Neolithic remains (Figure 2.31) (Krigbaum, 2005; Lloyd-Smith *et al.*, 2013). Environments

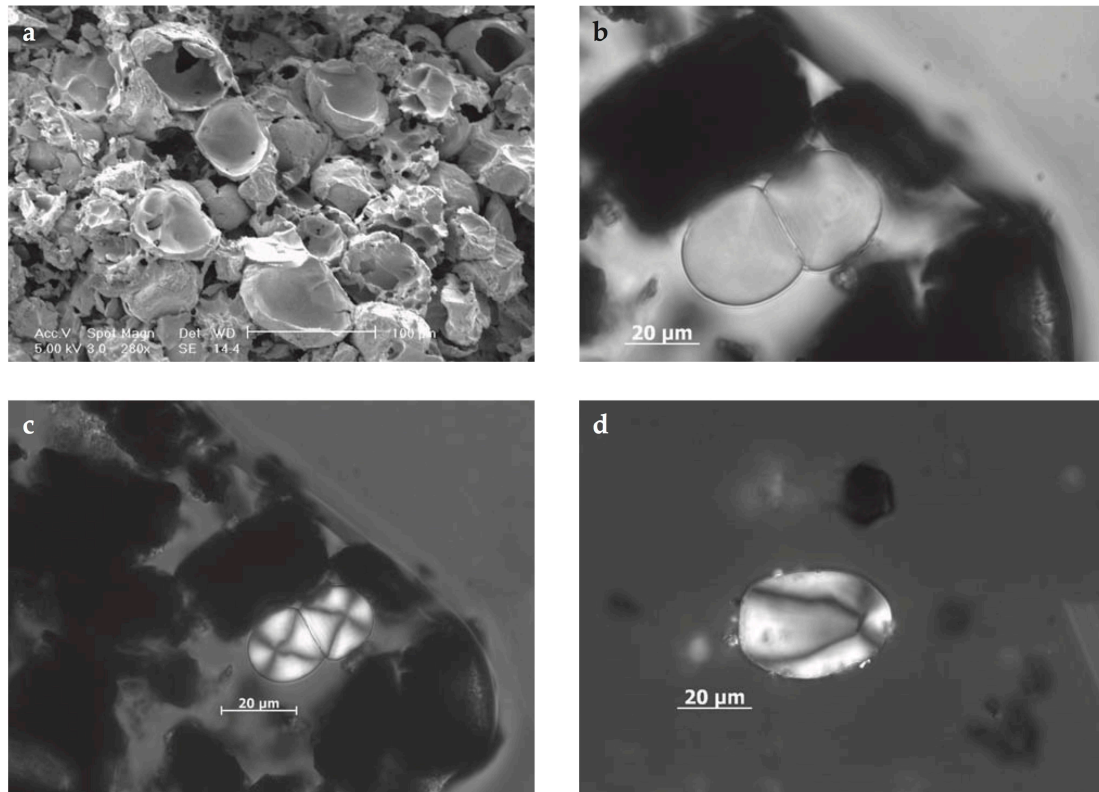


**Figure 2.31** Carbon isotope data from human skeletal remains at Niah. Tooth enamel from Neolithic human burials at Niah exhibit a  $\delta^{13}\text{C}$  signature indicative of diets derived from more open environments in comparison to those of pre-Neolithic people at Niah, despite morphological evidence for population continuity. Source: Lloyd-Smith *et al.* (2013), after Krigbaum (2005).

around Niah appear to have been changing from the mid-Holocene (eg Hunt & Rushworth, 2005), but the pollen evidence for disturbance and open landscapes seems to predate the isotopic evidence. Interpretation becomes further complicated when one considers the mid-late Holocene trend in ENSO intensification discussed earlier, that may have contributed to an opening of the landscape through drought-induced tree mortality and increased susceptibility of vegetation to fire.

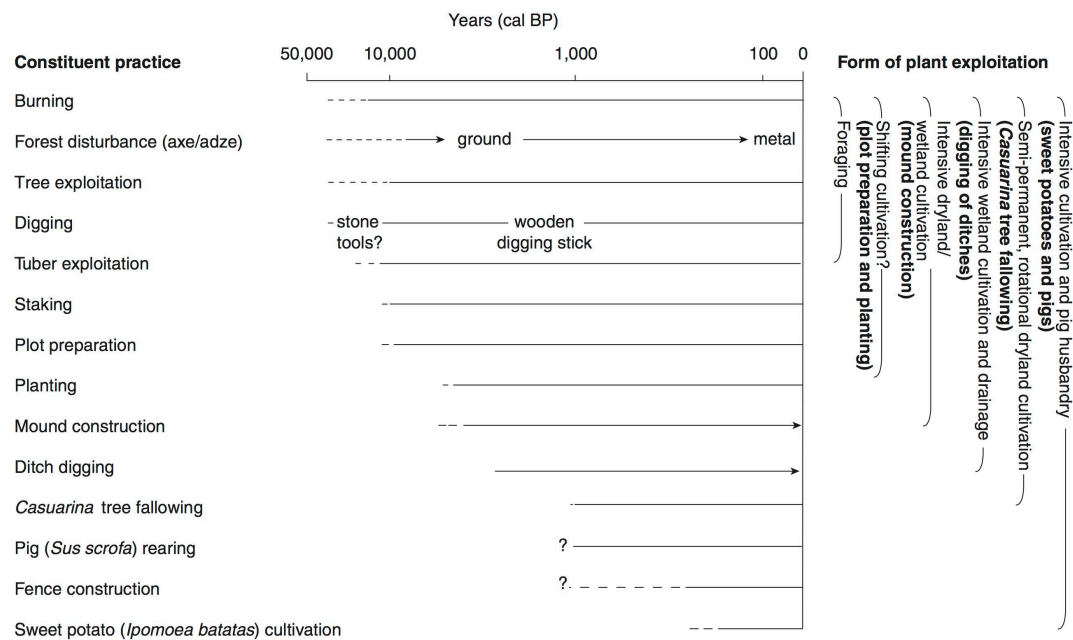
As described in the introductory chapter to this thesis, whilst archaeobotanical research in the region began in the late 1960s and early 1970s, it is only within the past decade that systematic application of best archaeobotanical practice (in the form of flotation of excavated sediments) has gained traction (eg Denham *et al.*, 2009; Fairbairn, 2005; Oliveira, 2008; Paz, 2005). Subsequent finds from Niah (Barton, 2005), Ille Cave in northern Palawan Island (Carlos, 2010), and sites across highland New Guinea (Fullagar *et al.*, 2006; Summerhayes *et al.*, 2010) provide previously undetected evidence for late Pleistocene and early Holocene exploitation of rainforest resources and starchy organs of other wild and cultivated plants (Figure 2.32).





**Figure 2.32** Starch grains from various tubers, found in pre-LGM archaeological sediments at Niah: a) *Colocasia elim esculenta*; b-c) *Alocasia longiloba*; d) *Dioscorea* sp. Source: Barton *et al.* (2013).

The view of human subsistence following the Last Glacial Maximum in ISEA that is emerging from sites such as Niah, Ille, Kuk, and Kosipe is one which encompasses a spectrum of arboricultural and vegecultural practices and management of rainforest resources (see Figure 2.33 for diagrammatic representation of the situation at Kuk). Timings and directions of movements of crops that are implicated in these practices are difficult to reconcile with the Austronesian hypothesis. Genetic studies of bananas (Carreel *et al.*, 2002), taro (Lebot *et al.*, 2004; Matthews, 2004), sugarcane (Grivet *et al.*, 2004), and the greater yam (Malapa *et al.*, 2005) suggest that all were originally domesticated in New Guinea and broader Melanesia. In the cases of at least taro and the greater yam, archaeobotanical remains that have notionally been attributed to these crops have been found in late Pleistocene – early Holocene contexts from sites in Borneo (Figure 2.29a&d; Barton *et al.*, 2013) and Palawan (Carlos, 2010; Barker *et al.*, 2011a). This implies that, prior to the hypothesised timing of the spread of Austronesian languages, at least some populations actively cultivated and translocated economically useful plants over large distances.



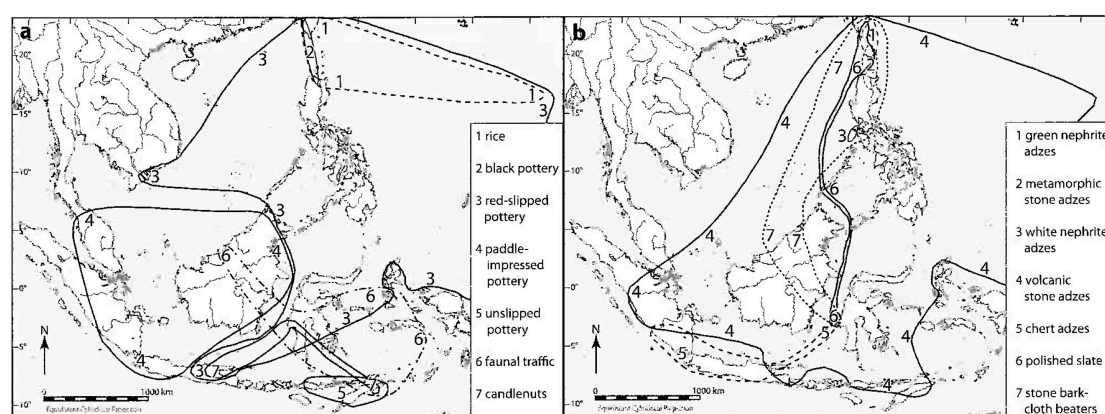
**Figure 2.33** Chronology of practices and forms of plant exploitation in the upper Waghi valley, inferred from archaeological evidence of earthworks, archaeobotanical residues on lithics and in sediments, and pollen sequences that suggest anthropogenic landscapes. Source: Denham (2015).

Additionally, whilst cultivated rice has been present in Sarawak since ~4000 BP (eg Doherty *et al.*, 2000), *sago* starch from the central pith of various species of palms was the preferred food staple for many communities until recent centuries (Barton, 2012). People in ISEA appear to have exploited this resource for many millennia. Hunt and Premathilake (2012) point to pollen and phytolith evidence from the coring site of Loagan Bunut about 60km east from Niah to suggest that people had moved the New Guinean sago palm *Metroxylon sagu* Rottb. between islands by the early-mid Holocene. Blench (2005) evokes linguistic evidence to argue that sago cultivation, along with harvesting of *Canarium*, were moved westward from their Melanesian origins prior to the Austronesian expansion. Indeed, Blench has since proposed “an ‘arc of vegeculture’ characterised by tubers, Musaceae, sago exploitation and sugar-cane which stretches between Melanesia and Eastern Nepal” (Blench, 2012: p. 1) and predates rice cultivation.

Paralleling these signs of early and multi-directional movements of economically useful plants between islands across ISEA, inter-island maritime exchange networks appear to have existed from the early Holocene and continued through the Neolithic (eg Bulbeck, 2008) (Figure 2.34). Evidence for

the early-Holocene movement of obsidian between islands in the Philippines (Neri *et al.*, 2015), and the speculation that the Sulawesi warty pig, *Sus celebensis* Müller & Schlegel, may have been translocated to Flores by 7000 BP (Piper *et al.*, 2009), provide further suggestions of pre-Austronesian maritime networks across ISEA.

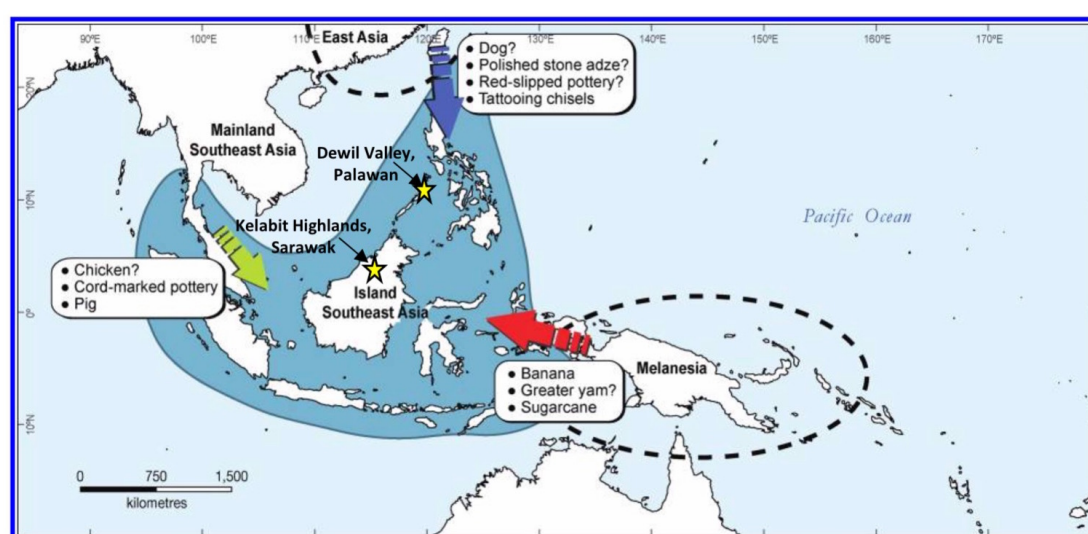
Spriggs (2011) notes that the majority of Neolithic open-landscape sites in ISEA lack bioarchaeological data, but those that do contain evidence for a mixture of shellfish collection, forest hunting and gathering, and vegiculture. Combined with the different elements of the Neolithic material culture and economic bases mentioned above, and the near absence of rice remains throughout the Wallacean region at the critical period (eg Paz, 2001 & 2005; Oliveira, 2008; Castillo & Fuller, 2010), the concept of a Neolithic ‘package’ diffusing as a unit from Taiwan after 4000 BP is not borne out by current evidence beyond northern Luzon. Rather, constituent elements of this ‘package’ are found in different combinations in widespread sites across ISEA roughly coincident with their appearance in Luzon (Barker & Richards, 2013), and without a clear link with rice farming. Spriggs (2011) concludes that Neolithisation across ISEA was less about farming than originally postulated, and more about ideology and social relations, with pottery and shell artefacts the primary material manifestations within the archaeological record.



**Figure 2.34** Distributions of elements of material culture (a & b) and economic plants (a) across ISEA from 4000-2500 BP, implying complex networks between Neolithic societies. Source: Lloyd-Smith *et al.* (2013), after Bulbeck (2008).

Donohue and Denham (2010) employ a combination of archaeobotanical (phytoliths, and crop genetics) and linguistic evidence to envision small-scale but cumulative cultural change within long-lived exchange systems across ISEA prior to the spread of Austronesian languages (see Figure 2.35). Similarly, and echoing aspects of Spriggs' (2011) conclusions, Blench (2012) sees the process of 'Austronesianisation' as cultural in nature rather than representing a discreet demographic event. Blench views Austronesian-speakers during the mid-late Holocene as mobile fisher-foragers with a trading ethos, and a powerful ideology manifest in elements of their symbolic material culture such as *linglingo*, and seated figures with splayed legs, that echo pervasive imagery throughout many of the traditional religions of forest spirits practised by various groups across ISEA prior to the spread of the major world religions (Barker & Richards, 2013).

The many contrasting interpretations of and narratives for Holocene prehistory across ISEA are in part the result of a crucial gap – or at least a thinness of evidence – in the archaeological record of what people were doing in the broader landscape between 4000-3000 BP. As Spriggs (2011) highlights, 'Neolithic' sites in the open landscape in ISEA are few, and spread across a vast area (Figure 2.36; the ISEA archaeological record is heavily biased toward cave sites, ie Barker *et al.*, 2005). This has created fertile ground for broad narratives that are difficult to test with current evidence. Barker and Richards (2013) offer



**Figure 2.35** A suggested model of pre-Austronesian movements of cultural items into and within ISEA. The two case study areas in the present study are labelled and shown as yellow stars. Source: Donohue & Denham (2010).



**Figure 2.36** Neolithic open-landscape archaeological sites in ISEA. Source: Spriggs (2011).

a more restrained assessment of the current data, which recalls Solheim's (1984/1985) original *Nusantao* hypothesis of Holocene cultural changes and inter-island linkages in ISEA:

*From the beginning of the Holocene, as the modern topography of the region took shape following sea-level rise, people, plants, animals, material culture, and information systems were entangled in pathways of movement and exchange that linked foragers and vegiculturalists in ISEA and Melanesia (New Guinea and the Bismarck Archipelago) with forager-farmers on the coasts of mainland Southeast Asia and Taiwan. (Barker & Richards, 2013: p. 272)*

In this context, the spread of parts of the Neolithic material culture often associated with the Austronesian hypothesis across ISEA around 4000-3500 BP may have represented a significant acceleration in the nature and scale of material and information exchange, the results of which were grafted onto existing networks between societies with indigenous economic bases and forms of subsistence.

## **2.6 Conclusion**

Interconnections between the geologic, biogeographic, palaeoclimatic, vegetational and human histories across ISEA have become apparent as geographical coverage of studies has expanded, as innovative techniques have been developed, and as the resolution of data has improved. Appreciation of such linkages has affected the ways in which histories of tropical vegetation and subsistence are compiled and analysed. Some long-held narratives are increasingly challenged by these new data and interpretations. The review presented in this chapter has shown that abiotic processes in operation in the past and present provide 'natural' mechanisms of ecological disturbance, the signs of which are observable within proxy palaeoenvironmental records. Island Southeast Asia has also been home to modern humans for over 50,000 years (Barker *et al.*, 2007; Brothwell, 1960; Détroit *et al.*, 2004; Fox, 1970; Harrison, 1959). Technologies which enabled anthropogenic disturbance to vegetation, such as fire (eg Jones, 1969) and stone tools (eg Groube *et al.*, 1990), have been part of the human toolkit since their Pleistocene entry into the region. Changes in the climatic and the cultural sequences across ISEA appear to co-occur with vegetational changes in the mid-late Holocene, from ~4000 BP. In particular relevance to the present study, problems of equifinality remain in assessing causal mechanisms of past disturbances observed in palaeoecological records.

In Chapter 3 to follow, knowledge gaps are defined that the review in this chapter has highlighted. Specific research questions are offered that are designed to address these gaps. A description and justification of the approach taken in answering these questions is then offered. Introductions to the sites of the two

case studies that demonstrate the modern analogue approach follow. Chapter 3 closes with a brief narrative of project development.





### **3 Approach and site introductions**

#### **3.1 Introduction**

This chapter begins with the definition of current gaps in our knowledge that the literature review in Chapter 2 has highlighted. Specific research questions that are designed to address these gaps are then offered. The modern analogue approach that this research takes to answering these questions is then described and justified. This is followed by introductions to the case study areas that are used to demonstrate application of the modern analogue approach. This chapter closes with a narrative of project development.

#### **3.2 Knowledge gaps**

The preceding review has highlighted the importance of the mid-late Holocene to our understandings of human and vegetational histories in ISEA. Evidence for climatic changes, as well as for human activity, display spatial and temporal heterogeneity throughout the region during this critical period. Suggestions of ENSO-induced droughts, exploitation of resources by people, and changes in vegetation and the importance of fire coincide at times and in places throughout ISEA during the last 5000-7000 years. Attempts at disentangling these signals in palaeoenvironmental records have thus far proved inconclusive. Deciphering the relative importances of past climate and land use in affecting vegetational change has the potential to provide useful data in testing hypotheses represented by archaeological narratives. Details about what people were doing in the broader landscape during this period are wanting. This is due to a bias in the archaeological record toward cave sites, and a bias in the palaeoecological record toward sedimentary sites, as well as the current, though gradually decreasing, paucity of coverage in archaeobotanical data. Therefore, the relevant knowledge gaps at this project's inception are:

- The causal mechanisms of Holocene changes in vegetation and fire regimes at sites across ISEA;

- Details about past arboricultural and vegecultural practices in ISEA within subsistence systems not based upon cereal staples.

Filling these current gaps in our knowledge with nuanced understandings of past subsistence practices and of drivers of past changes in vegetation can inform archaeological interpretations, as well as provide improved baseline data for conservation.

### **3.2.1 *Broad research questions***

In light of the knowledge gaps just defined, the research described in this thesis aims to address the following primary questions:

- Can we distinguish between past anthropogenic and climatically driven disturbance within sedimentary pollen and charcoal records from ISEA?
- Given the current paucity of archaeobotanical data across ISEA with which to draw direct inferences about past subsistence, can we detect specific practices of vegetation management indirectly through their imprints within fossil pollen records?

## **3.3 Approach**

### **3.3.1 *Modern pollen-vegetation relationships***

Ecologically meaningful interpretation of fossil pollen and spore (shortened to just ‘pollen’ from here onwards) assemblages relies upon uniformitarian principles (Davis, 1963; Wright, 1967; Flenley, 1973). Fossil assemblages are understood only through comparison with modern analogues. More specifically, an understanding of the relationship between a community of plants growing today within a particular landscape, and the assemblage of modern pollen that is deposited in the sediments beneath it, forms the foundation upon which pollen analysts infer which vegetation communities were present when a fossil assemblage was deposited. This is necessary, in part, due to the diversity of life history traits relating to pollen production and dispersal that has evolved amongst the ~400,000 species of land plants (‘embryophytes’,

which, counter to the vernacular term, also encompasses many derived aquatic lineages of flowering plants) (Willis & McElwain, 2014). The abundance of pollen that a given species produces, and the mechanism by which its reproductive cells are moved between members of a reproducing population (ie usually via wind or animal vectors, though the reproductive cycles of many ferns and non-vascular plants such as mosses are tied to water), affect that species contribution to sedimentary pollen assemblages (Davis, 1963; 1969). Additionally, the position of that pollen-producing individual within the overall architecture of the supporting vegetation community (Tauber, 1965; 1967), and the physical properties of the basin within which the encapsulating sediments have been deposited (Prentice, 1985; Sugita, 1994), affect the composition of the resulting assemblage in complex ways. Consequently, the taxa that are represented, and their relative abundances, within a sedimentary pollen assemblage often differ from those of the parent vegetation. These differences can be described through study of modern plant communities and associated modern pollen assemblages. Comparison of fossil assemblages with these modern data enables the inferred reconstruction of past vegetation.

A primary aim of fossil pollen analysis is to detect past changes in vegetation over time. Based upon uniformitarian principles, vertical sediment cores diachronically transect local depositional history. If the relationship between vegetation and pollen deposition in sediments within a particular environment is understood, then the changing pollen assemblages up through the vertical sequence of sediments can provide a record of changing vegetation through time. The interpretation of such a sequence relies upon sampling modern vegetation and pollen from a variety of extant environments (Wright, 1967). The selected modern sites are usually distributed along an environmental gradient of interest based upon the aims and research questions of the study. In a sense, the selection of the gradient(s) along which modern sites are distributed within a given study represents an implicit hypothesis relating to the range of vegetation types the analyst suspects might have been present in the past. This has been referred to as the modern analogue approach to vegetation reconstruction (eg Birks and Birks, 1980).

### ***Palaeoclimatic aims***

The early work done in the development of theory and methods underpinning the modern analogue approach had palaeoclimatic aims and research questions as their foci (eg Leopold, 1958; Davis, 1969). Many of the early studies took advantage of the natural laboratories of the numerous lakes of various sizes spread across northern central North America and Scandinavia, the basins of which were excavated by the Quaternary ice sheets. Modern vegetation and pollen were sampled from sites along latitudinal or altitudinal gradients as proxies for changing temperature (review in Wright, 1967). Comparison of these modern data with fossil sequences from temperate northern hemisphere lakes revealed how vegetation changes following the retreat of the ice sheets paralleled the temperature-controlled distributions of vegetation types in the modern landscape, thus implying past changes in temperature (Davis, 1969; Wright, 1967). This same study design enabled the production and interpretation of the datasets on changing altitudinal bands of vegetation types in New Guinea and Sumatra across the Pleistocene-Holocene transition that are summarised in Figures 2.26 and 2.28 in the previous chapter (pp 47 and 50).

### ***Detection of land use***

Where the aims of a study and its research questions are related to changes in past land use or human impact upon vegetation, the same concept might be applied whilst selecting modern sites to sample. A series of studies across Scandinavia during the 1980s and 1990s employed the modern analogue approach to deciphering past changes in subsistence relating to questions about Bronze and Iron Age histories of human land use (eg Berglund *et al.*, 1986; Gaillard *et al.*, 1992 & 1994; Hicks, 1992; Hicks & Birks, 1996; Hjelle, 1999). For example, in south Sweden, Gaillard *et al.* (1992; 1994) collected pollen from moss polsters, and surveyed modern vegetation, at sites with different vegetation types and land uses: non-fertilized grazed areas; burned and grazed heaths; traditionally managed fodder-producing meadows; cultivated fields; and deciduous forest. They then employed these modern data as inputs within transfer functions and weighted averaging regressions (ie Birks *et al.*, 1990) to translate fossil pollen data from sediment cores into evidence for various past

land uses. Their results support archaeological arguments for pre-Roman hay production since the Late Bronze Age, and that grazing was the main local land use since the Early Iron Age. Through multi-variate statistical comparison of fossil pollen assemblages with data from modern vegetation that recorded palynological signatures of land uses, it was possible to provide independent, indirect evidence of those land uses in the past.

This modern analogue approach to detection of past land use has not yet been applied within tropical environments. This may be due in part to the fact that enumeration of the flora of many tropical regions is still underway (Prance *et al.*, 2000). Within the Malesian floristic region, for example, the *Flora Malesiana* project has been ongoing since 1948. As of June 2016, published formal treatments within a modern taxonomic framework are widely available on only ~3820 taxa out of a flora that probably exceeds 45,000 species (Johns, 1995; Webb, 2016). The study of modern pollen-vegetation relationships within the region is even less mature. The published work that has been done has focused on climatic or ecological aims (eg Anderson & Müller, 1975; Anshari *et al.*, 2004; Flenley, 1973; Garrett-Jones, 1979; Hope, 1973; Kershaw & Hyland, 1975; Morley, 1982; Newsome, 1988; Taylor *et al.*, 2001; Walker & Sun, 2000). These previous studies, as well as comparable work within other tropical regions (eg Bonnefille *et al.*, 1999; Burney, 1988; Bush, 1991 & 1995; Bush & Rivera, 1998 & 2001; Elenga *et al.*, 2000; Gosling *et al.*, 2005 & 2009; Horn *et al.*, 1998; Lebamba, 2009; Marchant & Taylor, 2000; Marchant *et al.*, 2001 & 2006; Rodgers & Horn, 1996; Salgado-Labouriau, 1978; Vincens *et al.*, 1997 & 2000), have demonstrated that pollen-vegetation relationships within tropical environments are decipherable. This has been accepted despite initial reservation about the representativeness of sedimentary pollen in relation to vegetation in the tropics (eg Faegri, 1966). However, as Flenley (1973) concluded in his early global synthesis of studies of modern pollen rain from tropical environments, and which has since been repeatedly corroborated:

*There appears to be no fundamental difference yet demonstrated between tropical and temperate modern pollen rain. The differences are all of degree. (Flenley, 1973: p. 139)*

### ***Approach and justification***

The modern analogue approach is necessary to the understanding of fossil pollen assemblages. The utility of this approach in detecting past land use within temperate environments has been demonstrated. The taphonomy of modern pollen rain within temperate and tropical environments have been shown to be governed by the same fundamental principles. It follows that the modern analogue approach to detection of past land use within tropical environments might also have utility. The present study adopts this approach. The use of this approach within this context is viewed as an initial test of its utility within tropical environments.

The approach used in this study is the modern analogue approach, applied to the aim of detecting past land use within fossil pollen records. Botanical surveys of various vegetation types, encompassing modern land uses, as well as different 'natural' vegetation communities, are combined with pollen assemblages from surface sediments to create a modern training set that describes the palynological signatures of various human ecologies. This training set is then compared with fossil assemblages via multi-variate statistical techniques to infer the past presence of land uses comparable to those extant.

#### ***3.3.2 Assumptions***

The modern analogue approach that this study takes requires the assumptions that:

- Modern land uses exist that are analogous to some of those of the past.
- Pollen assemblages extracted from surface sediments represent modern pollen rain. Whether this pollen rain is produced by the local vegetation under human management is immaterial. A structural change to a local vegetation community as a result of manipulation by humans will likely produce changes to the pollen catchment area. These changes should be distinguishable in pollen assemblages, even if, or possibly *because*, they include pollen from extra-local vegetation that, itself, may or may not be influenced by people.

- The taphonomic processes responsible for the creation of the modern assemblages are comparable to those that produced the fossil assemblages.

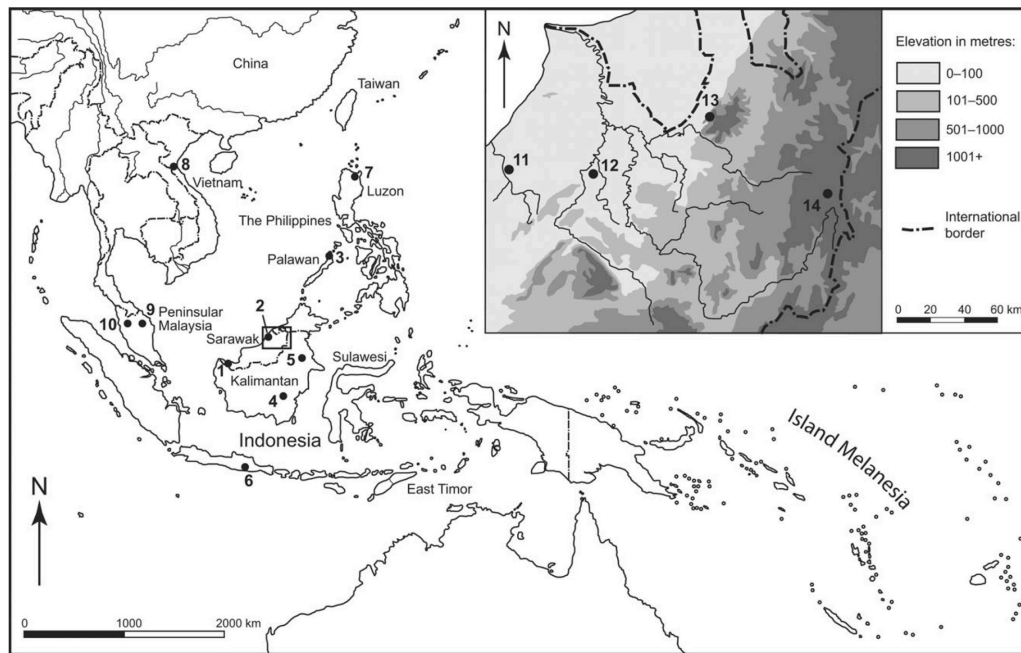
### **3.3.3 *Specific research questions***

The following specific research questions follow on from the broad questions defined at the beginning of the chapter:

- Are pollen assemblages from modern land uses within ISEA statistically distinct?
- Are fossil pollen assemblages from sediment cores in ISEA statistically similar to pollen assemblages from modern land uses?
- What patterns through time can we infer from the statistical relationships between modern and fossil assemblages from ISEA?
- Do these patterns appear to support previous interpretations of pollen records from comparable sites?
- How do the resultant patterns relate to existing archaeological narratives for the region?

## **3.4 Site introductions**

The following section introduces the two case study areas: the Kelabit Highlands of north-eastern Sarawak, Malaysian Borneo; and the Dewil Valley and surrounds within El Nido municipality of northern Palawan Island in the western Philippines (Figure 3.1). These sites were selected due to their crucial geographical locations along the shores and in the hinterlands around the South China Sea, where narratives of Holocene human dispersals and subsistence change coincide with measured influences of climatic changes associated with increased ENSO frequency and intensity since the mid-Holocene. Recent and ongoing archaeological and palaeoecological research projects are focused upon both locales, with scope remaining for existing questions to be answered.

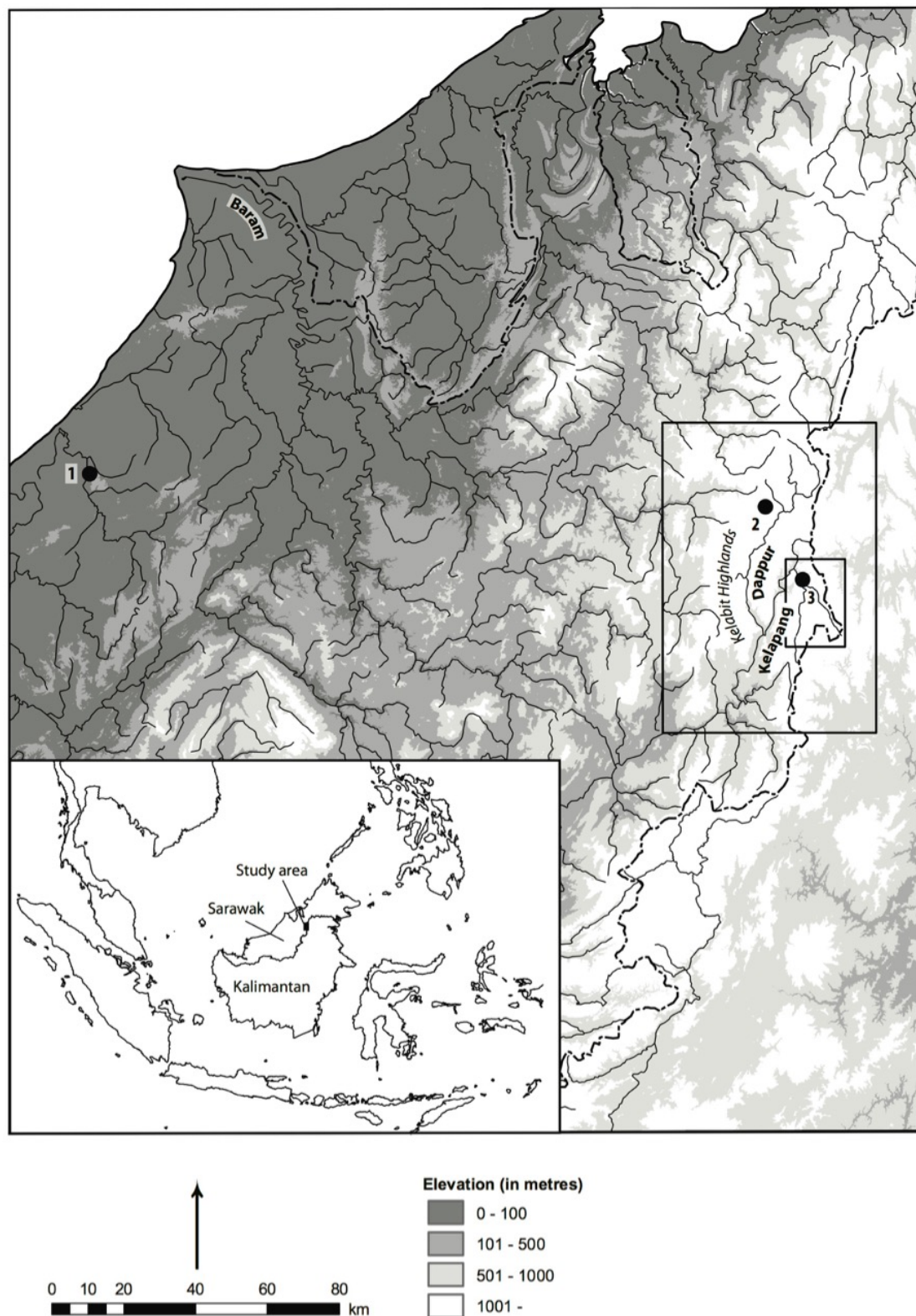


**Figure 3.1** Map of ISEA archaeological sites: the Kelabit Highlands (14) appear within the inset in the upper right; the Dewil Valley (3) is shown in the main portion of the map. Also mentioned in the chapter and appearing in the inset are Niah (11) and Loagan Bunut (12). Source: Barker et al. (2011b).

### **3.4.1 Kelabit Highlands, north-eastern Sarawak, Malaysian Borneo**

The portion of this study that focuses on the Kelabit Highlands in the northeast of the Malaysian state of Sarawak in northern Borneo (Figure 3.2) builds upon the multidisciplinary work of the Cultured Rain Forest (CRF) project (2007-2009). This project drew upon a team of archaeologists, anthropologists, and palaeoecologists to examine aspects of the mutual shaping of people and the physical world, including rain forests, in interior Borneo from the past through to the present. The CRF emerged conceptually from, and itself built upon, over two decades of anthropological work based in the southern Kelabit longhouse community at Pa' Dalih (ie Janowski, 1991; 1993; 1995; 1996; 2003; 2004; Janowski *et al.*, 2014; Janowski & Langub, 2011), as well as emergent questions following on from the 2000-2003 archaeological re-investigation of the 50,000-year human occupation sequence within the network of caves that tunnel through the Gunung Subis at Niah in lowland Sarawak (ie Barker, 2005; 2013; Barker *et al.*, 2007; 2011b). The archaeological and palaeoecological results from the Niah Caves Project (NCP) and associated studies at the coring site of Loagan Bunut have been mentioned briefly in Chapter 2, and will be revisited in more detail in the discussion within Chapter 8.





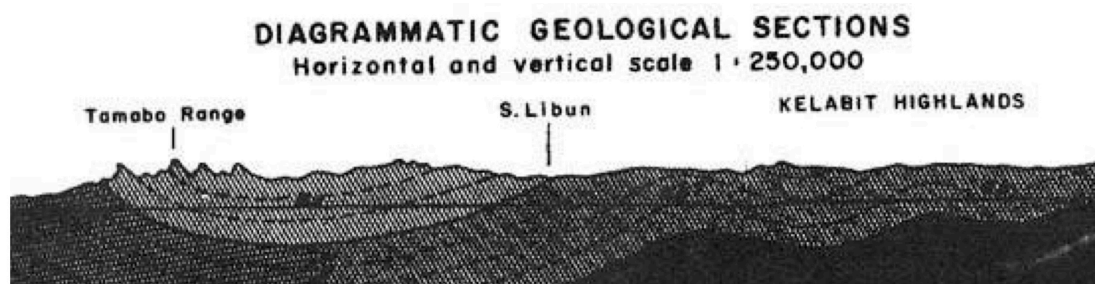
**Figure 3.2** Map of the Kelabit Highlands (rectangle at right) within the context of northern Sarawak along the north Borneo coast. The locations of the Niah Caves (1) are shown, as well as the towns of Bario (2) and Pa' Dalih (3) within the Kelabit Highlands. Source: Lloyd-Smith et al. (2013).

### ***Physical geography and vegetation***

Along with the adjacent Kerayan Tablelands to the east in Indonesian Kalimantan, the Kelabit Highlands comprise the western portion of a plateau at just above 1000m elevation at the headwaters the Baram River in north-eastern Sarawak. These highlands are situated ~220 km upriver (southeast) from the coastal town of Miri, and occupy an area of ~3000km<sup>2</sup>. The plateau is bounded on the west and north by the Tama Abu range that comprise sandstone ridges 1400-2400m above sea-level, as well as Sarawak's highest mountain, Gunung Murud at 2424m. The Apad Uat range delimits the Highlands to the east, forming the international border with the recently formed Indonesian state of North Kalimantan (2012) in which the more extensive Kerayan Tableland is located. The plateau itself is textured by low hills, as well as narrow alluvial plains and terraces associated with the drainage network of the upper tributaries of the Baram, namely the Dappur river in the north of the Highlands near the regional hub of Bario, and the Kelapang river in the south near the longhouse community at Pa' Dalih.

Average annual rainfall in the Kelabit Highlands, recorded at the State Government of Sarawak's Department of Irrigation and Drainage rainfall station in Bario, is reported to be 2000-2500mm (Lim, 2006) spread evenly across the year. There is a rainfall gradient across Sarawak from >5m in the southwest of the state near Kuching to the 2-2.5m of annual rainfall recorded in the Kelabit Highlands, with similar totals in the northern Sarawak coastal town of Miri. Historical temperature records are not available from the Malaysian Meteorological Department, but Lim (2006) notes daytime readings during his ecological surveys of 20-28°C in the forest, with temperatures at night falling to 14°C. Little temperature variation throughout the year has been noted.

The local surficial geology across the Kelabit Highlands is not well mapped (Lim, 2006; Malaysian Nature Society, 1998; Singh, 1999). The whole plateau appears to be an eroded anticline within the folded sandstones, shales, and turbidites that overly the Crocker Fan sandstones described in Chapter 2 (Figure 2.6; p. 24). The Tama Abu range that forms the northern and western



**Figure 3.3** Schematic geological section of the region, showing the ridge topography of the Tama Abu Range (appearing here as “Tamabo”) of Meligan Formation sandstones at left/west, and the plateau of the Kelabit Highlands at right/east which is composed of Kelabit Formation mudstones, shales, and sandy turbidites. Source: Singh (1999).

boundary of the Highlands is composed largely of the lower Oligocene-lower Miocene orthoquartzite sandstones of the Meligan Formation (Singh, 1999), with occasional exposures of the Setap Shale of similar age. Mudstones, impure limestones, and sandy turbidites of the Kelabit Formation occur in the south and east of the Highlands. Singh (1999) provides a diagram of an inferred geological section across the broad region (Figure 3.3).

The flora and vegetation of the Kelabit Highlands is predominantly composed of montane forests, the composition and distribution of which are driven locally by variations in the influence of edaphic and physiographic factors. In terms of the broad altitudinal vegetation bands mentioned in the previous chapter, the entirety of the plateau occurs within the ~900-1800m range of lower montane forest. Within this broad forest type, subtypes such as *kerangas* heath, alluvial forests, riparian forests, and vegetation communities that have been conspicuously modified by various human land uses occur across the Highlands. The topography is diverse, consisting of sandstone ridges incised by the upper reaches of tributary streams, limestone karstic formations, and alluvial valleys and plains of the main drainage network interspersed with low-lying hills. On a local scale, the various forest types occur alongside and generally grade into one another in a series of continua rather than as discreet and consistent floristic formations.

Lower montane forests (Figure 3.4) occur on middle to upper slopes of hills and mountains, and along ridge tops of the lower ranges (Lim, 2006). These communities are supported by loamy or sandy clays that are well-drained, and



**Figure 3.4** Two examples of lower montane forests in the Kelabit Highlands. Note mosses and lichens on boles, no understorey, and herbaceous groundcover. Sources: a) Lim (2006); b) Pearce (2006).

that are kept moist by a thick layer of leaf litter and organic material. Lim (2006) recorded 300 species from 72 families in a 2005 survey conducted ahead of the gazetting of the Pulong Tau National Park which spans the Tama Abu range on the north and western margins of the Highlands. The five most abundant families were Dipterocarpaceae, Clusiaceae, Fagaceae, Sapotaceae, and Theaceae. Canopy trees normally reach 25-30m in height and can achieve diameters at breast height (dbh) of 60-90cm. Lower montane forests within the Malesian floristic region are often referred to as oak-laurel forests in reference to the compositional prominence of trees of those families (Fagaceae and Lauraceae, respectively) within this forest type. In the Kelabit Highlands, genera of these families that are well-represented are *Castanopsis*, *Lithocarpus* (both in Fagaceae), *Beilschmiedia*, *Litsea*, and *Cinnamomum* (these last three in Lauraceae).

*Kerangas* forests (Figure 3.5) are associated with sandy soils and podzols. The predominant surficial geology of the ridges and mountains across the Kelabit Highlands, as well as late Quaternary fluvial deposits in valley bottoms and across alluvial plains, derive from the quartzose sandstones mentioned above. As such, *kerangas* forests are patchily yet widely distributed across the plateau. Substrates that support *kerangas* communities are silicate sands and sandstones, which may have a layer of peat at the surface (Lim, 2006). These soils are generally nutrient-poor and freely draining, requiring adaptations to low soil nutrient availability and increased drought-tolerance. Lim (2006) recorded 232 species in 67 families in his 2005 surveys, with the five most





**Figure 3.5** Kerangas forest in the Kelabit Highlands, showing densely growing pole-sized boles with relatively open canopy allowing for diffuse light to penetrate. Sources: a) Lim (2006); b) Pearce (2006).

abundant families being Clusiaceae, Myrtaceae, Fagaceae, Lauraceae, and Euphorbiaceae. The larger trees within *kerangas* communities are dominated by the Gondwanic conifers *Agathis* (Araucariaceae), *Dacrydium*, *Podocarpus*, and *Dacrycarpus* (the preceding three in Podocarpaceae), with large *Gymnostoma sumatranum* (Jungh. ex de Vriese) L.A.S. Johnson (Casuarinaceae) and *Tristaniopsis* (Myrtaceae) also noted. The structure of these communities is of lower stature than lower montane forest, reaching heights of 20-25m and with boles less than 60cm dbh and generally growing in high densities. Conspicuous elements of *kerangas* also include many *Rhododendron* (Ericaceae), pitcher plants (*Nepenthes* spp., Nepenthaceae), melastomes (Melastomataceae), and orchids (Orchidaceae).

Alluvial forests within the Kelabit Highlands are a subtype of lower montane forest (see Figure 3.6 for riparian portions of alluvial forest), and occur on the generally narrow terraces and plains ~2-3m above the present rivers. These environments are subject to periodic over-bank flows of the adjacent drainages, and as such soils here are usually clayey or loamy, occasionally waterlogged, and relatively fertile. Sixty species across 41 families were recorded in alluvial forests by Lim (2006), which encompass large trees 30-35m in height and greater than 60cm dbh. The five most abundant families were Euphorbiaceae, Fagaceae, Myrtaceae, Theaceae, and Lauraceae, with ground flora of *Pandanus* (Pandanaceae), ferns, sedges (Cyperaceae), orchids (Orchidaceae), and gingers (Zingiberaceae). Many rattans (palm subfamily Calamoideae) and other Arecaceae are also found in alluvial forests.



**Figure 3.6** Riparian vegetation along drainages in the Kelabit Highlands. The alluvial forest type described in text is a floristic sub-type of lower montane forest, with similar structure. The riparian forests pictured here grade into alluvial forests. Sources: a) Lim (2006); b) Pearce (2006).

Disturbed vegetation (Figure 3.7), which owes to both natural and anthropogenic processes, occurs at all elevations across the Kelabit Highlands. The sharp topographic relief over sedimentary geology leads to irregular landslips, especially following heavy rains. *El Niño*-induced droughts also lead to intra-annual recurrences of stress to vegetation, as well as increased susceptibility to fire, irrespective of ignition source. Local Kelabit and Penan groups employ a spectrum of management practices which have various impacts upon the surrounding vegetation communities. These practices include: collecting and harvesting of wild fruits, nuts, tubers, and young vegetative tissues, as well as material for crafts and construction; translocation of various clonally-propagating monocotyledonous plants and pteridophytes such as varieties of taro (*Colocasia esculenta* (L.) Schott, Araceae), bananas (*Musa* spp., Musaceae), gingers (*Zingiber* spp., Zingiberaceae), at least five different species



**Figure 3.7** Patches of open, disturbed vegetation in the Kelabit Highlands: a) patch dominated by bamboo en route to Gunung Murud; b) *Gleichenia*-dominated patch. Source: Lim (2006).



of yam (*Dioscorea* spp., Dioscoreaceae), and an assortment of ferns; a one-off clearance of notches in vegetation in a visibly prominent location such as a ridgetop (Figure 3.8a) in order to commemorate an auspicious occasion, referred to as *kawang*; swiddens in forest, cleared and burnt, planted with hill rice (*Oryza sativa* L., Poaceae) and other crops (Figure 3.8b), and then left fallow in order for secondary forest to regenerate through a succession that also contains useful plants; and multi-generational fruit tree orchards and permanent wet rice paddies associated with Kelabit settlements (Christensen, 2002; Puri, 2001).

The disturbed vegetation communities that these management practices, as well as the natural processes of landslips, drought, and floods, produce within the lower montane forest zone vary based upon intensity and persistence of disturbance. Secondary forests result from less severe or infrequent disturbance, often have a more open canopy than surrounding vegetation, consist of trees with smaller boles and shorter statures, and commonly support species of the genera *Macaranga* (Euphorbiaceae), *Adinandra* (Pentaphylacaceae), *Ficus* (Moraceae), gingers (Zingiberaceae), and bamboos (Bambusoideae). Open vegetated patches are the result of more severe or frequent disturbance, are often associated with settlements and agriculture, and composed of an impoverished range of taxa which is dominated by ferns such as *Gleichenia* and *Pteridium* (bracken), gingers (Zingiberaceae), and shrubs such as *Melastoma* (Melastomataceae) with no trees (Lim, 2006).



**Figure 3.8** Anthropogenic vegetation in the Kelabit Highlands: a) wet rice paddies in Bario, with secondary forests containing bamboos on slopes, and the Millennium Kawang along the ridgetop at right (Photo: S. O'Donnell); b) planting hill rice near Pa' Dalih in a fresh swidden (Source: Christensen, 2002).

### ***Ethnography***

Janowski and Langub (2011) contrast the two groups of people currently living in the Kelabit Highlands, the Kelabit and the Eastern Penan, by the ways in which they conceptualise their respective relationships with the surrounding forest and its resources. The Penan are often classified as foragers, despite also managing and harvesting sago; the Kelabit farm rice in permanent ‘wet’ paddies and in cleared ‘dry’ hill swiddens, but also derive the majority of the non-rice component of their diets from hunting and foraging wild resources in the forest. Neither group today is exclusively foragers nor farmers; both rely upon a mix of managed and wild resources from the forest. Janowski and Langub (2011) instead employ the metaphor of long-lasting ‘marks’ or *etuu* that the Kelabit make in the landscape (Figure 3.9a) with their megalithic monuments, rice paddies, and longhouse settlements, with the ephemeral ‘footprints’ or *uban* of Penan. These differing concepts about the impressions that people make in the landscape reflect the different attitudes toward the forest and its resources that the two groups hold. An aim of the multidisciplinary approach of the CRF was to investigate the time-depth of these attitudes through archaeological excavation and palaeoecological analyses, and also to examine whether these have changed through time.



**Figure 3.9** Differing attitudes to landscape between the Kelabit and Penan, reflected in the impressions they leave: a) carved stone in the Kelabit Highlands, a form of *etuu*; b) nomadic Penan community at Ba Puak. Source of both photos: Janowski & Langub (2011).



Christensen's (2002) ethnobotanical study of the Kelabit longhouse community at Pa' Dalih aimed to exhaustively document the uses and species of all plants used during her six months of immersive observation spread across three stays in the mid-1990s. This work recorded use by Kelabit of 650 species, which span all major groups including eudicotyledons, monocotyledons, basal angiosperms, gymnosperms, ferns, mosses, lichens, as well as fungi (which are not plants, but were documented within Christensen's ethnobotanical study). Christensen classified these species and uses into five major use-groups: edible species; uses of chemical compounds; religious and magic uses; technical uses; and other uses. Within these major groupings, specific use-subgroups were defined. For example, edible species comprise plants consumed as: fresh fruits; nuts and other seeds; vegetables, raw or cooked; spices and flavours; stimulants; potable water; host for edible larvae; and host for honeybees. Just under half of all species with documented uses (49 per cent) were used in more than one way, with an average of 1.7 uses for each of the 650 species recorded. Only 154 of these species were assessed as cultivated, semi-managed, or naturalised, which means that nearly 500 species of wild plants and fungi are used by the Kelabit in some form (Christensen, 2002), usually occurring within secondary forest of all ages. These data chime well with Janowski and Langub's (2011) observation, noted above, that Kelabit are often regarded as rice farmers, but the majority of their non-rice diet comprises wild species harvested from the forest.

### ***Archaeology***

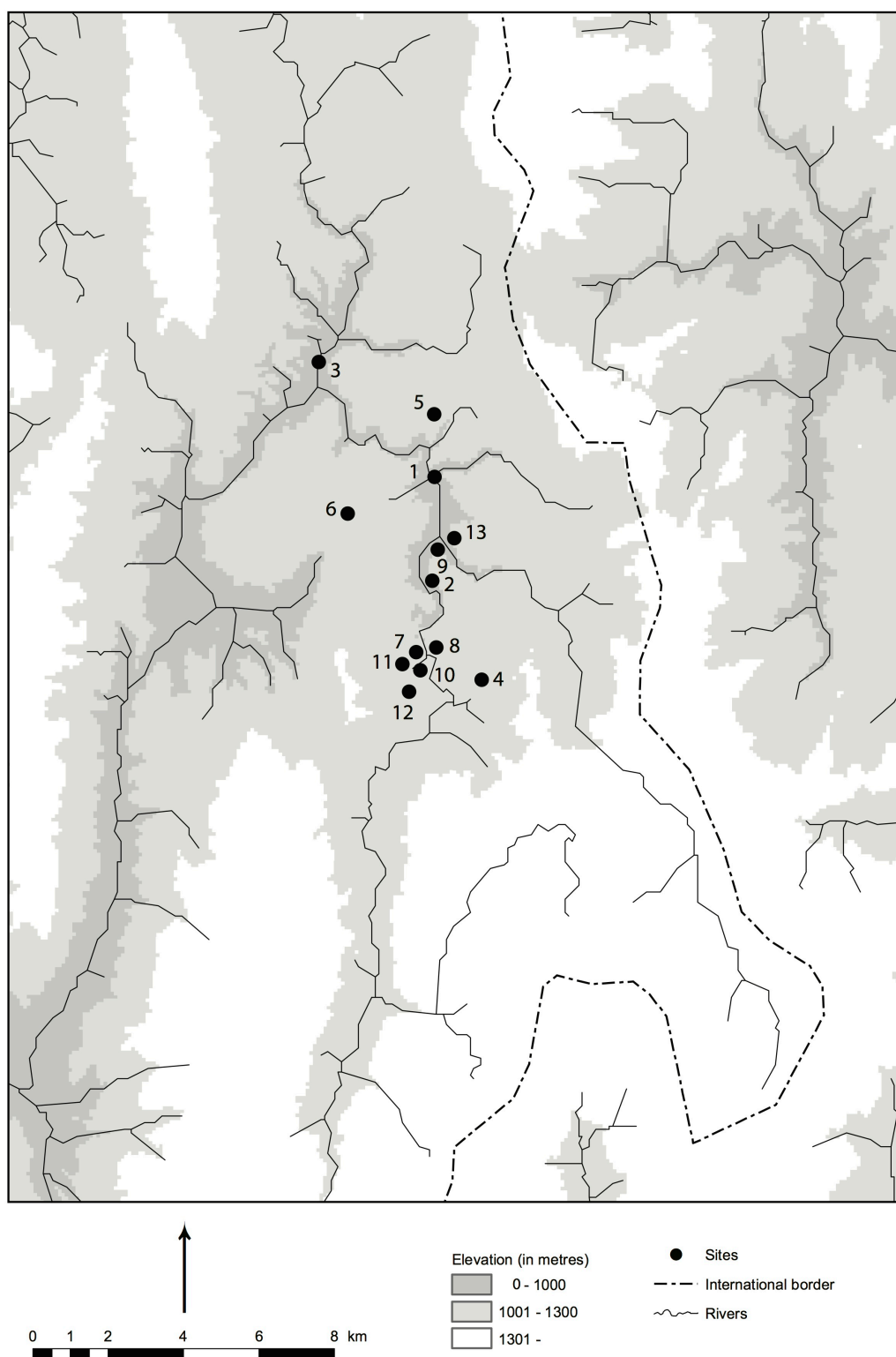
Tom Harrisson's initial descriptions of the archaeology of the Highlands from the time that he spent in Bario in the mid-1940s suggested the range of artefact and site types that systematic surveys and subsurface excavation might reveal (Harrisson, 1958). The International Tropical Timber Organization (ITTO) performed the first such surveys of the region in 2005 as part of an effort to identify and document important sites for protection and further investigation prior to logging (Lloyd-Smith *et al.*, 2013), and in conjunction with the gazetting of Pulong Tau National Park. Around 50 sites were mapped across the Kelabit Highlands as part of these surveys, which centred on megalithic sites and cemeteries. These prior surveys, by the ITTO as well as Harrisson, provided

reconnaissance for the site selection process of the Cultured Rain Forest project (CRF). The CRF began with a pilot study in 2006, followed by three consecutive seasons of fieldwork, with archaeological excavations comprising a main focus.

The pilot study located over 30 archaeological sites, and allowed for the CRF team to begin to define site types. The five most numerous types of sites were determined to be: old settlements or ancient occupation sites, referred to as *ruma ma'on*; megalithic sites, encompassing stone jars, slab-built structures, stone mounds (*perupun*), and standing stones; non-megalithic cemeteries, or *menatuh*; ditch-cuttings; and rock shelters (Lloyd-Smith *et al.*, 2013).

Excavations in subsequent seasons across a range of topographic features began to establish a chronology. The oldest radiocarbon age from an archaeological site of 4260-3980 cal BP comes from charcoal, probably reworked charcoal, in a buried soil horizon at the old riverside settlement of *Ruma Ma'on Dakah* (Lloyd-Smith *et al.*, 2010). Sediment accumulation at the site suggests its repeated use over hundreds and possibly thousands of years. Other sites within the upper Kelapang valley in the southern portion of the Kelabit Highlands indicate open-air settlement in the mid-first millennium AD, widespread evidence for riverside settlement and agriculture through the past 500 years, and ridgetop settlement through the same period. The stone jars at *Menatoh Long Di'it* appear to have been erected within the past 1300 years, whilst the stone mound of *Perupun Long Kelit* was probably built in the last 500 years.

Surveys during the 2009 field season recorded an additional 27 sites, which included past settlements and cemeteries (Dragon Jar sites, as well as slab-built dolmen-like structures). Subsurface excavations in 2009 were continued at three sites of particular interest (Figure 3.10): the megalithic cemetery at *Menatoh Long Di'it*, and the old settlement sites of *Ruma Ma'on Dakah* and *Ruma Ma'on Taa Payo* on the banks of the Kelapang opposite one another. Results from these three sites are discussed briefly below.



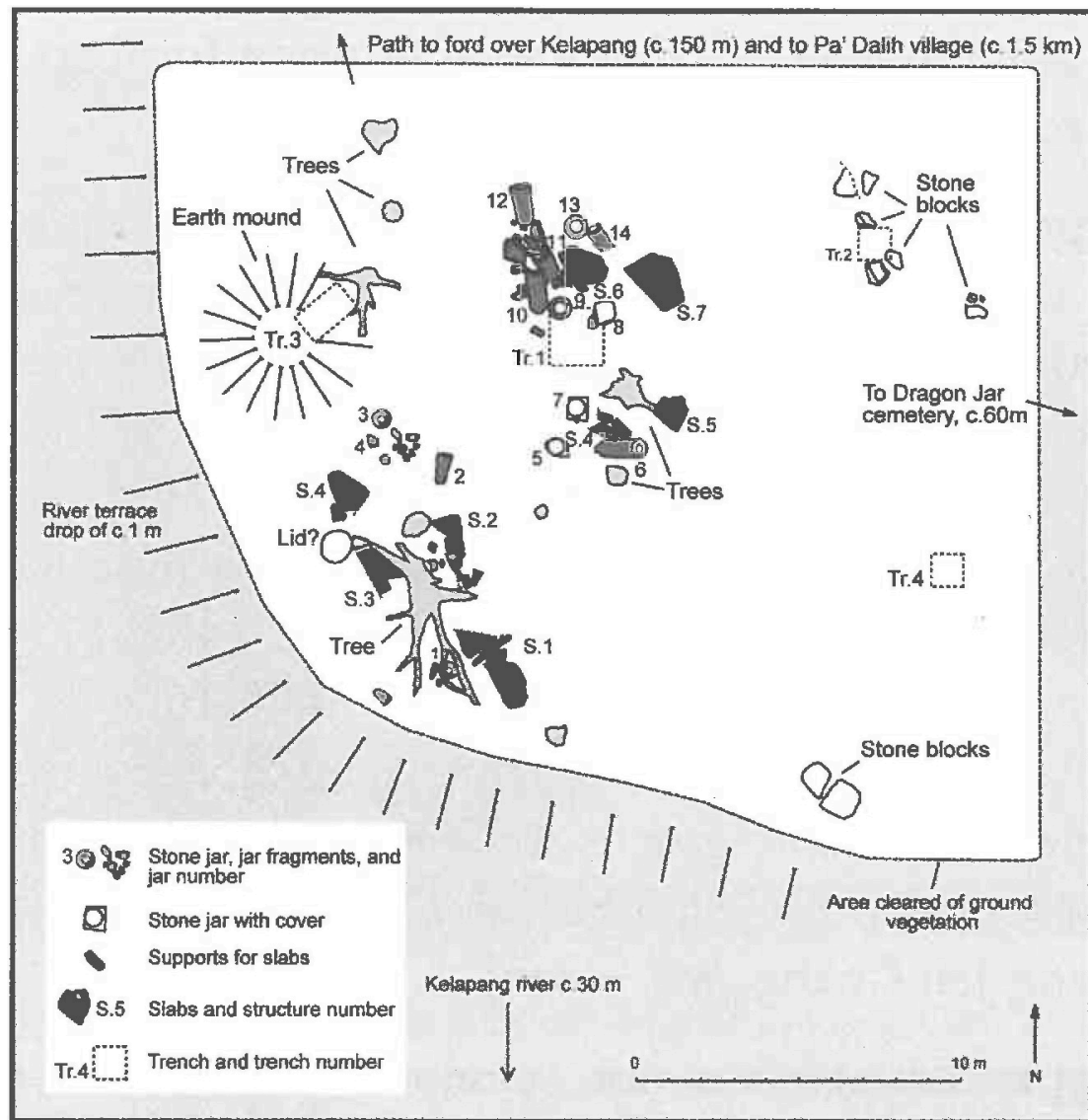
**Figure 3.10** Location of archaeological sites in the southern Kelabit Highlands. Sites mentioned in text: Pa' Dalih (1); Ruma Ma'on Dakah (7); Ruma Ma'on Taa Payo (8); Menatoh Long Di'it (9). Source: Lloyd-Smith et al. (2013).

### ***Menatoh Long Di'it***

The megalithic cemetery site of *Menatoh Long Di'it* (Figure 3.11) is located 1.5km south (upriver) from the Kelabit longhouse community at Pa' Dalih, on a low terrace at the confluence of the Di'it and Kelapang rivers. The site consists of 14 stone jars and five slab or cist-like structures in two clusters. A small trench at the base of two standing stone jars at the centre of the site (Figure 3.12) revealed stratified sequences containing earthenware, stoneware, and porcelain vessels; beads; iron knives; a whetstone; and bronze bells, as well as small fragments of burnt human bone and teeth which were assumed to represent depositional events associated with secondary burials (Lloyd-Smith *et al.*, 2010). Cremation has not been practised in living memory nor is there any folk memory or Kelabit myths of the practise (Harrisson, 1962b; Lian-Saging & Bulan, 1989). As such, the cremated remains likely represent earlier use of the site, perhaps in association with the stone jars. A charcoal sample from directly beneath a central cluster of earthenware shreds in Trench 2 yielded an age of 1710-1530 cal BP, whilst charcoal from the base of a notional posthole within Trench 4 produced an age of 2350-2300 cal BP. This leads to the suggestion that this site housed habitation structures prior to its use as a megalithic cemetery (Lloyd-Smith *et al.*, 2010).



**Figure 3.11** Central cluster of five stone jars at Menatoh Long Di'it, looking southeast. Photo: S. O'Donnell.

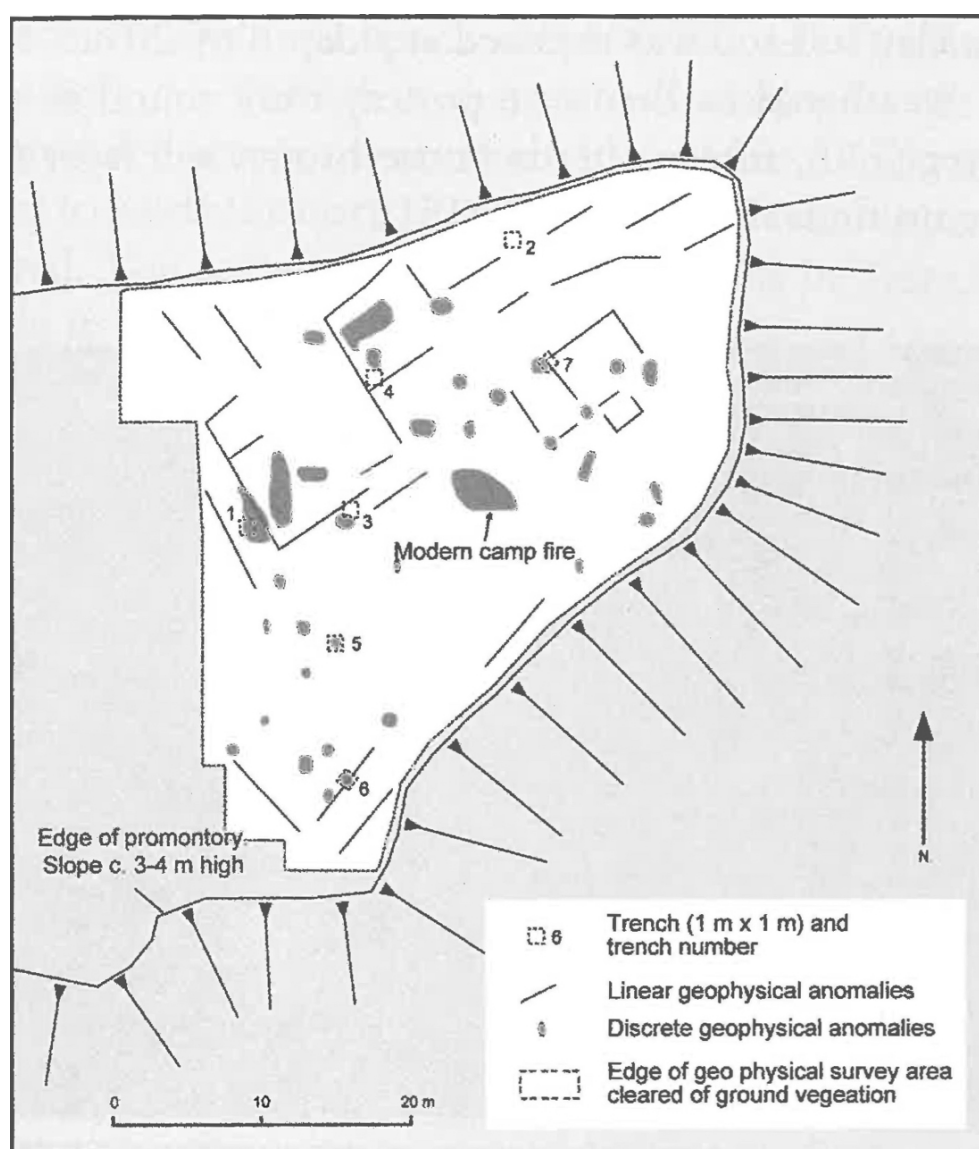


**Figure 3.12** Site plan of Menatoh Long Di'it. Trenches 2 and 4, from where the two old radiocarbon ages derive, are along the eastern edge of the site at right. Source: Lloyd-Smith et al. (2010).

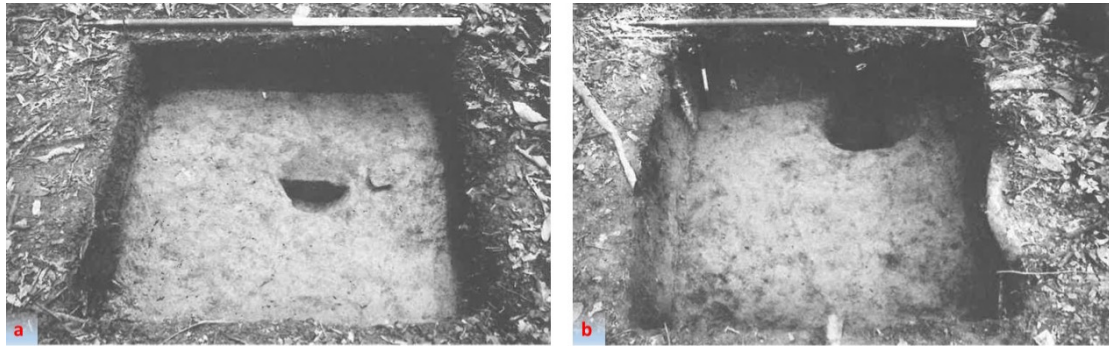
### ***Ruma Ma'on Dakah***

The old longhouse site of *Ruma Ma'on Dakah* is located on a spur of a second river terrace on the left (west) bank of the Kelapang river, approximately 5km south from Pa' Dalih. Local informants say it was last inhabited in the first half of the 1900s, probably early in the century (Lloyd-Smith *et al.*, 2010). Excavation of Trench 2 yielded earthenware sherds, and a posthole containing Qing Dynasty (1700-1900s) porcelain in its fill. Charcoal from the base of this fill produced a radiocarbon age of 4260-3980 cal BP, which has been interpreted as reworked so does not date the posthole. However, it does hint at long use of the site (Lloyd-Smith *et al.*, 2010). A programme of geophysical surveys directed

excavation of Trenches 3-7, where linear features and signals producing rectangular shapes in the subsurface were located (Figure 3.13). Excavation at these locations uncovered two more postholes (Figure 3.14), gully-like features, pieces of iron, burnt stones, and weathered earthenware sherds. These artefacts are interpreted to represent previous occupation and traces of structures, perhaps previous longhouses. Based upon comparison with modern Kelabit constructions, the size and shape of a posthole excavated in Trench 7 implies a supporting post for a hearth. Charcoal from the base of a posthole in Trench 6 produced a radiocarbon age of 2050-1880 cal BP.



**Figure 3.13** Site plan of Ruma Ma'on Dakah , showing numbered trenches, as well as linear subsurface features revealed by the geophysical surveys. Locations of gully-like features and postholes uncovered by excavations in Trenches 6 and 7, combined with the geophysical survey data, suggest large habitation structures. Source: Lloyd-Smith et al. (2010).

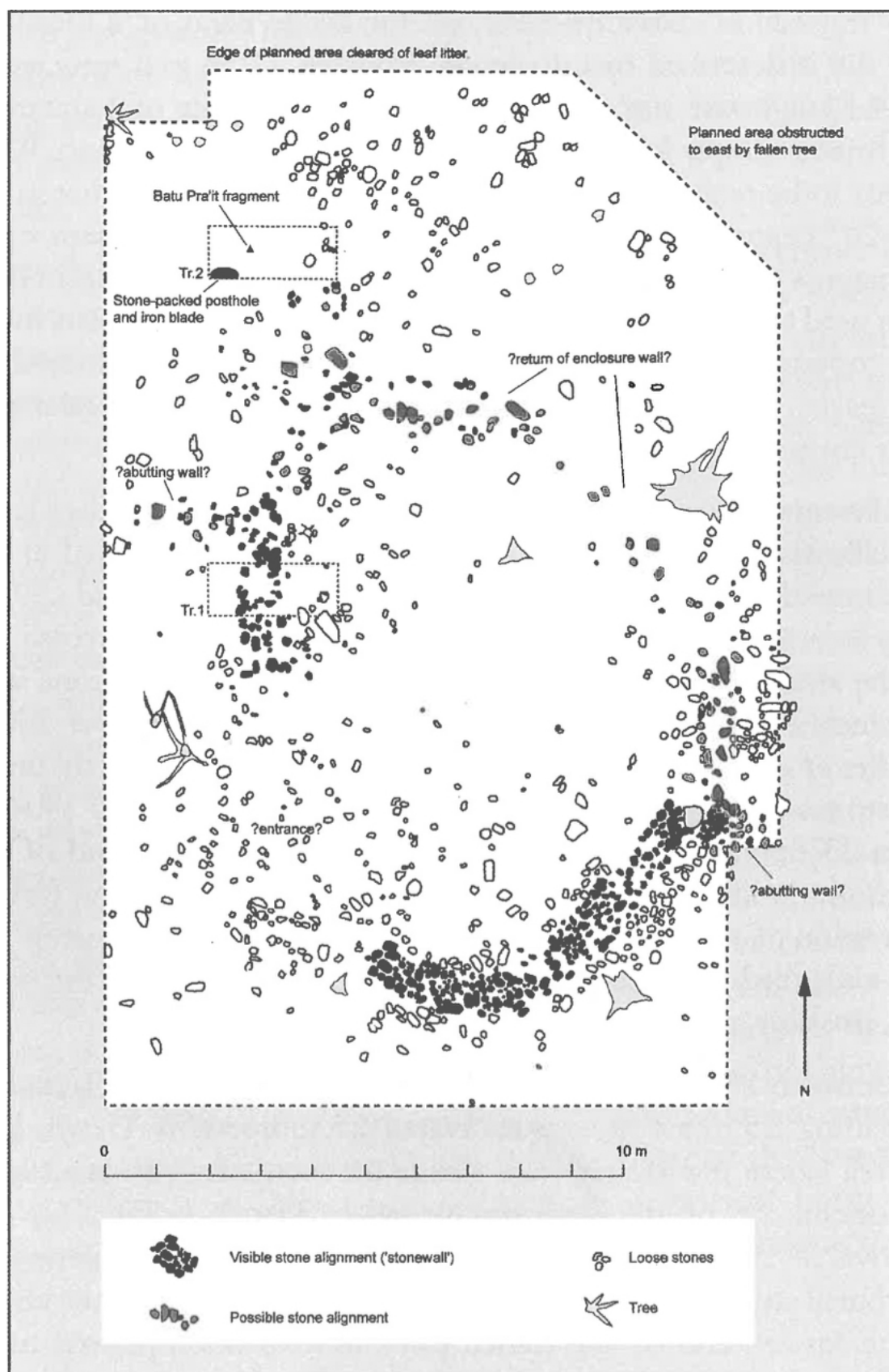


**Figure 3.14** Postholes at Ruma Ma'on Dakah : a) Trench 6, containing the posthole from which charcoal was recovered that produced an age of 2050-1880 cal BP; b) Trench 7, which contains the posthole that is the size and shape of posts that support hearths within modern Kelabit constructions. Source: Lloyd-Smith et al. (2010).

### ***Ruma Ma'on Taa Payo***

Located directly across the Kelapang river from *Ruma Ma'on Dakah*, the old longhouse site of *Ruma Ma'on Taa Payo* (Figure 3.15) occupies a flat-topped terrace on the inside bend of a meander ~20m above the river channel. Informants are uncertain as to when in the past this site was inhabited, but that sambar deer used to be kept here in enclosures for slaughter at *irau* feasts. The site is delimited by alignments of river-rolled cobbles on three sides, and on its eastern side by a palaeochannel of the Kelapang. Trenches 2.5m x 1m were located across these stone alignments, and magnetometer surveys conducted throughout the site. Earthenware pottery was contained within the base of what is interpreted as a stone wall, with charcoal from a layer immediately beneath the stones that produced a radiocarbon age of 1610-1400 cal BP (Lloyd-Smith *et al.*, 2010). Excavation of additional trenches across these stone structures uncovered a ditch underneath, that possibly represents a fenced palisade (Barker *et al.*, 2009). Along with earthenware sherds, an iron blade, and two postholes, two cylindrical stone pounders known as *batu pera'it* ('thunder stones') were uncovered from the western end of Trench 2 (Figure 3.16). The surfaces of these pounders yielded starch granules that are identifiable to the palm family, Arecaceae. Tom Harrisson collected many *batu pera'it* in the central highlands and identified them as pounders for making sago flour (Harrison, 1951). Charcoal from the fill of one of the postholes produced an age of 1540-1360 cal BP (Lloyd-Smith *et al.*, 2010).





**Figure 3.15** Site plan of Ruma Ma'on Taa Payo. Trench 2, from which the stone pounders were recovered, is located 6.5m north of Trench 1 along the western edge of the site. Source: Lloyd-Smith et al. (2010).





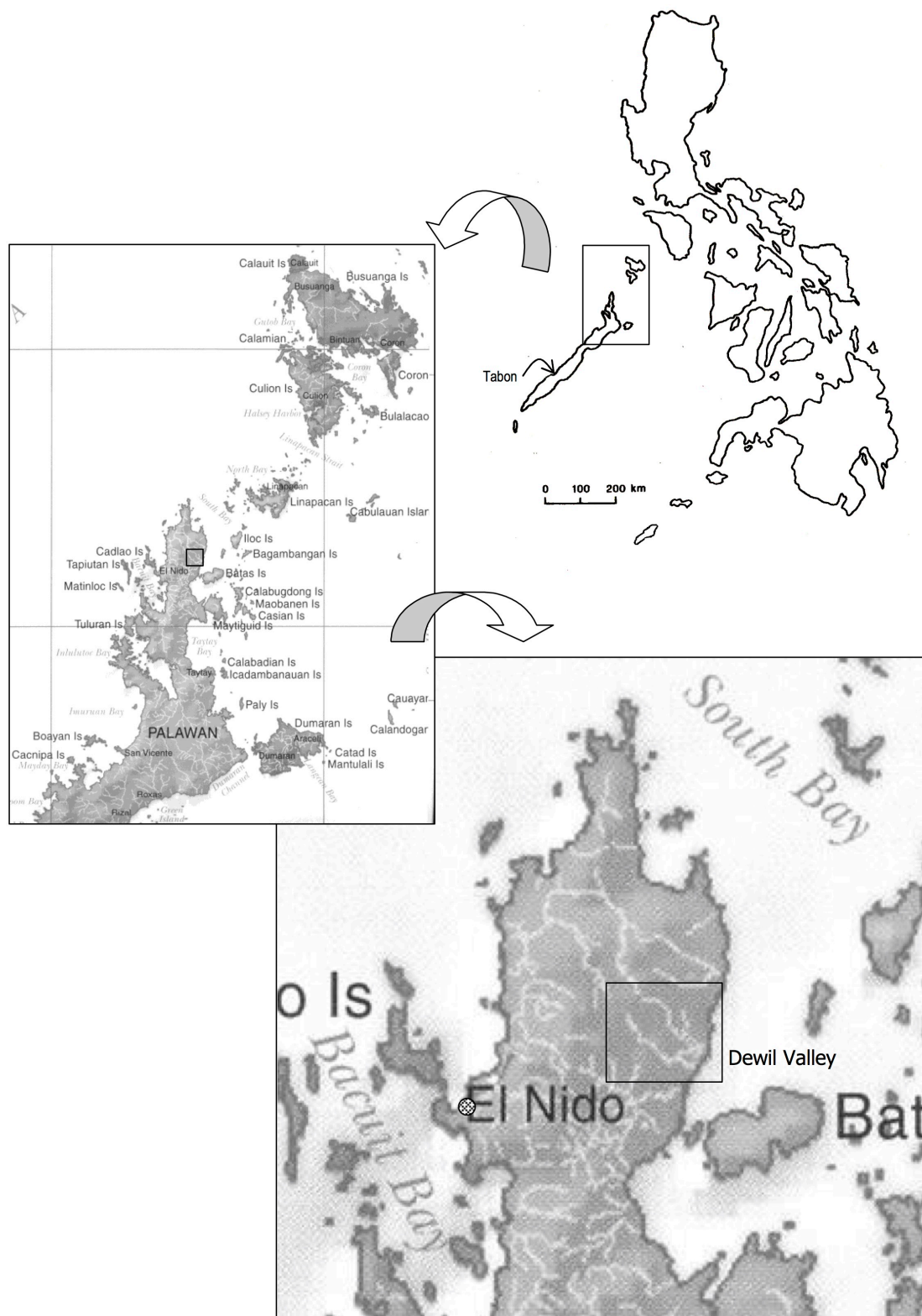
**Figure 3.16** Notional sago pounder (a) (batu pera'it) from Trench 2 at Ruma Ma'on Taa Payo; ditch and posthole which possibly represent a fenced palisade, beneath a stone wall at Ruma Ma'on Taa Payo. Source: Lloyd-Smith et al. (2010).

### ***Palaeoecology***

The entirety of previous palaeoecological work conducted within the Kelabit Highlands derives from Samantha Jones' PhD research (2012) as a member of the Cultured Rain Forest project team. Her work is described in Chapter 4 as context to the site selection process for the present study, and her results are examined in detail within Chapter 6. Jones (2012) established a ~50,000-year vegetation history for the Kelabit Highlands region, albeit with discontinuities spanning the LGM, terminal Pleistocene, and earliest Holocene, through a piecemeal approach which targeted deposits of various ages within palaeochannels of the drainage network across the Highlands, as well as from an organic sediment-filled depression on an ancient terrace of the Dappur river near Bario. Her records show signs during OIS 3 (~50-30 ka BP) of upper montane forest elements that are restricted to higher elevations today, suggesting depressed temperature during this time. Holocene portions suggest dynamic hydrological and fluvial processes, as well as disturbance to vegetation in the form of charcoal, lithological changes, and pollen of open landscape and pioneer taxa, combined with pollen of taxa that include economically useful plants. Jones (2012) interprets many of these changes as indicative of human impact.

#### ***3.4.2 Dewil Valley, El Nido, northern Palawan Island, Philippines***

The portion of this thesis that focuses upon the Dewil Valley (Figures 3.17 & 3.18) and surrounding landscapes in northern Palawan Island in the western



**Figure 3.17** Location of the Dewil Valley at the northern tip of Palawan Island in the western Philippines. The location of Tabon in southern Palawan is also shown in the broad-scale map. Source: Paz et al. (2010).



**Figure 3.18** Dewil Valley landscape looking northwest from a fresh swidden on the slopes south of Ille. Four karst towers that house caves with archaeology are visible (from left to right): Makangit complex; Istar (pyramid-shape in distance); Diribungan (in distance, right of Istar); Ille. Photo: S. O'Donnell.

Philippines was conducted as part of the Palawan Island Palaeohistoric Research Project (PIPRP). This project grew out of initial surveys of the area by Robert Fox in the 1960s (Fox, 1970; Paz *et al.*, 2010), which led to the first excavations at the Ille Cave and Rockshelter Site in 1998-2002 directed by Wilhelm Solheim II. After a one-year hiatus, excavations in their present form resumed in 2004 as the PIPRP, and have operated an annual field programme of surveys, excavations, and outreach every year since. Prior to the initiation of the PIPRP, Philippine archaeology was focused on the archaic human as well as Neolithic and Metal Age sites in northern Luzon, and, in Palawan, on the network of caves at Lipuun Point in Quezon municipality which constitute the Tabon Caves (Paz *et al.*, 2010). The stratified deposits at Ille and Pasimbahan-Magsanib Cave and Rockshelter Site (also within the Dewil Valley, ~1.5km northwest from Ille) have provided evidence for human occupation and exploitation of changing environments and resources within the Dewil Valley from as far back as 14,000 cal BP (Lewis *et al.*, 2008; Ochoa *et al.*, 2014; Piper *et al.*, 2011) and continuing through the late Holocene. The archaeology at these sites includes the earliest directly-dated human cremation burial in the Southeast Asian region (Lewis *et al.*, 2008; Lara *et al.*, 2013), symbolic boat-shaped burial markers (ie Paz, 2012), anthropomorphic and zoomorphic design motifs in pottery (Paz *et al.*, 2010), as well as shell, stone, and bone implements and personal ornamentation.

### ***Physical geography and vegetation***

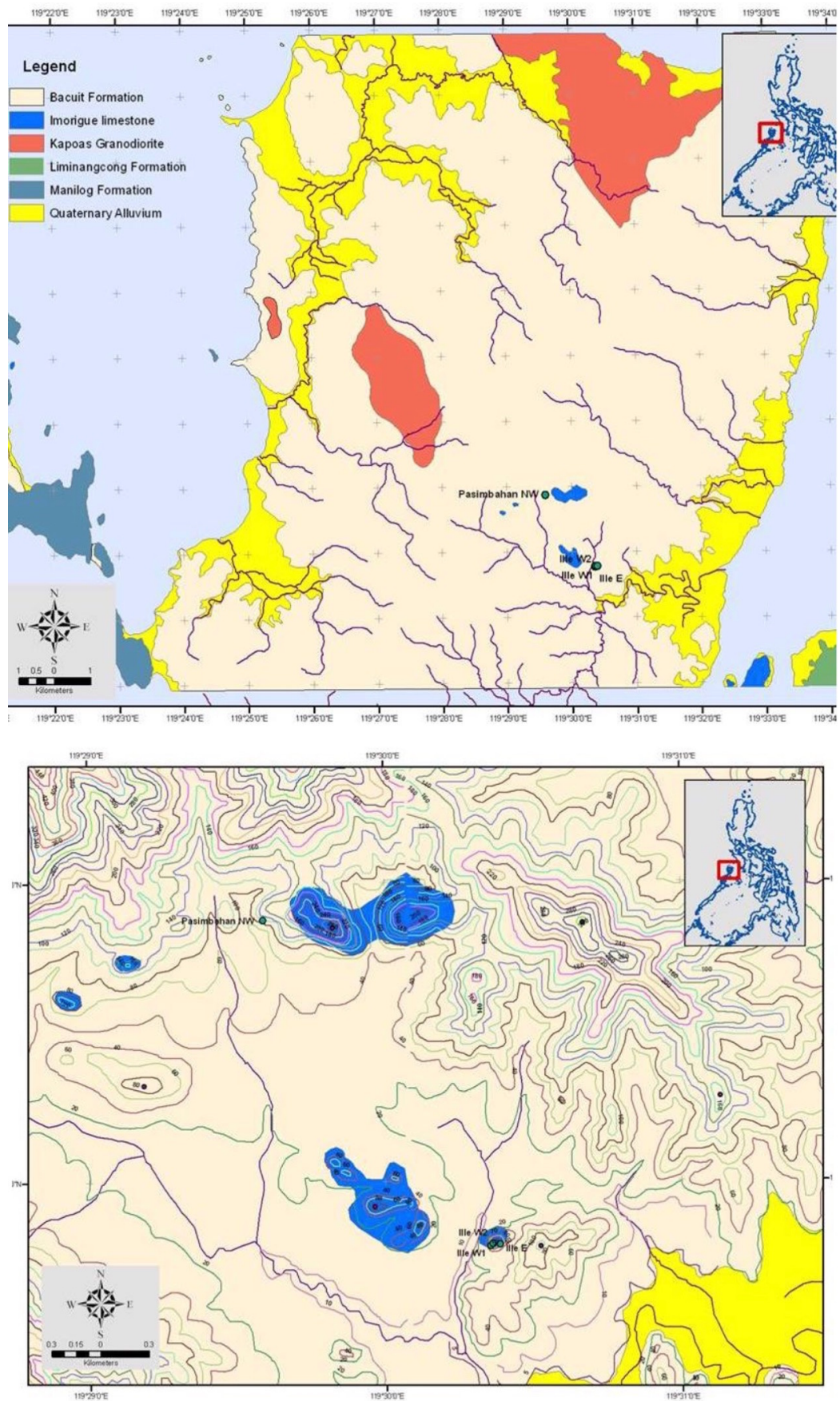
The narrow island of Palawan is ~425km long with a maximum breadth of 40km, covering an area of around 11,785km<sup>2</sup> (Piper *et al.*, 2011). The Dewil Valley study area is located within El Nido municipality in the north of the island,

~19km east of the town of El Nido. Sites within the valley and fringing slopes that were surveyed for the present study all occur below 100m elevation, whilst the highest surrounding peaks reach ~600m (Cayron, 2012). On an annual scale, the climate is dominated by monsoonal influences. Mean annual rainfall across the island ranges from 1600-3000mm, with a unimodal distribution and a dry season from January to April (Baillie *et al.*, 2000). In northern Palawan, Cayron (2012) cites a six-month dry season from November to May, followed by a wet summer season from June to October during which 2000-4000mm of rain falls annually. Mean annual temperatures in the lowlands are 26-28°C, with little seasonal variation (Baillie *et al.*, 2000). On a sub-decadal scale, Palawan's location on the northern edge of the Indo-Pacific Warm Pool means that the average rainfall figures just mentioned are subject to prolonged drought conditions associated with *El Niño* events.

Whilst Suggate *et al.* (2014) map the surficial geology of the North Palawan Block as Mesozoic Mélange, Baillie *et al.* (2000) and Kiessling and Flügel (2000) refer locally within El Nido municipality to the Bacuit Formation of sandstones, shales, and chert, and their low grade metamorphic derivatives. Baillie *et al.* (2000) compare the folded sedimentary units of the North Palawan Block to the geosynclinal rocks of the Rajang Group flysch in central and interior north Borneo. Within the Dewil Valley, remnant karst formations composed of the Jurassic Imorigue Limestone overlie the Permian and early Mesozoic sedimentary units of the Bacuit Formation (Figure 3.19).

Modern environments and altitudinal zonation of vegetation on Palawan are broadly comparable to those of northern Borneo (Heaney, 2001; Piper *et al.*, 2011), with lowland evergreen dipterocarp rain forest up to ~1200m. Wikramanayake *et al.* (2001) consider Palawan and the surrounding small islands off its coast to be a single ecoregion, with semi-deciduous forests occurring in the rain shadow east of the Central Cordillera. Habitat heterogeneity is also patterned by the various limestone and ultramafic substrates, as well as along coasts where beach forests and extensive mangroves occur (Bird *et al.*, 2007). No published ecological studies exist for the Dewil Valley, though Ashton (2014) maps the whole of Palawan within the distribution of seasonal evergreen





**Figure 3.19** Geologic maps of northern Palawan (top) and Dewil Valley (bottom). Source Foronda (2010).



rainforests that border the mixed dipterocarp forests of the perhumid Sundaland core centred on northwest Borneo to Palawan's southwest (Figure 2.20; p. 39). Botanical taxon lists have been compiled for the Dewil Valley as part of the PIPRP on two separate occasions by Ramon Bandong: in 2005 in association with palynological reconnaissance of the valley; and in 2013 as part of the



**Figure 3.20** Dewil Valley vegetation types: a) alluvial landscape dominated by patchwork of rice paddies, swidden regrowth, and fringing slopes of secondary dipterocarp forest; b) secondary dipterocarp forest on slopes; c) riparian vegetation; d) limestone forest; e) mangrove; f) wetland, dominated by sedges; g) wetland, dominated by *Typha angustifolia*; h) riparian forest, with planted mango tree and coffee; i) remnant back mangrove vegetation; j) bunded Tilapia pond fringed by sedges, taro and coconut palms; k) irrigated rice paddy; l) secondary mixed dipterocarp forest; m) large gingers along heavily-travelled path; n) freshly burnt swidden; o) three-year-old swidden regrowth dominated by bamboos. Photos: S. O'Donnell

present study. These data are discussed in Chapter 7, and a complete list of taxa identified across both programmes of botanical surveys appear in Appendix 1. Figure 3.20 shows the range of vegetation types encountered within the Dewil Valley, encompassing: secondary mixed dipterocarp rain forest on surrounding slopes; carbonate-adapted limestone forests on karst towers; riparian communities along streams and rivers; wetland vegetation in perennially marshy areas where drainage is impounded; rain-fed, as well as irrigated, rice paddies; vegetable gardens and orchards; swidden at various stages of regrowth, tending toward the development of bamboo thickets where clearance via burning is frequent; and mangrove and beach forest communities along the coastal margin.

### ***Ethnography***

The Barangay of New Ibajay is the nearest town to the Dewil Valley archaeological sites. Its population is composed of settlers and their descendants from the large island of Panay to the east of Palawan in the western Visayas, the bulk of whom migrated to the Dewil Valley in the late twentieth century (Paz *et al.*, 2014). Most of the families within New Ibajay came from the northern Panay province of Aklan, and today speak the local Aklan language along with Cuyon and Filipino. The population of the surrounding area within the Dewil Valley but outside of New Ibajay, as well as the rest of the El Nido municipality, belongs predominantly to the Cuyon ethnolinguistic group (Cayron, 2012). The alluvial landscape of the Dewil Valley comprises numerous rain-fed rice paddies, orchards, and vegetable gardens that are tended and harvested by families from New Ibajay. Surrounding slopes are also managed under a system of shifting swidden cultivation in which dry rice, cassava, and other vegetables are planted. The many karst towers scattered across and around the valley house colonies of swifts and hives of bees, the nests and honey from which, respectively, are harvested by the local residents (Cayron, 2012).

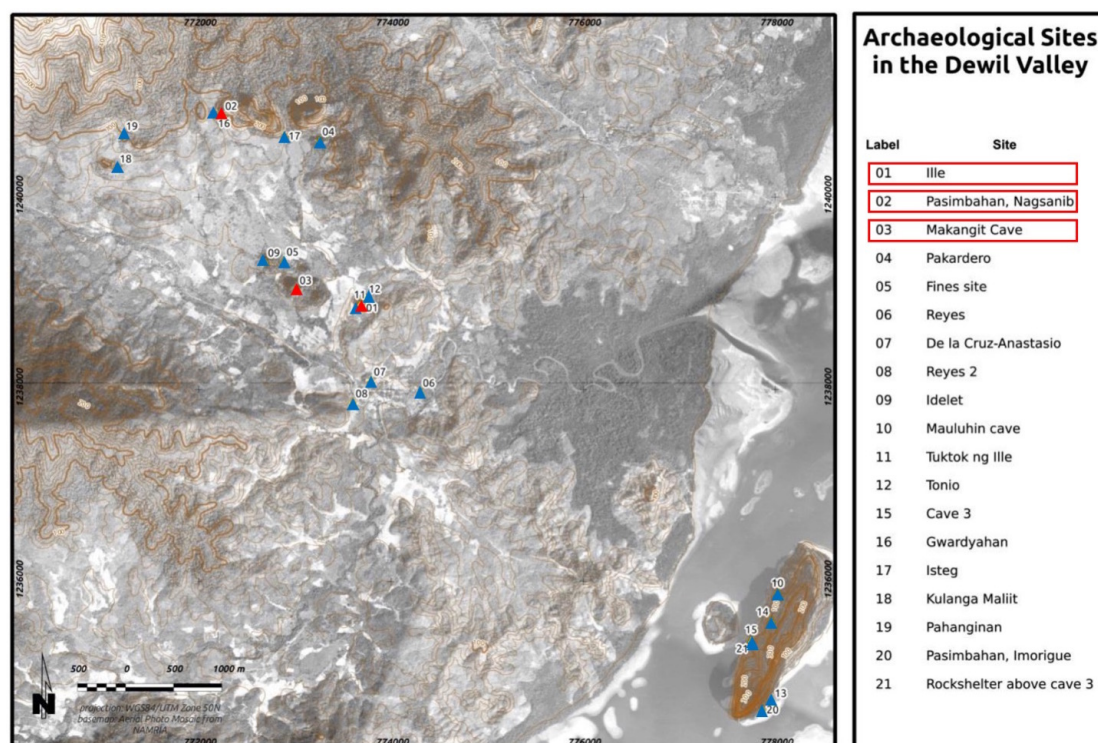
In contrast to the Kelabit Highlands, no exhaustive enthobotanical study of the Aklan and Cuyon inhabitants of the Dewil Valley has been completed. However, Cayron (2012) offers some insights into plants used by Dewil Valley

residents, compiled from a combination of personal observations and interviews. According to Cayron (2012), burning for the swidden mentioned above is done as preparation for planting, as well as in conjunction with charcoal production. Rice is the primary crop, supplemented with vegetables and fruits trees. Of particular economic importance are the extensive cashew groves near dwellings and on slopes surrounding the valley. The majority of the rice crop is for local domestic consumption, but in bumper years the surplus will be traded at market. Sale of cashew harvests, on the other hand, provide an important source of income for Dewil Valley residents during the dry season. Many species of rattan (from various genera in the palm subfamily Calamoideae), *Pandanus* (Pandanaceae), and the mangrove palm *Nypa fruticans* Wurb are used for weaving, basketry, and thatch. Though illegal, the various mangrove tree taxa (species of *Rhizophora*, *Bruigiera*, *Ceriops*, *Avicennia*, and *Sonneratia*) are collected or harvested as the preferred material charcoal production. Coconut wine, vinegar, and sugar are all made from the liquid portion of the endosperm of *Cocos nucifera* L. (Arecaceae), whilst the fleshy portion of the endosperm is consumed raw or as a condiment, and coconut leaves constitute a versatile material for basketry and weaving. The two species of bamboo that occur in the valley, *Dinorchloa palawanensis* (Gamble) S.Dransfield and *Schizostachyum lumampao* (Blanco) Merr., are used ubiquitously in construction as well as fashioned with machete-like knives called *parang* into all manner of utilitarian objects ranging from bench and flooring slats to cutlery and ash trays. Cayron lists *Pterocarpus indicus* Willd. (Fabaceae), *Diospyros pulgarensis* (Elmer) Merr. (Ebenaceae), and *Dipterocarpus grandiflorus* (Blanco) Blanco (Dipterocarpaceae) as the three most important timber sources exploited within the Dewil Valley.

### ***Archaeology***

Dissolution caves at the bases of and tunnelling within the eight limestone karst towers spread throughout the Dewil Valley contain numerous deposits with archaeological remains (Figure 3.21). Subsurface excavations since 1998 have focused on the >14,000-year sequence and history of use at the Ille Cave





**Figure 3.21** Locations of Dewil Valley archaeological sites. The three main sites of previous studies described in this chapter are shown in the map by red triangles, with red boxes around their entries in the legend at right. All sites occur below 100m elevation. Thick brown lines are 100m contours; thin brown lines are 20m contours. The large mangrove complex at the mouth of the Dewil River is visible at the centre-right, whilst the Makinit coring site, described in Chapter 7, is eight km NW from the Dewil Valley. Source: Paz et al. (2012).

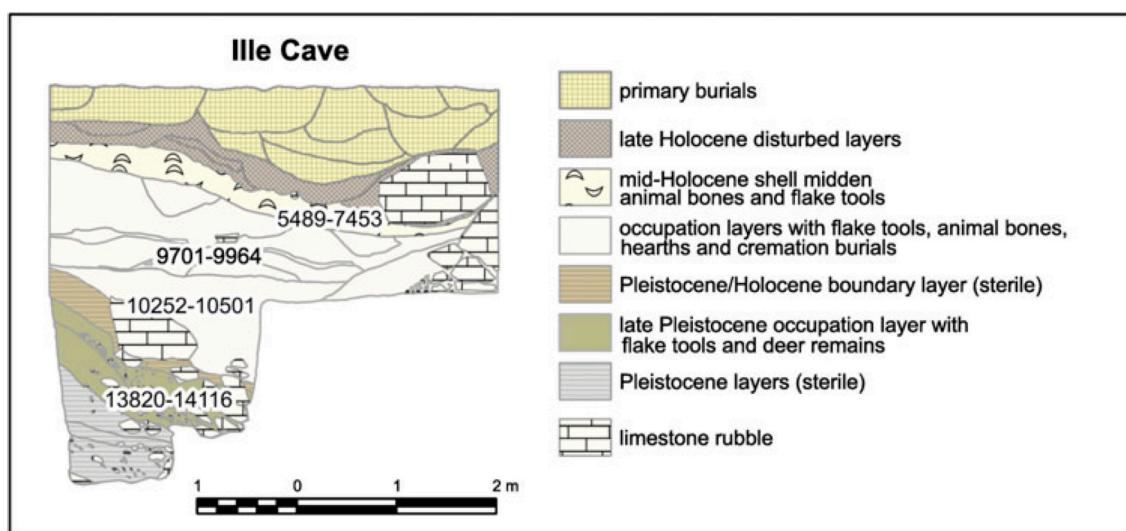
and Rockshelter Site. The site is located about 800m north from the town of New Ibajay, which is reached via a 20-minute walk down a forested footpath between the town and some of the dwellings within the alluvial landscape of the Dewil Valley. The cave is located at the base of the south side of the Ille limestone karst tower, which is ~75m in height. There are two main openings (east and west) which lead to a single chamber within 5m of the cave entrances. In front of the entrances, underneath the overhanging limestone, is a flat platform 3-15m wide and that covers an area of about 450m<sup>2</sup> (Figure 3.22) (Pawlik, 2004; Szabó *et al.*, 2004).

Over 30 radiocarbon ages provide chronological control for the sequence within the East Mouth trench (Figure 3.23). Context 1306 is the oldest deposit at Ille that contains evidence of human occupation in the form of stone tools and animal bones. This context directly underlies Context 866, from which was



**Figure 3.22** Looking northeast across the platform at the Ille Cave and Rockshelter Site. The West Mouth is at left of photo; the East Mouth is behind the people. Source: Barker et al. (2011); photo: V. Paz.

recovered charcoal that produced a late Pleistocene radiocarbon age of 13,820-14,116 cal BP (Lewis *et al.*, 2008). Above these are steeply sloping layers of oxidised clays that variably contain evidence of human activity, suggesting intermittent cave occupation at the Pleistocene-Holocene boundary. A sequence of silty clay deposits dating to between 9400-11,000 cal BP and containing hearths, charcoal, shell, unburnt and burnt animal bones, and stone tools, overlies these clays. Above these early Holocene silty clays is a cremation

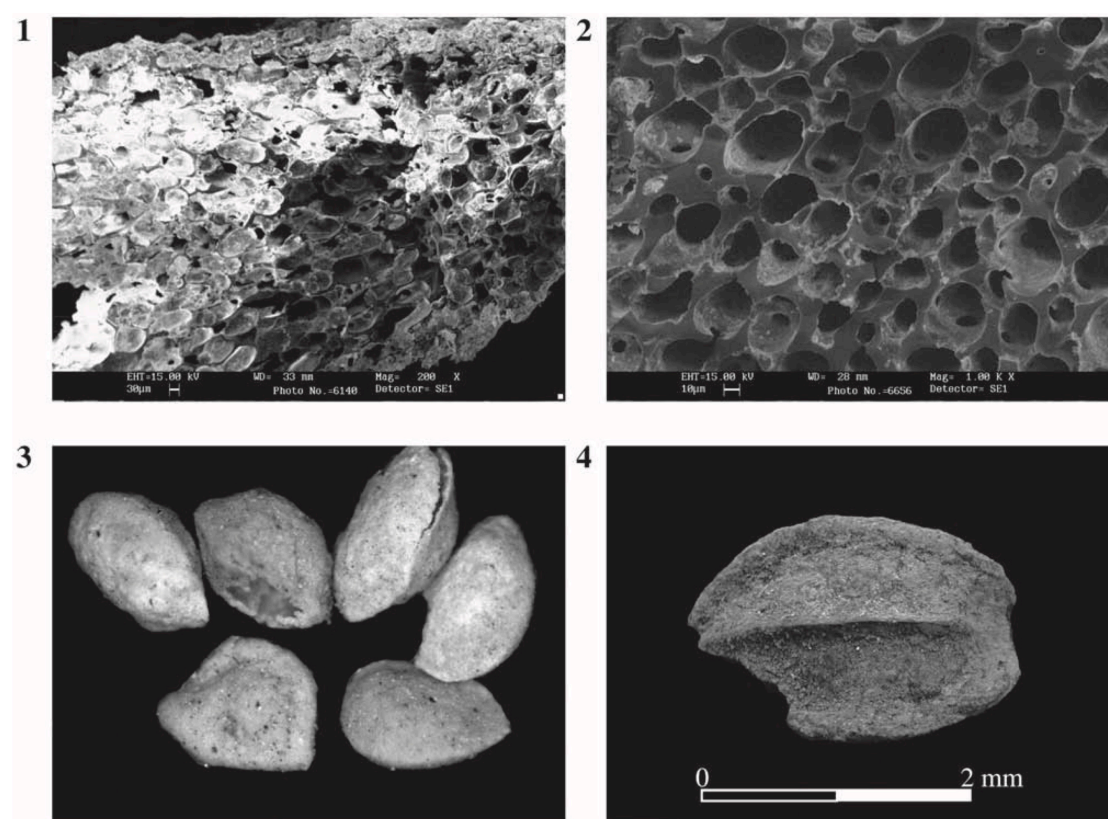


**Figure 3.23** Simplified section drawing and rough chronostratigraphy of the west-facing wall of the East Mouth trench at Ille Cave. Over 30 radiocarbon ages have been obtained on material from the East Mouth. Source: Robles et al. (2015).



cemetery (Lewis *et al.*, 2008; Lara *et al.*, 2013), bones from which have been directly dated to 9006-9260 cal BP and 9280-9425 cal BP. Overlying the cremation cemetery is a shell midden that also contains diverse animal bones and flaked stone tools, and which dates to 5000-7000 cal BP. The upper layers in both the East Mouth and West Mouth trenches comprise late prehistoric and protohistoric burials and pits, which are cut through other sedimentary layers that overlie the mid-Holocene shell midden (Piper *et al.*, 2011).

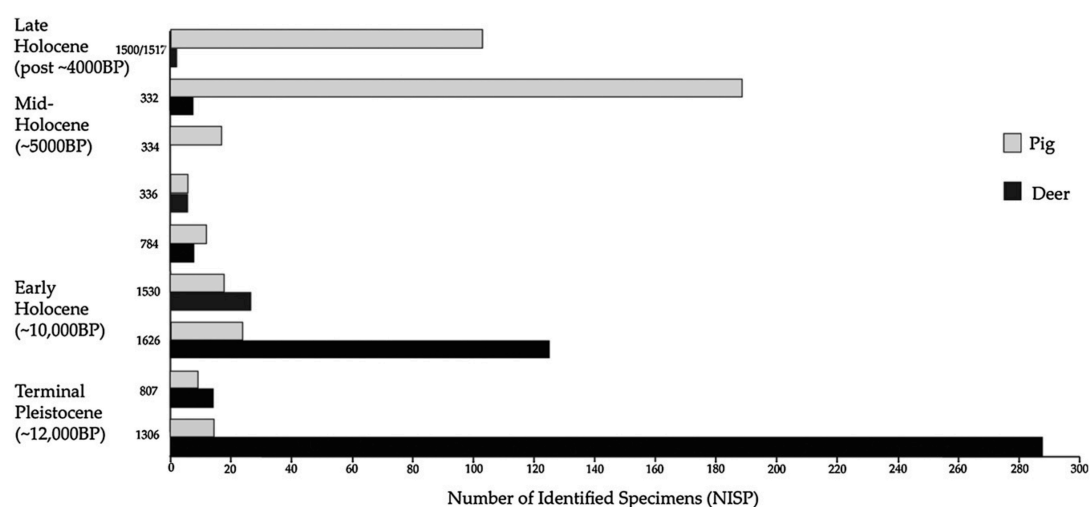
In addition to the abundance of worked stone, bone, and shell tools and personal ornamentation, as well as later pottery, beads, and regional tradeware, a sequence of bioarchaeological remains from Ille and from the site of Pasimbahan-Magsanib 1.5km to the northwest, provide a record of plant and animal resources exploited by the inhabitants. These remains also hint at changing environments in the surrounding landscape. Carlos (2010) and Ochoa *et al.* (2014) describe late Pleistocene and early Holocene charred and mineralised seeds and parenchymatous tissues from starchy tubers such as yams



**Figure 3.24** Late Pleistocene / early Holocene archaeobotanical remains from Ille Cave: 1) elim. *Dioscorea* sp.; 2) elim. *Colocasia* sp.; 3) *Boehmeria* cf. *platanifolia*; 4) *Canarium hirsutum*. Source: Barker *et al.* (2011); photos: J. Carlos.

and taro, and from forest resources such as *Canarium* and *Boehmeria* (Figure 3.24). *Boehmeria*, a genus of plants exploited for its fibres (Burkill, 1935), is more common within the early Holocene contexts of both caves, whereas *Canarium*, which produce edible nuts and aromatic resin, is more common in the mid-late Holocene deposits. Both of these genera are interpreted to represent exploitation of primary lowland rain forest resources (Ochoa *et al.*, 2014).

An interesting pattern that has emerged from analyses of the zooarchaeological remains at both Ille and Pasimbahan-Magsanib is the clear shift from late Pleistocene and early Holocene assemblages dominated by deer to the late Holocene preponderance of pig bones (Figure 3.25). The deer remains encompass those from two species: *Axis calamianensis*, the small Calamian hog deer which is now extirpated from the island; and an extinct larger-bodied deer ascribed to the genus *Cervus*. Piper *et al.* (2011) and Ochoa *et al.* (2014) attribute the shift from dominance of deer to pig bones within the zooarchaeological assemblages to a likely combination of both climatic and human hunting pressures. The larger-bodied deer disappears from the record in the early Holocene, whereas the smaller hog deer is found into the late Holocene contexts. The authors interpret these patterns as signs of early Holocene forest expansion which reduced the open habitat of the larger-bodied deer. The smaller, more forest-adapted hog deer was able to survive the habitat changes associated with



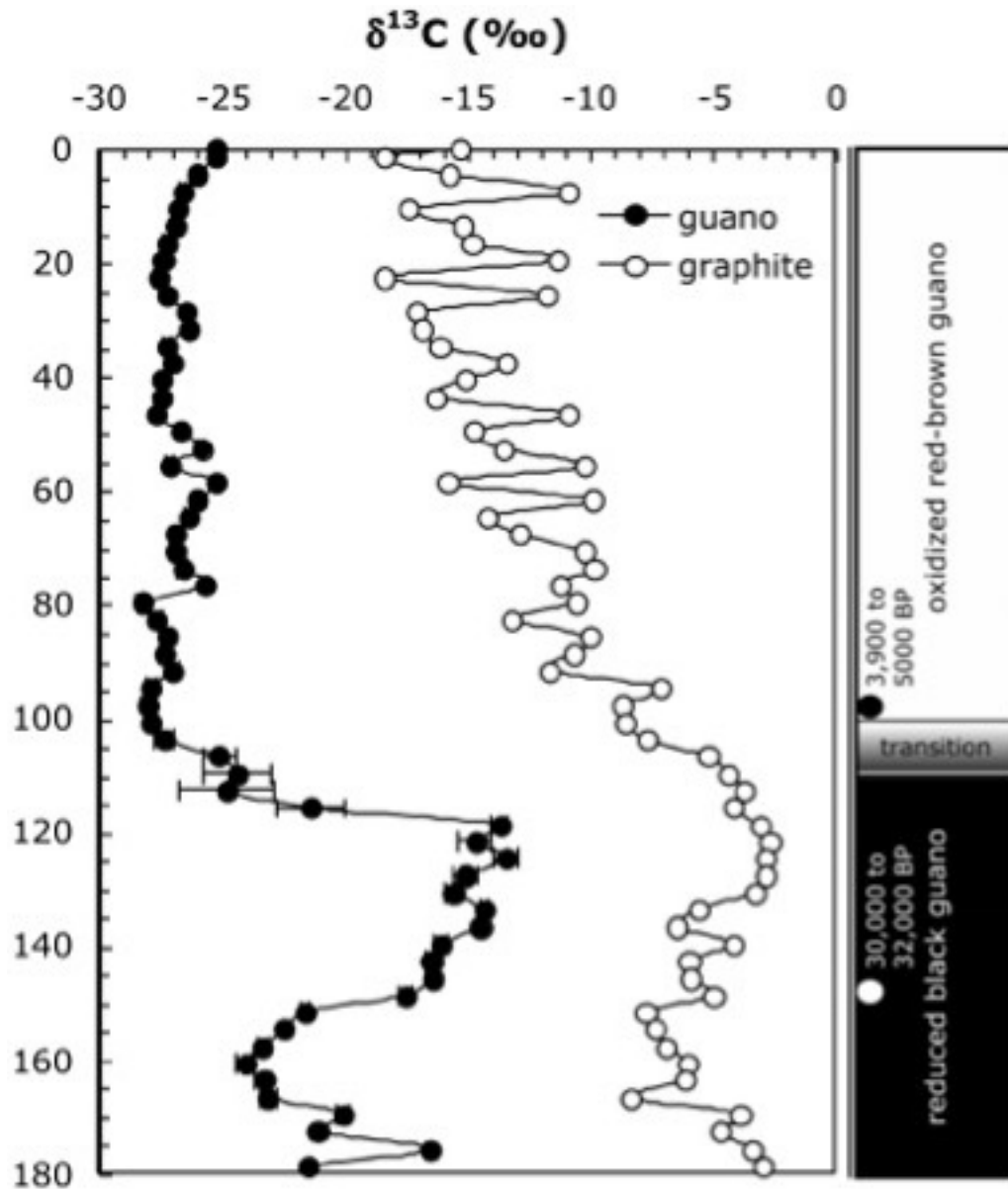
**Figure 3.25** Frequencies of occurrence of pig and deer remains from the terminal Pleistocene to late Holocene portion of the Ille Cave sequence. Source: Piper *et al.* (2011).

Holocene climatic amelioration, but succumbed to human hunting pressures, requiring late Holocene human populations to rely more heavily upon pig.

### ***Palaeoenvironment***

Palawan is of palaeoenvironmental interest due to its position on the northern edge of the ever-wet Sundaland core and the associated humid tropical rain forests. Changes to cooler and drier climates, as have been suggested for the LGM, could potentially have led to the replacement of this moist forest by more open vegetation types across much of the island (eg Bird *et al.*, 2005; Heaney, 1991). No record of vegetation history for Palawan existed prior to the present study, though efforts were made in conjunction with the 2005 PIPRP field season to obtain proxy palaeoenvironmental records from the Dewil Valley in the forms of pollen cores and environmental isotopic sequences. Stevenson *et al.*'s (2006) programme of exploratory coring and pollen analysis yielded a core with a basal age of ~18,000 cal BP, but with unusably poor pollen preservation. Similar assessments were made of excavated sediments from the sequence at Ille Cave.

However, during that same season a sequence of samples from stratified bird and bat guano deposits within a cave of the Makangit karst complex ~500m west from Ille produced a carbon isotope record that spans the pre-LGM through the late Holocene (Bird *et al.*, 2007). This record is interpreted as a proxy for vegetation growing in the surrounding Dewil Valley landscape. The guano deposit derives from insectivores which make up the vast majority of bat and bird populations that roost in tropical caves. This a food web that leads ultimately back to the local vegetation. The isotopic signatures within the guano sequence thus preserve the changes through time of the chemistry of the vegetation. The record of changing  $\delta^{13}\text{C}$  values between the pre-LGM levels and those of the late Holocene (Figure 3.26) reflect climatically-driven habitat changes from more open-structured vegetation dominated by plants that employ the C4 photosynthetic pathway to more closed forest comprised predominantly of C3 plants (Bird *et al.*, 2007). These results appear to corroborate the archaeobotanical and zooarchaeological sequences from Ille and Pasimbahan-Magsanib.



**Figure 3.26** Makangit guano record of  $\delta^{13}\text{C}$ , showing the shift to more negative values from the mid-Holocene, implying more closed vegetation that uses C3 photosynthesis. Source: Bird et al. (2007).

### 3.4.3 Project development

The initial focus of this research was the detection of past changes in biodiversity using macro- and microfossil analyses from palaeoecological samples. Flotation samples and phytoliths from excavated archaeological sediments were to supplement the palaeoecological analyses. The following broad questions initially guided this project:

- How have past changes in biodiversity related to changes in subsistence, as inferred from the palaeoecological and archaeobotanical records?
- From the ethnographic record, how might such changes relate to cosmologies / worldviews?
- How do these changes relate to current understandings of the histories of foraging and farming across Southeast Asia?

The initial few months of this research were spent assessing the progress and current status of various facets of the Cultured Rainforest (CRF) project, namely where there might be scope to carve out an associated PhD project structured around a palaeoenvironmental and archaeobotanical focus. From this initial assessment, it became clear that there was in fact less remaining scope than had originally been envisioned on the CRF project. Much related palaeoecological work was already completed as part of Samantha Jones' PhD (2012) at Queens University Belfast (QUB), and pilot studies of CRF excavation sediments yielded little in the way of macroscopic archaeobotanical remains. The options then became: to shift gears and focus on an a phytolith-based archaeobotanical approach and questions pertaining directly to past subsistence; or, to widen the geographical gaze and continue to pursue questions relating to Holocene human-environment interactions. The opportunity to do the latter was facilitated by Graeme Barker who arranged for me to join Victor Paz and Helen Lewis' ongoing work at Ille Cave in northern Palawan in the western Philippines. Both Victor and Helen had completed their respective PhDs within the Department of Archaeology at the University of Cambridge, and so networks were already established to facilitate a collaborative approach.

January and February 2011 were spent attending a three-week tropical botany course in Leiden with a focus on plants from Malesia, run jointly by the Nationaal Herbarium Nederland at Leiden (NHN) and the Netherlands Centre for Biodiversity Naturalis (NCB). This botany course in Leiden facilitated development of skills in field identification of plants from the tropics, which were deemed valuable in guiding the acquisition of specimens for a reference collection, and in identifying seeds and other plant remains that I might come

across whilst analysing my samples. This course also provided foundational insights into the plant taxonomy, field botanical identification, biogeography, and ecology of the Malesian region.

The first stretch of fieldwork for the present study began in April 2011, based at the Ille Site in northern Palawan. Across the one month spent in the field as part of the PIPRP team alongside Victor Paz, Helen Lewis, and colleagues and students from the Archaeological Studies Program at the University of the Philippines, Diliman (Metro Manila) and University College Dublin, excavation and flotation experience with tropical cave sediments was gained. Landscape reconnaissance across the Dewil Valley was performed, in which depositional environments for palaeoecological coring, as well as landforms to test pit/auger for potential open-landscape habitation sites, were located. Three potential palaeoecological sites were augered, subsamples from which were wet sieved and housed within the PIPRP's store room in Manila. This was followed in May 2011 by two weeks in the Kelabit Highlands, Sarawak, during which time three of the CRF sites that produced pollen records were augered with the aim of obtaining macrobotanical remains to supplement the microfossil sequences. As it turned out, no identifiable macroscopic botanical remains were recovered from the auger cores from Palawan, nor from the Kelabit Highlands pollen coring sites (PDH 223, PDH 212, and Pa' Buda, which are all examined by comparison with modern analogues in Chapter 6).

An altered approach was developed in 2012, involving an expanded geographical scope which now encompassed the palaeoecological coring site of Loagan Bunut in the lowlands of Sarawak, ~60km east from Niah (Hunt & Premathilake, 2012). The revised plan was to analyse potential macrobotanical remains from CRF colleague Chris Hunt's Loagan Bunut cores, which contained pollen and phytolith assemblages that suggest the early Holocene presence and possible use of rice and sago. Late Pleistocene (~15 ka BP) monoliths that Chris Hunt extracted from sediment profiles at Samantha Jones's coring site near Bario to supplement pre-Holocene portions of Jones's (2012) pollen records, were to complement the potential macrobotanical remains from lowland Sarawak. These materials having been collected during previous field programmes by



collaborators in 2007 and housed at QUB, processing required only a trip to Belfast and a short stay whilst working in the laboratories of the School of Geography, Archaeology, and Palaeoecology. Unfortunately, these materials also produced no identifiable macroscopic botanical remains.

Spring of 2012 saw a return to the Dewil Valley in conjunction with the 2012 field season of the PIPRP. Geomorphologist Gez Foster was invited to join the 2012 field season to conduct an assessment of the valley's fluvial landforms and dynamics. An aim of Gez's work was to aid in site prospection of potential open-landscape habitation sites. I joined these landscape surveys. Sediment samples from an exposed section of a representative river terrace ('DR1'), as well as a sediment core from a perennially marshy wetland amongst the rain-fed rice paddies in an adjacent catchment to the south of the Dewil Valley ('*Baryaw-baryaw*'), were collected. In addition, at a site within an adjacent catchment to the northwest which was identified on the advice of a local informant, an exploratory 2.5m core was made with a Russian D-section corer. This site, called *Makinit* (the local term for 'hot spring'), held promise due to its peaty sediments that support a vegetation community of riparian and back mangrove elements surrounding a standing pool and outlet stream of a hot spring. The local landowners claimed that this patch of vegetation had never been cleared, despite being surrounded by intensive rain-fed rice paddies, and cashew, coconut, and *buri* orchards. The upper 215cm of this exploratory core consisted of peat at various stages of humification; the lowest 35cm comprised a series of laminated silts, clays, and charcoal bands. The base of the deposit was not reached, but coring was not extended any deeper in 2012 due to limited coring extension rods. Once back in Cambridge, pilot processing of all of these samples revealed that only this peat core from the Makinit site contained sediments with acceptable preservation of pollen and spores.

The shape of the present study emerged prior to the spring 2013 field season of the PIPRP. In addition to the plan to do more extensive coring of the Makinit peat deposit that was discovered in 2012 in Palawan, a previously unanalysed core from the Bario area of the Kelabit Highlands, that was collected in 2007 as part of the CRF project, was made available by Chris Hunt at QUB. It

was suggested that this core from Bario, and a core that might be recovered from Palawan, alongside modern pollen and vegetation sampling would provide important contributions to understanding the palaeoecology associated with both the CRF and PIPRP. The idea to combine the modern analogue approach to vegetation reconstruction with sampling of various modern land uses thus guided fieldwork in 2013. The original aim was to produce parallel datasets of modern botanical surveys, surface sediment samples, and fossil pollen cores from both study areas. However, due to unavoidable delays in obtaining necessary permits to export the material collected from the Philippines, the pollen residues extracted from surface sediments from the Dewil Valley landscapes arrived in an unusable state of micro-organismal attack and decay. Despite this, it is this programme of coring, surveying, and sampling that is described in detail in the following chapter, and which led to the recovery of the material and the production of the data that is presented in Chapters 5-7.

### **3.5 Conclusion**

The approach that this study takes to attempt to disentangle climatic from anthropogenic drivers of past vegetation changes is based upon the modern analogue approach to vegetation reconstruction. The Kelabit Highlands of north-eastern Sarawak, and the Dewil Valley of northern Palawan Island, have been introduced as the case study areas where the modern analogue approach is demonstrated. A brief narrative of the development of this approach in the context of the present study has been offered. The following chapter describes in detail the methods used in the execution of this modern analogue approach.

## **4 Methods and materials**

### **4.1 Introduction**

Detailed descriptions of techniques and analyses used in field, laboratory, and desktop-based collection and processing of materials and data constitute the bulk of this chapter. Justification for decisions made in favour of a given technique are provided here. Potential implications of such decisions and their alternatives will be explored within the Discussion chapter. As detailed reviews of field sites appear in the preceding Approaches chapter, sites are referred to here by name, with reference to relevant figures from Chapter 3 following in brackets. In general, this study employs standard field, laboratory, and data handling techniques. An exception to this generalisation is the use of a minimally destructive pollen processing technique, cf Hunt (1985).

### **4.2 Field techniques**

The following descriptions focus on the field techniques employed in recovering material that yielded the data reported in the three results chapters to follow. The narrative of project development presented in Chapter 3 refers to numerous exploratory augering, coring, and sampling efforts in Sarawak and on Palawan Island. Methods used across these exploratory endeavours are presented within Appendix 2, reflecting the qualitative contributions of these pilot projects in shaping the evolution of this study's design.

#### **4.2.1 *Site selection***

As described in the preceding chapter, this study sits within and builds upon previous work associated with the Cultured Rain Forest project (CRF) in the Kelabit Highlands of northeast Sarawak, Malaysian Borneo and the Palawan Island Palaeohistoric Research Project (PIPRP) in the Dewil Valley of northern Palawan Island, Philippines. Previous work and ongoing reconnaissance by colleagues involved with both projects and by the author informed the selection process of sites for sample collection in the present study. This process played out in different ways in each of the two study areas, so the site selection processes for each are described individually below. The unifying thread across

site selection within each of the two regions is the common modern analogue approach taken to detection of past land use. The explicit aim of this approach is to uncover the anthropogenic imprint upon vegetation histories and ecologies spanning a critical period and in locales which can be argued to be central to a more nuanced understanding of the mid-late Holocene development of land management systems across northern ISEA.

### ***Kelabit Highlands, Sarawak***

The archaeological component of the CRF project examined a broad physiographic range of archaeological sites during the three seasons of active fieldwork from 2007-2009. These sites span anthropogenic features on montane ridge tops, lower montane slopes, and the extensive flatter alluvial floodplains, river terraces, palaeochannels, and stream meanders surrounding the contemporary Kelabit longhouse communities at Bario and Pa' Dalih. Palaeoecological enquiry focused upon the palaeochannels of the upper stretches of the Kelapang River near Pa' Dalih and of the Dappur River near Bario. Details and implications of the results of this previous work, conducted by Samantha Jones during her PhD research at Queen's University Belfast (QUB), are discussed in Chapters 6 and 8. The relevance of this previous work for the present chapter rests with its value in describing the site selection process for the core from the Bario area (core BIO-7) analysed in the present study.

Our current understanding of the palaeohistory of local vegetation change in the Kelabit Highlands stems entirely from Jones' PhD work (2012). Due to the absence of a large sedimentary basin with physiographic characteristics conducive to continuous deposition and preservation of organic remains across timescales of tens of thousands of years, Jones assembled the ~50,000-year record of vegetation change we now have via a piecemeal approach. She analysed sedimentary fossil pollen sequences from six different sites across the plateau, coming from: infilled oxbows on the floodplains of the contemporary drainage network (youngest, late Holocene in age); palaeochannel deposits on fluvial terraces adjacent to and above modern floodplains (intermediate in age, spanning late glacial to early Holocene); and a single core from a deposit of

swamp sediments thinly capped by minerotrophic peats (oldest, along with a core from one of the aforementioned palaeochannels, stretching back to the limits of reliability of radiocarbon age determination, but with significant discontinuities spanning the Last Glacial Maximum (LGM), terminal Pleistocene, and mid-late Holocene).

The BIO-7 core comes from the infill of a palaeochannel of the Dappur River that was cut into a fluvial terrace that is higher up and more distant from the modern river and, hence, also older than the terrace immediately adjacent to the active floodplain. Still higher above this terrace on which the BIO-7 palaeochannel infill sits is the broad, relatively flat surface of peat and swamp deposits from which Samantha Jones extracted her 'Ba1' core (see Figure 6.1; p. 202). The pollen record from this Ba1 core is, in part, what extends our view of local vegetation history back to ~50,000 BP, but with a large and crucial gap spanning the LGM through the mid-late Holocene. Site selection for the BIO-7 core aimed to fill part or all of the temporal gap in the existing record. The environmental history of the region during this time period in the mid-late Holocene is of great archaeological interest as it is from about 4,500 BP that the earliest traces of cultivated rice are found in archaeological sites in the lowlands of Sarawak (Bellwood *et al.*, 1992; Datan & Bellwood, 1991; Doherty *et al.*, 2000). The environmental context, and any apparently anthropogenic signatures seen therein, has the potential to shed light on how people were making a living in highland interior Sarawak coincident with the corresponding ages of the scarce early rice finds in the lowlands and the regionally widespread changes in material culture interpreted by some to represent an 'Austronesian expansion' (Bellwood, 2005 & 2007; Blust, 1984/1985).

### ***Modern analogue sampling***

In parallel with the coring programme, modern botanical surveys and surface sediment sampling were also undertaken. As described in Chapter 3, the data from this work are used to aid in interpretation of the fossil pollen assemblages extracted from sediment cores. As such, and in light of the aims and research questions of the present study, sites sampled as part of this modern

comparative programme span a gradient in contemporary land use intensities. This gradient encompasses various 'natural' vegetation types, through notionally managed stands of economically important plants, to cultivated swiddens, and on to hydrologically managed rice paddy monocrops with associated taro plantings, fruit tree orchards, and vegetable gardens. Kit Pearce, a Kuching-based botanist with prior experience in the Kelabit Highlands working with the CRF team, in concert with the author located individual sites for surveys and sampling based upon Pearce's prior knowledge and upon information from local Kelabit informants. The aim was to sample across the variety of vegetation types that occur today on the plateau and surrounding slopes. These vegetation types encompass the whole spectrum of the ways in which people on the plateau today interact with the plant world. The assumption in using such an approach, as described in Chapter 3, is that some of these modes of contemporary people-plant interactions might resemble those of the past, traces of which might be discernible at different points in the palaeoenvironmental record. With this guiding logic, sixteen sites spanning ridge-top and steeply sloping Lower Montane Forest (LMF), well-drained and nutrient-poor *kerangas* forest, floodplain sites covered by alluvial and riparian forest, as well as notionally-managed stands of hill sago (*Eugeissona utilis* Becc., Arecaceae), swiddens at various stages of regrowth, rice paddies and orchards were surveyed and sampled.

#### ***Dewil Valley and adjacent, Palawan Island***

Site selection within and adjacent to the Dewil Valley of northern Palawan Island, Philippines followed the same approach as that taken in Sarawak. However, the foundation of previous palynological work in the region on which to build a strategy for sampling was less substantial, with no pollen record published from Palawan, and only two records from the whole of the Philippines published at the time of project inception (2010). With that said, Janelle Stevenson, a Quaternary palynologist, joined Victor Paz and Helen Lewis and team on their PIPRP 2005 field season at Ille Cave and surrounds. Stevenson's aim was to locate and core any potential sites for palaeoenvironmental reconstruction to supplement the on-going archaeological work of the PIPRP.

She conducted some exploratory coring of a couple of marshy, waterlogged sites within the heavily utilised alluvial landscape between the karst towers which contain caves with archaeological remains. As these efforts, as well as those of the author during the 2011 and 2012 PIPRP field seasons, yielded no sufficiently preserved pollen record, the sites sampled, methods used and data obtained are presented in Appendix 2.

The Makinit Site, from which the core that yielded the pollen record presented in Chapter 7 was extracted, lies 8 km to the northwest of the Dewil Valley in an adjacent catchment (see Figure 7.1; p. 256). This site was located via information obtained by a local informant and one of the PIPRP crew members from the nearby town of New Ibajay, Jojo Sugbo. Some exploratory augering and coring was conducted at the Makinit Site in the 2012 field season by Emil Robles, Vito Hernandez, and the author. This site was selected for more in-depth coring the following field season (2013) for three primary reasons: 1) the deposit of sands, laminated clays, and capping peats form the substrate into which a patch of relict back mangrove vegetation grows, implying that this deposit has remained relatively undisturbed by the surrounding intensive agriculture for a substantial period of time considering that the coast and attendant mangrove environments have not been this far inland since the mid Holocene (Maeda *et al.*, 2004); 2) the nature and heterogeneity of the sediment sequence represents significant changes in depositional environments which could reflect changes in climate and/or land use, and pollen preservation is such that corresponding changes in surrounding vegetation should be discernible; and 3) the site is in a nearly identical physiographic setting as that of the Ille Site in the adjacent Dewil Valley from where the corpus of archaeological data from the PIPRP come, thus providing a sound basis for comparison between the archaeological and environmental datasets from the Dewil Valley sites with the pollen record from the Makinit Site.

As in Sarawak, a programme of contemporary botanical surveying and modern surface sediment sampling supplemented the coring in northern Palawan. With the same guiding logic as described above, sixteen sites encompassing various minimally-disturbed vegetation types as well as spanning

a gradient in modern land use intensities were sampled. These sites were located once again via a combination of the experience and expertise of Ramon Bandong, a University of the Philippines botanist who worked in the Dewil Valley with Stevenson and the PIPRP team in 2005, as well as information from local informants. These informants were usually PIPRP crew members from the nearby town of New Ibajay, but relevant useful information was also obtained from other residents of the surrounding agrarian landscape.

#### **4.2.2 Coring**

Each of the two sediment cores from which fossil pollen data for this thesis come will be addressed individually, as the BIO-7 core from the Bario area of the Kelabit Highlands in northeast Sarawak was made by a colleague (C Hunt) on a previous field visit in 2007 for which the author of this thesis was not present. Both of the final cores analysed were extracted using Russian D-section corers with 50cm long and 50mm diameter sediment chambers. The resultant cores from both sites were thus extracted in 50cm long, 5cm wide semi-cylindrical segments. Information pertaining to further details of the coring processes at the respective sites differs; descriptions follow individually for both sites.

##### ***Bario, Kelabit Highlands, Sarawak***

The following descriptions of core extraction, transport, and storage for the BIO-7 core are second-hand accounts, as the core was made in 2007 by Chris Hunt who was then at QUB and a member of the CRF project team. Once the coring site was selected as described above, a series of five boreholes were made with a Dutch auger to probe deposit depth and examine lateral variation in stratigraphy. The precise coring location for the final BIO-7 core was determined by maximum deposit depth. As will be described in detail in Chapter 6, this effort yielded a 68cm long core composed primarily of brown organic silts overlying a short basal unit of white silicate sands.

As there was no access to refrigeration in the field, core segments were wrapped in plastic cling film, aluminium foil and cellophane tape on site and stored horizontally in semi-cylindrical sections of PVC piping for support and



placed in the shade in a cool place under one of the longhouses. Samples were exported from Malaysia and into the UK via CRF project permits. Once in the UK, the BIO-7 core segments were stored at 4°C in the cold storage of the School of Geography, Archaeology and Palaeoecology at Queen's University, Belfast.

### ***Palawan Island, Philippines***

As noted above, the Makinit Site was located based on the information provided by one of the local resident PIPRP crew members. Exploratory probing with a narrow gouge head, augering with a Dutch auger and coring with a Russian D-section corer of the deposit was conducted towards the end of the April 2012 field season. The accessible portion of the deposit surrounds the outlet stream of a small standing pool that is fed from beneath by a hot spring. There is no fluvial input to this pool. Deposit depth and stratigraphy were probed in a longstream direction from close to the outlet point to about 10m downstream. Deposit depth steadily decreased with both increasing longstream distance from the outlet point and lateral distance from the stream. A 250cm long core was made during this 2012 coring effort at the point where the deposit is deepest, and as close as safely possible to the pool. The water in this pool is warmer than 60°C, and as can be imagined from the upper stratigraphy consisting of over 2m of peat capped by a thin mineral crust, the structural integrity of the ground surface was uncertain. So, the safest core location was about 2m back from the edge of the pool, and about 1m laterally displaced from the small outlet stream. This initial 250cm long core consisted of 215cm of peat underlain by at least 35cm of alternately grey, brown and black laminated clays. The base of the deposit was not reached. Due to the exploratory nature of these 2012 coring efforts, only 2m worth of extension rods were to hand, hence the limited length of this initial core.

Core segments were wrapped in plastic cling film and aluminium foil on site, and were temporarily stored in semi-cylindrical sections of PVC piping and out of direct sunlight at PIPRP base camp near Ille Site in the Dewil Valley. After transport from Palawan to the UP-ASP labs in Quezon City, Metro Manila, this core was then subsampled at 10cm depth increments. Subsamples were then

transported to Cambridge on respective export and import permits from the PIPRP project and the Division of Archaeology at Cambridge University's DEFRA import permit. Pollen was then extracted from these subsamples via standard acetolysis and HF-maceration (<http://www.geog.cam.ac.uk/facilities/laboratories/techniques/pollen.html>) to assess pollen preservation.

Following positive confirmation of marginal yet satisfactory pollen preservation, the Makinit Site was revisited in the 2013 PIPRP field season with more extensive coring equipment to hand. Two boreholes, approximately one meter apart and located in roughly the same position as that of the 2012 assessment core, were made to avoid compression of underlying strata. Core sections were extracted in 50cm segments, alternating between the two boreholes so that no two consecutive 50cm depth segments came from the same hole. As mentioned above, this was to avoid extraction of sediments compressed by the downward plunge of the corer during extraction of the overlying core segment. A total core depth of 480cm was achieved, with a 20cm overlap of the deepest segment with the penultimate segment. The core bottoms out in stiff, coarse sands. Further depth was not achievable without heavy mechanical aid.

As before, core segments were wrapped in cling film and aluminium foil on site, supported in semi-cylindrical lengths of PVC piping, temporarily stored in the field at the PIPRP basecamp near Ille Site, and transported to the UP-ASP PIPRP project storage rooms in Quezon City, Metro Manila after the end of the field season. Due to the bulk of entire core segments as opposed to small subsamples, the ten 50cm long core segments remained in UP-ASP storage facilities whilst requisite National Museum of the Philippines export permits were obtained by colleagues at the University of the Philippines. Once these materials were successfully transported to Cambridge, core segments were stored in the DEFRA Cold Store room in the basement of the West Building of the Division of Archaeology at the University of Cambridge.

#### **4.2.3 Modern botanical surveys**

Programmes of targeted modern botanical surveys were conducted within both study areas as integral components of the modern analogue approach described in Chapter 3. Botanists with prior field experience in the respective locales were hired in both of the study areas to complete these programmes. In Sarawak this was Kit Pearce, an independent botanist based in Kuching and who has worked with the Forest Department Sarawak and the Sarawak Herbarium at sites across the state, as well as with the Cultured Rain Forest project team in the Kelabit Highlands; in Palawan, Ramon Bandong of the Institute of Biology at the University of the Philippines, Diliman led the botanical surveys.

Within both study areas, access to and between individual sites was on foot. Resources for the present study were such that time with both of the botanists was limited, thus constricting the quantity and depth of botanical data obtained from each site to: broad descriptions of vegetation type (i.e. Lower Montane Forest, Back mangrove, or Swidden 3-year regrowth); notes on local site history and physiography, often obtained from local informants; species lists of dominant taxa within each structural layer; dominant plant families of other plants not assigned a specific determination. Square plots of 20 x 20m were surveyed at each site sampled, with the above listed data collected for each. At this level of detail, an average of three sites per day were visited across the one week of botanical work in each of the study areas.

#### **4.2.4 Surface sediment sampling**

Surface sediment sampling at the 32 sites examined as part of the modern calibration study (16 sites on Palawan Island, and 16 sites in the Kelabit Highlands, Sarawak) followed collection procedures used previously by QUB colleagues and CRF collaborators, Chris Hunt and then-PhD student Samantha Jones. In parallel with the botanical surveys within each 20 x 20m patch of modern vegetation, surface sediment samples were collected for pollen analysis. Small volumes of approximately five cc of sediment and leaf litter from the upper five cm of topsoil were collected from 8-10 different spots within each 20 x 20m

plot. At each plot, these volumes were aggregated into a single bag in order to acquire a representative sample (Adam & Mehringer, 1975). An explicit assumption of this sampling strategy is that pollen assemblages extracted from surface sediment samples represent the pollen produced by the contemporary vegetation extant at or closely adjacent to each site at the time of sampling. Implications of this assumption, as well as alternative sampling strategies, will be discussed in Chapter 8.

#### **4.2.5 Geolocation**

Geolocation was achieved within both study regions via GPS waypoints taken with a hand-held Garmin GPS using the WGS84 map projection. Waypoints were made for all coring locations, botanical surveys and surface sediment sampling sites. Data were uploaded from the GPS unit to a personal laptop. Maps and figures displaying geolocational data were organised and produced using Garmin's BaseCamp Version 4.2.4 free software suite, as well as GoogleEarth.

### **4.3 Laboratory processing and analyses**

The following subsections contain descriptions of laboratory techniques employed in the processing of material gathered in the field. In general, the techniques employed follow standard protocols and use common equipment held in the Physical Geography laboratories within the Department of Geography, University of Cambridge (<http://www.geog.cam.ac.uk/facilities/laboratories/>). An exception to this generalisation is the use of a minimally destructive pollen processing technique, cf Hunt (1985).

#### **4.3.1 Lithology and magnetic susceptibility**

Prior to any destructive subsampling, lithologies of sediment cores were visually described across their entire respective depths. In the case of the BIO-7 core from the Bario area of the Kelabit Highlands, Sarawak, these descriptions were compiled whilst in the laboratory in Cambridge, as the author was not present in the field when this core was made. The lithology of the core from the Makinit Site in northern Palawan Island, Philippines was described in the field as

the core sections were extracted from the ground. In both cases, core sections were laid horizontally alongside a ruler so that visible features could be tied into the overall core depth as each 50cm core segment was extracted, described, and wrapped for transport from the field to the laboratory. Lithologic descriptions follow a modified version of the Treols-Smith system of sediment classification (Kershaw, 1997). A summary core map was then drawn for each core, showing major stratigraphic units in order to aid in selection of positions for individual subsamples for other physical analyses, radiocarbon age determinations, and for pollen extraction.

In the Physical Geography Laboratories in Cambridge, core segments were passed through the scanning loop of a Bartington Magnetic Susceptibility Meter (MS2B) in order to measure the relative abundances of ferromagnetic minerals across core depths. Magnetic susceptibility readings were taken at one centimetre depth increments across the entireties of both sediment cores. These measurements are used in concert with other physical data to draw inferences about sediment source areas, as a proxy for upstream erosion and as an indicator of *in situ* biogeochemical processes after deposition. More will be said about this following description of the loss-on-ignition technique below.

Loss-on-ignition (LOI) analyses followed a protocol of successive combustion stages graduated by increasing temperature (<http://www.geog.cam.ac.uk/facilities/laboratories/techniques/loi.html>; accessed 24 June 2016). This protocol is designed to determine percentages-by-weight of different physical components that have known combustion thresholds. One cubic centimetre volumetric subsamples were removed at regular depth intervals from both respective cores. For the 68cm long BIO-7 core, this depth interval was five cm; for the longer, 480cm Makinit core, subsamples were taken at ten cm depth intervals. Empty crucibles were weighed. Individual volumetric subsamples were then placed into each crucible and weighed again to determine wet weight and density of each one cc sediment sample. Subsamples were then placed into a muffle furnace and subjected to a minimum of four hours at each stage of a succession of graduated combustions, with weights measured and loss of weight calculated after each stage: 105°C to

determine water content; 400°C to measure carbohydrate content; 480°C to calculate total carbon; 950°C to derive calcium carbonate and remaining mineral fractions.

These LOI data, in concert with the magnetic susceptibility data, were used to infer sediment sources, modes of sediment transport, and depositional environments represented by the stratigraphic sequences across each core. The inferences from these physical data provide independent proxies for aspects of the palaeoenvironment that can supplement, strengthen, or fine-tune reconstructions from pollen analysis alone. Data such as organic content and total carbon can also inform the stratigraphic placement of subsamples for pollen analysis and radiocarbon age determinations.

#### **4.3.2 Pollen preparation**

A minimally destructive pollen processing technique was employed on all subsamples for pollen analysis, both fossil and modern. The details of this processing technique, which follows Hunt (1985), are described in the following paragraph. The reasons for opting for this method, as opposed to more widely used traditional techniques based upon iterative chemical digestions including acetolysis and hydrofluoric acid (HF) maceration (ie Moore *et al.*, 1991), are four-fold: 1) existing palynological datasets from the Kelabit Highlands (Jones, 2012) and lowland Sarawak (Hunt & Rushworth, 2005; Hunt & Premathilake, 2012), to which the data produced in the present study are to be directly compared and cross-referenced, derive from material processed using the Hunt (1985) technique, so its use in the present study ensures consistency; 2) as indicated by previous attempts at palynological research within the Dewil Valley (Stevenson *et al.*, 2006) as well as by the assessment core made from the Makinit Site in 2012, pollen preservation within the alluvial landscapes of northern Palawan was deemed marginal and thus requires a gentler approach to pollen extraction; 3) with access to requisite reference material, a less destructive pollen processing technique such as that derived from Hunt (1985) facilitates the retention of a much broader range of microfossils that yield additional palaeoenvironmental information (collectively termed 'palynofacies' or

'cryptopalynology'); and 4) safe use of HF maceration and acetolysis is more resource intensive in terms of both money, time, and access to well-fitted laboratory space than is the minimally destructive technique described below.

Individual sediment subsamples were placed into separate 500ml glass beakers, to which 50ml of de-ionized (DI) water was added. Fifty millilitres of ten per cent potassium hydroxide (KOH) and 50ml of ten per cent tetrasodium pyrophosphate ( $\text{Na}_4\text{P}_2\text{O}_7$ ) were then added. Beakers were placed on a hot plate and boiled for 20 minutes. These two chemicals have the combined effect of deflocculating samples held together electrostatically by fine-grained mineral clays and/or cemented together by significant humic fractions. Boiling the samples at this stage speeds up any chemical reactions and also provides a minor amount of mechanical agitation that aids in deflocculation. Contents of beakers were then poured through 300 $\mu\text{m}$  aperture nylon mesh stretched over a plastic sieve frame and into an underlying six  $\mu\text{m}$  aperture nylon mesh sieve. The portion of the subsample retained by the 300 $\mu\text{m}$  sieve was examined for macroscopic remains; the portion that passed through both sieves was discarded, as no remains smaller than six  $\mu\text{m}$  were examined. The majority of pollen types exist within the size range of  $\sim 8\text{-}120\ \mu\text{m}$ , with most of those in the 15-40 $\mu\text{m}$  range. Hence, the fraction of each subsample that passed through the 300 $\mu\text{m}$  sieve and was retained by the six  $\mu\text{m}$  sieve contains the pollen assemblages analysed in this study. At this stage, however, the residues also contain an obfuscating mineral fraction within the 6-300 $\mu\text{m}$  size class. So, a final density separation stage is required. This was achieved by placing the 6-300 $\mu\text{m}$  size class residues individually into a 30cm in diameter circular, concave plastic dish (modelled after a clock glass) along with a small volume of DI water. Samples were then gently agitated in a circular motion so as to entrain in the water the light organic fraction while the heavy mineral component remains settled on the dish. The supernatant containing the entrained organic residues was then poured off into a glass beaker. Safranin was added as a stain to make pollen grains more easily visible, and residues were mounted in a water-miscible mount called Aquatex on microscope slides sealed with cover slips bordered with nail varnish.

### 4.3.3 Microscopy

All microscopy was completed using a Leica DMLB high-powered transmitted light microscope at 400x magnification. Pollen grains, fern spores, and microscopic charcoal particles were all counted on each respective slide. Target counts of 300 grains per subsample were set as a compromise between statistical robustness of each respective assemblage and number of subsamples analysed, given limited time.

Pollen and fern spore identification was achieved using a piecemeal of existing reference material: the online ANU-maintained Australasian Pollen and Spore Atlas (APSA) (APSA Members, 2007); Samantha Jones' reference collection of 253 taxa compiled during her PhD work in the Kelabit Highlands, Sarawak (Jones & Pearce, 2015); Tseng-Chieng Huang's *Pollen Flora of Taiwan* (Huang, 1972); *Spore Flora of Taiwan* (Huang, 1981); *Pollen Flora of Yunnan, Vol. 1* (Fujiki *et al.*, 2005); *Pollen and Spores of Barro Colorado Island* (Roubik & Moreno, 1991). The only published pollen reference images from the Philippines exist in the out-of-print *Pollen Flora of the Philippines, Vol. 1* (Bulalacao, 1997), a copy of which was not available. Hence, using the species lists compiled by Ramon Bandong during his two stints of botanical surveying on PIPRP (2006 & 2013) as well as the *Co's Digital Flora of the Philippines* (Pelser *et al.*, 2011) and phytogeographical data from on-going *Flora Malesiana* (<http://floramalesiana.org/index.html>) treatments, a "Palawan-relevant Pollen Images" spreadsheet was created. This was achieved by consolidating digital images of relevant pollen types from the disparate sources mentioned above (see Appendix 3).

Microscopic charcoal fragments were identified as black, angular and opaque particles amongst palynological assemblages. Charcoal was counted on the same slides prepared for pollen and spore analyses. Charcoal abundance was quantified in two ways: 1) via the 'point count method' (Clark, 1982); and 2) via a size class distribution method. As with the quantification of relative abundances of different pollen types within an assemblage, both methods of charcoal quantification are based upon extrapolation of proportional data for a



representative subset to the entire subsample for that stratigraphic level. The principles and details of the point count method are described in Clark (1982). In the present study, 100 microscope fields of view (FOV) at 400x magnification were examined for each subsample. The number of fixed points in each FOV – as defined by the ends of each eyepiece graticule hash mark that were overlain by a charcoal particle of any size were counted. Any exotic *Lycopodium* spike grains that were encountered were also tallied in order to facilitate concentration calculations. For the size class distribution method of charcoal abundance quantification, every charcoal particle encountered was tallied and its length and width measured. From these measurements, total charcoal counts for each stratigraphic level were broken up into three size classes by area:  $\leq 400\mu\text{m}^2$ ;  $400\mu\text{m}^2 < 1600\mu\text{m}^2$ ;  $\geq 1600\mu\text{m}^2$ . These size class distributions enable inferences regarding the relative importances of local and regional burning that are masked by the conflated charcoal abundance values from the point count method.

#### **4.4 Data preparation and analyses**

The following subsections describe various aspects of the data handling processes: software used; decisions involved in pollen diagram construction; and statistical approaches employed.

##### **4.4.1 Software**

As mentioned above in subsection 4.2.5, geolocational data were stored and displayed using Garmin's BaseCamp freeware and GoogleEarth. All word processing and spreadsheet management employed Mac versions of the Microsoft Office programs Word and Excel. Scatter plots and regressions were created in Excel from tabular data in spreadsheets. Palynological data were plotted using the purpose-built pollen plotting software *psimpoll* version 4.26 for Mac (Bennett, 2008). Comparative multivariate statistics on palynological data and corresponding ordination plots were performed using Community Analysis Package (CAP) version 5 (Seaby *et al.*, 2014), a multivariate statistics software program designed for analyses of multi-taxa ecological datasets.

#### 4.4.2 Pollen diagrams and zonation

Raw pollen counts were tabulated in Microsoft Excel spreadsheets, where summary and proportional calculations were also performed. Microsoft Word was used as a text editor to format the resulting data into text files in preparation for running *psimpoll*. All pollen diagrams were created in *psimpoll*. For both the BIO-7 and Makinit sequences, core depth in centimetres forms the y-axis and percentage abundances of identified taxa span the x-axis of the main diagram. Taxa are arranged firstly into groups corresponding to structural life form, ie Trees and shrubs / Herbs, epiphytes, and climbers / Ferns and lower plants / Aquatics. Within each of these structural groups, taxa are then arranged according to the most recent cladistic analyses of the Angiosperm Phylogeny Group (APG III, 2009). Taxon names follow currently accepted botanical Latin nomenclature as listed on The Plant List website (The Plant List, 2013), maintained jointly by the Royal Botanic Gardens, Kew and the Missouri Botanical Garden. A Main Sum consisting of all grains except for those of aquatic taxa was used to calculate percentage abundances of all individual terrestrial taxa as well as their corresponding structural groups within the summary diagrams. A Total Sum consisting of all grains counted was used to calculate percentage abundances for individual aquatic taxa and indeterminate grains as well as for the life form groupings in summary diagrams (Moore *et al.*, 1991).

A 10x magnification curve appears as a lightly coloured thin line above the filled solid curve for taxa whose relative abundances do not exceed 5% in consecutive subsample levels. A summary lithology column appears to the left of the y-axis depth hashes, as do place-marks and values for corresponding AMS radiocarbon age determinations. Zonation of the pollen diagrams is based upon CONISS cluster analyses (Grimm, 1987) and presented in the form of dendrograms plotted along the right margin of each pollen diagram. The parameters of these analyses will be described in the following subsection. A threshold dissimilarity value of 50 per cent defines pollen zones, below which all branching within the dendrograms represent subzones.

#### 4.4.3 Multivariate analyses

Input files for the CAP software used in the multivariate analyses are effectively transposed matrices of the input files used in pollen diagram creation. Spreadsheets containing proportional pollen data were transposed in Excel and then opened directly in CAP. Two main analyses were performed on all palynological datasets: ordination and clustering. Both of these analyses represent means of graphically depicting internal structure in complex, multivariate datasets. Eigenanalyses on a covariance matrix are used to determine similarities and dissimilarities between samples and taxa (Hotelling, 1933; Pearson, 1901). Ordinations plot these relationships in Cartesian space defined by axes that have no units but that represent explanatory power in examining structure within the data. Samples show up as points in this XY-space that may cluster with similar samples, while taxa are represented by vectors with varying lengths and directional orientations corresponding to each taxon's relative importance in explaining structural relationships within the data. Clustering analyses yield dichotomous dendrograms useful for defining groups of similar samples or taxa.

For the Barrio data presented in Chapter 6, both fossil and modern pollen data are combined and run together in CAP. Similarly, Chapter 6 contains results for multivariate analyses that combine Samantha Jones' fossil pollen data with the author's modern pollen data. In both of these instances, for pollen types that were identified with varying taxonomic resolution, ie Rubiaceae (a family of flowering plants) and *Tarenna* (a genus within the family Rubiaceae), datasets were reduced to the lowest common taxonomic denominator before input into CAP. For the example just given, all grains identified as either Rubiaceae or *Tarenna* in both datasets are counted as Rubiaceae in the combined dataset.

#### 4.5 Chronological control

Chronological control across the two fossil sequences analysed was achieved via five AMS radiocarbon age determinations: two ages were obtained from the BIO-7 core; three ages were returned from samples submitted from the Makinit sequence. A piece of wood embedded within the basal silicate sands of

the BIO-7 sequence, as well as two bulk sediment samples from the lower 2m of the Makinit sequence, were submitted to the  $^{14}\text{C}$ HRONO Centre at Queen's University, Belfast for AMS radiocarbon age determinations. An additional bulk sediment sample from the upper layers of both the BIO-7 and the Makinit sequences, respectively, were submitted to Beta Analytic for AMS age determinations, representing the remaining two AMS ages. Linear age-depth models were interpolated between these absolute ages. As will be discussed in corresponding results chapters and the Discussion chapter, further inferences regarding sedimentation rates, potential hiatuses in deposition, and explanations for an anomalous age reversal are inferred from the various physical, tactile, and visual data pertaining to lithology and stratigraphy of the respective sediment sequences.

#### **4.6 Conclusion**

This chapter has described the field, laboratory, and data handling techniques employed in this study. Standard palynological methods were used, excepting the minimally destructive pollen extraction technique, cf Hunt (1985); innovation lies in the methodological approach and framework within which established palaeoecological methods are applied (Chapter 3). The three chapters to follow (Chapters 5-7) detail results thus obtained.

## **5 Modern botanical and palynological results from the Kelabit Highlands, Sarawak**

### **5.1 Introduction**

As indicated in the introductory chapters, few modern pollen assemblages in Southeast Asia are available, on which to base analyses of fossil material using uniformitarian principles. A key aim of this thesis is to address this issue. Detailed descriptions of data and results from the programme of modern sampling across the Kelabit Highlands region of north-eastern Sarawak, Malaysian Borneo constitute this chapter. These results encompass data derived from execution of the various aspects of the modern analogue approach described in Chapters 3 and 4. Data relating to modern botanical surveys and palynological analyses of surface sediment samples are presented first by individual site. Summary pollen diagrams of surface sedimentary assemblages, which display data from all sites side-by-side, are presented next. Multivariate statistical analyses then offer quantitative support for the various classifications and groupings of similar assemblages, and the interpretations of their ecological and anthropological meanings.

### **5.2 Modern vegetation and surface sediment samples**

Botanical surveys were conducted and surface sediment samples collected from 16 sites within the modern landscape across the Kelabit Highlands (Figure 5.1) in accordance with the methodological framework described in Chapters 3 and 4. The aim of this sampling strategy is to compile a training set composed of botanically well-described vegetation communities along with the respective sedimentary pollen assemblages associated with those communities. Given fossil pollen sequences from the area can then be analysed using this training set in order to reveal potential temporal patterning in vegetation changes related to the gradient along which the modern sites are distributed. The need and precedents for using such an approach have been described in Chapter 3 (cf Berglund *et al.*, 1986). A primary contribution



**Figure 5.1** Locations of the 16 modern sampling sites within the Kelabit Highlands, Sarawak, Malaysian Borneo. Note the two clusters: a northern cluster of ten sites around the regional hub of Bario; and a southern cluster of six sites around the longhouse settlement at Pa' Dalih. Base map source: GoogleEarth.

of this study lies with the site selection strategy employed in the derivation of this modern training set, described as follows. In lieu of sampling along an altitudinal gradient as a proxy employed for detection of climatically controlled vegetation changes, as has traditionally been done in studies with a primarily palaeoecological focus (eg Birks and Birks, 1980; Morley, 1982), the suite of 16 sites sampled in the present study span a gradient in modern land uses and intensities. Multivariate statistical comparison of such a training set with fossil pollen sequences facilitates a more nuanced understanding of the fossil data which will be shown here to reveal potential patterns in past land uses. This is

achieved via identification of pollen assemblages that preserve the attendant imprints that certain modern land uses thought to resemble in some way those of the past leave upon surrounding vegetation communities.

Descriptive data from the modern botanical surveys are presented in summary first (Table 5.1). Since land use intensity is difficult to quantify, sites are presented in the order of lowest elevation to highest. Comments in the text pertaining to individual sites within the subsection following the summary data then aim to qualitatively place each site in its respective position along a land use intensity gradient. These qualitative assessments were based upon accounts from Kelabit informants, as well as field observations. Considerations were paid to the degrees and persistence of vegetation modification. This is expanded upon later in this chapter within the portion of the text on page 192 that describes Figure 5.32.

Of the 16 sites sampled, all 16 yielded sufficiently detailed botanical taxon lists. Thirteen of those sites also produced complementary pollen assemblages in adequate concentration and state of preservation to include in the present analyses. The three sites that failed to produce useable pollen – Pa' Dalih Orchard, Ruma Ma'on Dakah, and Alluvial Forest 2 – are denoted within Table 5.1 by an asterisk preceding the site name; within the individual site treatments to follow, the botanical data from these same three sites are presented after the 13 sites that yielded complete datasets.

### **5.2.1 *Modern botanical surveys***

The following are general comments regarding the modern botanical data collected as a whole. The spatial distribution of these sites across the Kelabit Highlands formed two clusters (Figure 5.1), reflecting the two bases from which sampling efforts embarked: a northern cluster of ten sites centred around the town of Bario, which is the regional hub of the Kelabit Highlands; and a southern cluster focused on the more remote Kelabit longhouse community at Pa' Dalih. Sites were sampled at an average rate of roughly three sites per day across the week of botanical surveying and sediment sampling conducted in May 2013. This daily rate was driven largely by the logistics and time involved in getting from

**Table 5.1** Summary botanical data from all 16 sites sampled. Sites arranged by elevation, from lowest to highest. Asterisk preceding site name indicates sites that did not yield useable pollen assemblages.

Site name	Elevation	Soil type	Important taxa	Notes (physiography & other)
<b>Pa' Dalih Padi</b>	977m	Waterlogged clays	<i>Colocasia esculenta</i> , <i>Hydrocotyle sibthorpioides</i> , 5 Cyperaceae spp., 5 Poaceae spp., <i>Monochoria vaginalis</i> .	Fallow wet paddy field; neither fields nor bunds ever sprayed with herbicides.
<b>*Pa' Dalih Orchard</b>	985m	Clay loam / alluvium	<i>Durio</i> spp., <i>Mangifera</i> sp., <i>Baccaurea macrocarpa</i> , <i>Lithocarpus</i> sp., <i>Dimocarpus longan</i> , <i>Alocasia</i> sp., <i>Nephrolepis biserrata</i> .	Flat land on terrace of the Pa' Kelapang with soggy depressions; fruit trees planted by and belong to individuals; tall ground cover including saplings; same orchard as Jones' PDH223.
<b>*Ruma Ma'on Dakah</b>	1000m	7cm humus & leaf litter over clay loam	<i>Dimocarpus longan</i> , <i>Artocarpus odoratissimus</i> , <i>Chisocheton</i> sp., <i>Durio zibethinus</i> , <i>Eugeissona utilis</i> .	Flat area above floodplain and within a large meander of the Pa' Kelapang; old site of longhouse; fruit trees planted long ago, but fruits still collected.
<b>Padi Bukit</b>	1021m	Yellow clay	<i>Melastoma</i> sp., <i>Macaranga</i> sp., <i>Saurauia</i> sp., <i>Pteridium esculentum</i> , 3 Poaceae spp.	Cleared and planted 3 years ago; thicket-type veg., secondary trees ~3-5m tall; surrounded by paddies and gardens at Pa' Dalih, and secondary LMF.
<b>Sago Stand 2</b>	1065m	Loam under litter layer	<i>Eugeissona utilis</i> , <i>Garcinia</i> sp., <i>Baccaurea</i> sp., <i>Syzygium</i> spp., <i>Cinnamomum</i> sp., <i>Amorphophallus</i> sp.	Edge of ridge, steep slopes either side; sago stand used for roofing in past; some large trees amongst, 20+m tall, 45cm dbh.
<b>*Alluvial Forest 2</b>	1072m	Dark organic silty loam	<i>Saurauia</i> sp., 3 Rubiaceae spp., <i>Etlingera</i> sp., <i>Pandanus</i> sp., Arecaceae sp., Cyperaceae sp.	Undulating floodplain ~6m above stream level; fairly open, canopy ~15-16m tall, understorey of scattered trees, dense ground flora; undisturbed.
<b>Alluvial Forest 3</b>	1073m	Fine alluvium, not sandy	<i>Shorea monticola</i> , <i>Eugeissona utilis</i> , <i>Licuala</i> sp., 3 rattan spp., <i>Cyathea</i> sp. <i>Selaginella</i> spp., <i>Syzygium bankense</i> , Fagaceae sp.	Undulating floodplain with channels; scattered, naturally-dispersed <i>Eugeissona utilis</i> ; undisturbed; transitional to LMF; canopy >30m, with understorey of saplings.
<b>Alluvial Forest 1</b>	1078m	Dark organic silts; buffalo disturbance	<i>Ardisia</i> sp.; <i>Schefflera</i> sp.; <i>Lindernia</i> sp.; Poaceae spp. ("grass" & bamboo)	Flat, alluvial floodplain with some back swamp; disturbed.



<b>Pa' Ramapuh Orchard</b>	1079m	Clay alluvium	<i>Dimocarpus longan</i> , <i>Artocarpus odoratissimus</i> , <i>Baccaurea macrocarpa</i> , <i>Stenochlaena palustris</i> , <i>Asplenium</i> sp., <i>Nephrolepis</i> sp., 2 <i>Poaceae</i> spp.	Flat, alluvial plain in meander of Pa' Ramapuh River. Fruit tree orchard planted long ago with coffee; now abandoned but fruits are still collected, undergrowth cut once in a while; surrounded by paddy & secondary <i>kerangas</i> .
<b>Pa' Ramapuh Padi</b>	1083m	Waterlogged clays	8 <i>Cyperaceae</i> spp., 3 <i>Asteraceae</i> spp., 2 <i>Poaceae</i> spp., <i>Monochoria vaginalis</i> , <i>Melastoma malabathricum</i>	Bunded wet paddy field harvested Jan/Feb 2013, now fallow; planted and harvested once per year.
<b>Kerangas 2</b>	1083m	Sandy, on hard white sandstone	<i>Rhododendron</i> (3 spp.), <i>Dacrydium</i> sp., <i>Ardisia</i> sp., <i>Nepenthes stenophylla</i> , <i>Dicranopteris linearis</i>	Open scrub on medium slope with maximum tree height of ~5m ( <i>Tristaniaopsis</i> sp. and a rattan), rest ~3m or less; undisturbed despite heavy logging in nearby LMF.
<b>Kerangas 1</b>	1098m	> 10cm of moist sandy peat	<i>Dacrydium</i> sp., <i>Agathis endertii</i> , <i>Syzygium</i> spp., <i>Rhododendron</i> spp., <i>Nepenthes</i> sp., <i>Melastomataceae</i> , <i>Orchidaceae</i> , <i>Sphagnum</i>	Gentle slope; undulating with channels filled with water; <i>Agathis</i> have been selectively logged for timber.
<b>Sago Stand 1</b>	1183m	Thin peat over orange mineral clay	<i>Eugeissona utilis</i> & <i>Syzygium</i> spp. (canopy); <i>Ardisia</i> sp. (understory)	Sago managed for longhouse roofing; steep slope with ephemeral watercourses cutting through thin peat.
<b>Lower Montane Forest (LMF) 1</b>	1310m	Sandy clays derived from underlying sandstones	<i>Lithocarpus</i> sp.; <i>Macaranga gigantifolia</i> ; <i>Shorea platyclados</i>	Stream valley side; canopy open; trees scattered, up to 25m, 60cm dbh, some trunks moss-covered 7-8m from ground; abundant epiphytes.
<b>Bukit Kelit</b>	1357m	Leaf litter atop >10cm humus and fine root mat; spongy, almost peaty	<i>Agathis endertii</i> , <i>Shorea venulosa</i> , <i>Lithocarpus</i> sp., <i>Ficus</i> sp., <i>Syzygium bankense</i> , <i>Schefflera</i> sp., 3 <i>Arecaceae</i> spp., <i>Pandanus</i> sp.	Along ridge to summit; community reserve for <i>Agathis</i> for damar resin; <i>Agathis</i> > 1m dbh along ridge, reproducing; large <i>Ficus</i> and <i>Shorea</i> trees; canopy open, 20+m tall; lichens & mosses on some trees.
<b>Kawang</b>	1434m	Dry, sandy loam	<i>Poaceae</i> spp.; <i>Globba</i> ; <i>Vernonia arborea</i> ; <i>Macaranga gigantifolia</i>	Anthropogenic clearing on gently sloping ridge leading down to steeper slope with remaining tree cover; large trees on ridge felled by chainsaw in 2000 to form 'Millennium Kawang'.

site to site. Mode of transport from each of the two bases to daily sampling locales was largely on foot, with opportunistic use of borrowed or hired 4x4 employed to navigate the unpaved and mire-like clayey logging roads that traverse the highlands.

As funds limited the possible length of time to one week that botanist Dr Kit Pearce, who led the botanical surveys, could be hired, and as transit time between sites made palpable the trade-off between number of sites sampled and detail of data collected, these surveys were exploratory rather than exhaustive. Still, meaningful data pertaining to mostly generic-level taxonomic determinations of ecologically and culturally important plants, as well as notes on overall stand architecture, substrate, physiographic context, and land use history as gathered from local informants were compiled.

A few general comments and conclusions can be made pertaining to the summary data presented in Table 5.1. Sites span an altitudinal range from 977m (Pa' Dalih Padi) to 1434m (Kawang). This places all 16 sites within the elevation band of Pearce's (2006) and Lim's (2006) lower montane forest (LMF). However, these sites occupy various physiographic (ie slope, aspect, exposure, susceptibility to inundation), edaphic, and land use contexts, thus modifying the climatically controlled vegetation type at these elevations. All three of the sites that failed to yield useable pollen assemblages from surface sediments occupy river floodplains or low terraces that are subject to periodic inundation and, thus, evidently also to regular scouring of the surface layers of sediment that would have encapsulated modern pollen rain. Sites supporting vegetation of greatest structural complexity (ie multi-strata architecture) are the alluvial forest sites; those with the least such complexity occur at sites with recent anthropogenic disturbance in the form of forest clearance or maintenance of an open landscape, as in the paddy fields. Whilst potentially informative, attempts at quantitative measures such as diversity indices or stand evenness were not possible due to the non-exhaustive nature of the surveys and to the collection of taxon lists in the absence of relative cover / abundance estimates. Given more resources, as well as the author's anticipated future development of improved

field botanical expertise, collection of these types of data will benefit similar future studies.

***Pa' Dalih Padi (977m)***

As its name suggests, site Pa' Dalih Padi is a wet rice paddy field on the margins of the southern Kelabit Highlands community of Pa' Dalih (Figure 5.2). Both the site and the community of Pa' Dalih sit atop a low terrace of the Kelapang river. This terrace is situated adjacent to the modern river channel. There is evidence in the form of unlithified fine-grained bedded deposits of silts and sands that the Kelapang and tributary streamlets periodically top their banks and inundate lower portions of this terrace, blurring the delimitation of the active floodplain and this terrace in the vicinity of the village. Pa' Dalih Padi is one of the many wet rice paddy fields that local Kelabit residents have constructed within the palaeochannels of the Kelapang which are cut into the terrace on which the community of Pa' Dalih sits. The substrate into which the



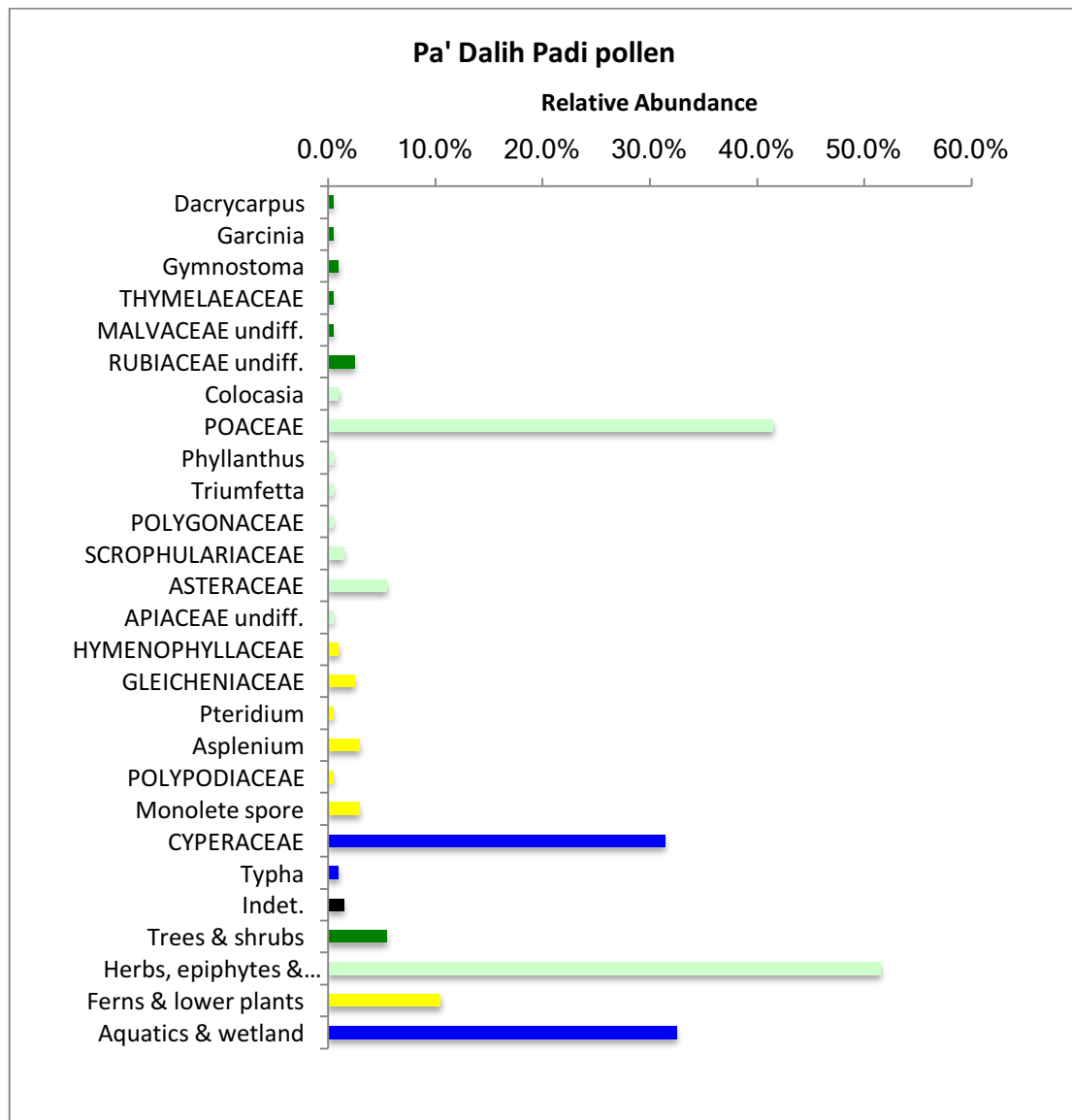
**Figure 5.2** Herbaceous ground cover at site Pa' Dalih Padi. Vegetation and sediments were sampled from within the wet paddy field. Note the surrounding orchard and forest. Photo: S. O'Donnell

vegetation at the site is growing consists of waterlogged alluvial clays. The field was in fallow when sampled in May 2013. A landscape mosaic of domestic gardens, fruit trees, active paddy fields, fields and swiddens in fallow, and patches of secondary lower montane forest surround the site.

**Table 5.2** Taxon list from botanical survey of site Pa' Dalih Padi. Taxa are grouped according to life-form, as denoted by left-hand column.

<b>Pa' Dalih Padi vegetation</b>		
	<b>Taxon</b>	<b>Family</b>
<b>Trees &amp; shrubs</b>	<i>Melastoma</i> sp.	Melastomataceae
<b>Herbs, epiphytes &amp; climbers</b>	<i>Isachne</i> sp.	Poaceae
	<i>Leersia</i> sp.	Poaceae
	<i>Paspalum</i> sp.	Poaceae
	Poaceae sp.	Poaceae
	<i>Pseudechinolaena</i> sp.	Poaceae
	<i>Sacciolepis</i> sp.	Poaceae
	<i>Phyllanthus urinaria</i> L.	Phyllanthaceae
	<i>Urena lobata</i> L.	Malvaceae
	<i>Oldenlandia diffusa</i> (Willd.) Roxb.	Rubiaceae
	<i>Hyptis brevipes</i> Poit.	Lamiaceae
	<i>Lindernia</i> spp.	Linderniaceae
	<i>Torenia</i> sp.	Linderniaceae
	<i>Ageratum conyzoides</i> (L.) L.	Asteraceae
	<i>Crassocephalum crepidioides</i> (Benth.) S.Moore	Asteraceae
	<i>Elephantopus scaber</i> L.	Asteraceae
	<i>Emilia sonchifolia</i> (L.) DC. ex DC.	Asteraceae
	<i>Hydrocotyle sibthorpioides</i> Lam.	Araliaceae
<b>Ferns &amp; lower plants</b>	<i>Lygodium scandens</i> (L.) Sw.	Lygodiaceae
<b>Aquatics, swamp &amp; wetland</b>	<i>Cyperus digitatus</i> Roxb.	Cyperaceae
	<i>Fimbristylis pauciflora</i> R.Br.	Cyperaceae
	<i>Fimbristylis quinquangularis</i> (Vahl) Kunth	Cyperaceae
	<i>Fimbristylis</i> sp.	Cyperaceae
	<i>Rhynchospora colorata</i> (L.) H.Pfeiff.	Cyperaceae
	<i>Rhynchospora corymbosa</i> (L.) Britton	Cyperaceae
	<i>Scirpus</i> sp.	Cyperaceae
	<i>Monochoria vaginalis</i> (Burm.f.) C.Presl	Pontederiaceae
	<i>Ludwigia octovalvis</i> (Jacq.) P.H.Raven	Onagraceae
	<i>Alternanthera sessilis</i> (L.) R.Br. ex DC.	Amaranthaceae
	<i>Centella asiatica</i> (L.) Urb.	Apiaceae

The vegetation community that Pa' Dalih Padi supports is dominated by low-lying annual herbaceous plants that are tolerant of inundation (Table 5.2). The sedge family (Cyperaceae) thus dominates the site's taxon list, whilst the wind-dispersed and fast-growing herbs of the grasses (Poaceae) and daisies (Asteraceae) are also significant components of this artificially open patch in the landscape. Many of these plants are common weeds of upland rice fields across



**Figure 5.3** Modern pollen spectra from surface sediments at site Pa' Dalih Padi. Pollen taxa are colour-coded according to life-form. Relative abundance histograms for pollen types representing trees and shrubs are in dark green; those for herbs, epiphytes and climbers are in light green; ferns and lower plants are shown in yellow; aquatics and wetland taxa are in blue. Summary histograms for the various life-forms are shown in corresponding colours comprising the bottom four taxa.

the Southeast Asian region (Galinato *et al.*, 1999), including: *Paspalum* sp. (Poaceae); *Urena lobata* L. (Malvaceae); *Lindernia* sp. (Linderniaceae); *Ageratum conyzoides* (L.) L. (Asteraceae); *Crassocephalum crepidioides* (Benth.) S. Moore (Asteraceae); *Emilia sonchifolia* (L.) DC ex DC. (Asteraceae); *Fimbristylis quinquangularis* (Vahl) Kunth (Cyperaceae); and *Centella asiatica* (L.) Urb. (Apiaceae). Perennial shrubs of pioneering taxa (ie *Melastoma* sp., Melastomataceae) punctuate bunds and field margins. Taro (*Colocasia esculenta* (L.) Schott, Araceae) was not recorded in the immediate vicinity of this site,

though it was noted surrounding adjacent paddies growing on the bunds intervening fields.

Wet rice paddy fields appear to be the most intensively managed of the various conspicuously human-modified landscapes across the Kelabit Highlands. This is not surprising considering the cultural and economic significance of rice within Kelabit society (Janowski, 1991). According to local informants, neither the particular field sampled at site Pa' Dalih Padi nor the surrounding bunds have ever been sprayed with chemical pesticides or herbicides. This is reflected partially in the prominence within the site's taxon list of weeds common to this ecological context.

If we are to speak of 'palynological signatures' of these modern human ecologies, the bottom four histograms in Figure 5.3, that represent summary relative abundances of pollen from taxa of the various vegetative life-forms, are most telling. Over half of the modern pollen rain recovered from the sediments at Pa' Dalih Padi comes from herbaceous plants (51.5 per cent), nearly a third from aquatics and wetland taxa (32.5 per cent), with the remainder split relatively evenly between ferns and woody plants. Of particular note is the minor though significant representation of extra-local wind-dispersed pollen from trees and shrubs (ie *Dacrycarpus* and *Gymnostoma*), reflecting the taphonomic importance of pollen dispersal vectors and of the architecture of on-site vegetation (specifically degree of openness) in forming the sedimentary pollen signatures of various landscapes.

The pollen assemblage from site Pa' Dalih Padi (Figure 5.3) is dominated by the grasses (Poaceae) and sedges (Cyperaceae), and with a substantial representation of daisies (Asteraceae) as well as multiple fern taxa (yellow histograms). Combined with the extra-local input of *Dacrycarpus* and *Gymnostoma* pollen mentioned above, this pollen assemblage is indicative of an artificially open and heavily disturbed parent vegetation within a landscape mosaic that includes patches of *kerangas* and lower montane forests.



### ***Padi Bukit (1021m)***

Site Padi Bukit is a thick patch of low shrubby and herbaceous vegetation about 0.5ha in area growing on the slope of a hill overlooking the village of Pa' Dalih from the southwest (Figure 5.4). Soils supporting this vegetation consist of yellow clays with little apparent organic component and very blocky structure. The patch sampled is surrounded by secondary lower montane forest on adjacent slopes, and by wet paddy fields and fruit tree orchards downslope associated with the settlement. The site is also situated just off the logging road that connects Pa' Dalih with Bario to the north and with the rest of the Highlands. According to local informants, the secondary lower montane forest that previously occupied this site was cleared three years prior to our sampling in May 2013 and planted with hill paddy (site name Padi Bukit means "hill paddy" in Bahasa Melayu). The site was in fallow at the time of sampling.



**Figure 5.4** Thick scrubby regrowth at site Padi Bukit, a site that was cleared and planted with hill paddy three years ago. This site is on the slopes abutting Pa' Dalih village, on the southwest overlooking the longhouse community and wet paddy fields.

In her chapter entitled “Kelabit Agriculture”, Janowski (2003) describes the distribution of dry rice hill paddy, such as that practiced at site Padi Bukit three years previous to sampling for the present study, as concentrated in the hillier southern portion of the Kelabit Highlands where Pa’ Dalih is located. In contrast, at the time of Janowski’s fieldwork in the late 1980s and early 1990s the preferable wet rice paddies were far more abundant in the Bario area where more flat, low-lying, and easily irrigated land is located. Janowski noted a trend in Pa’ Dalih toward more labour investment in wet paddy than in dry paddy in the late 20<sup>th</sup> century, and this trend is supported by site Padi Bukit providing the only example of swidden regrowth sampled in the present study’s 16 sites distributed across both the southern and northern portions of the Kelabit Highlands.

The taxon list for site Padi Bukit (Table 5.3) shows an even split between shrubby and herbaceous plants known locally and regionally to be pioneers of recently cleared land within this elevation band (cf Pearce, 2006; Lim, 2006). These taxa include: *Macaranga* sp. (Euphorbiaceae); *Ficus* sp. (Moraceae); *Melastoma* sp. (Melastomataceae); *Bambusoideae* sp. (Poaceae); *Miscanthus floridulus* Warb. ex K.Schum. & Lauterb. (Poaceae); Zingiberaceae sp.; and *Pteridium esculentum* (Forst.) Cockayne (Dennstaedtiaceae). This composition reflects the early successional stage of the secondary vegetation occupying the site at the time of sampling. Kelabit informants were not asked about whether any of these plants of common regeneration taxa are used locally in Pa’ Dalih. However, Christensen (2002) lists *Clethra canescens* Herb.Reinw. ex Blume and *Clethra pachyphylla* Merr. (Clethraceae) as used by Kelabit for sources of construction material and firewood; the leaves of *Tetracera arborescens* Jack (Dilleniaceae) as sandpaper, and water from the cut stem of this liana as potable; twigs of *Homolanthus populneus* (Geisler) Pax (Euphorbiaceae) as used to stir meat dishes to speed cooking, the white latex exudate being the active component; wood from *Macaranga costulata* Pax & K.Hoffm. (Euphorbiaceae) as used for construction material; the fruits of *Curculigo* spp. (Hypoxidaceae) as being edible and tasty; the fruits of *Melastoma malabathricum* L. (Melastomataceae) as being edible and tasty, and the leaves as having various

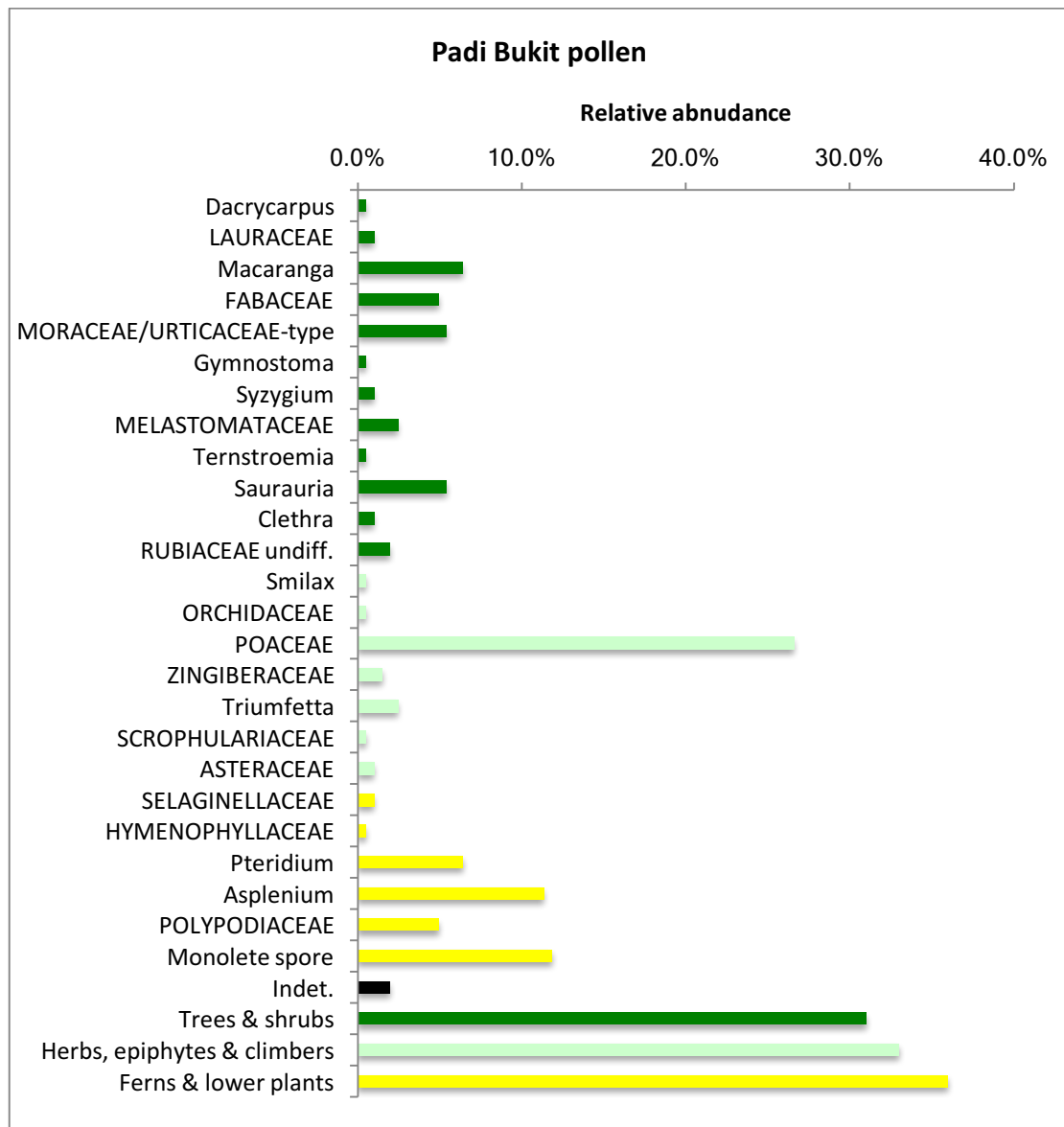


medicinal applications; many *Syzygium* spp. (Myrtaceae) as having edible fruits and useful wood; *Miscanthus floridulus* as used in religious ceremonies and rituals; the wood of *Wendlandia dasythyrsa* Miq. (Rubiaceae) as a source of material for tool construction, living fence posts, and firewood; the fruits of multiple species of *Saurauia* (Actinidiaceae) as being edible, and the wood of which being good for fence posts; and many species of the ginger family, Zingiberaceae, with edible fruits and other plant parts. Such documented use by Kelabits of so many taxa that occur in this swidden regrowth show that this land use is potentially more intensive and continuous than is commonly inferred from the descriptive phrase 'shifting cultivation'. Indeed, a landscape mosaic of swidden fallows at various stages of regrowth, such as this three-year regrowth at site Padi Bukit, can and does provide a whole laundry list of economically useful plants! No doubt this forms part of the subsistence strategy.

The pollen assemblage depicted in Figure 5.5 is dominated by pioneering taxa and, thus, disturbance indicators. Grass pollen is most abundant, with strong representation of multiple open-landscape fern taxa as well as the early-mid seral stage shrubs and treelets of *Macaranga*, Fabaceae, and Melastomataceae. Also, as in the pollen assemblage from the open site of Pa' Dalih Padi, that of Padi Bukit contains small percentages of extra-local wind-pollinated trees such as *Dacrycarpus* and *Gymnostoma* which seem to be good indicators of the open structure of the on-site vegetation rather than elements of the local vegetation itself. These taxa are both common elements of *kerangas* communities that occur across the highlands.

**Table 5.3** Taxon list from the botanical survey of site Padi Bukit. Taxa are grouped according to life-form, as denoted by left-hand column.

Padi Bukit vegetation		
	Taxon	Family
Trees & shrubs	<i>Homalanthus</i> sp.	Euphorbiaceae
	<i>Macaranga</i> sp.	Euphorbiaceae
	<i>Ficus</i> sp.	Moraceae
	<i>Melastoma</i> sp.	Melastomataceae
	<i>Syzygium</i> sp.	Myrtaceae
	<i>Saurauia</i> sp.	Actinidiaceae
	<i>Clethra</i> sp.	Clethraceae
	Rubiaceae sp.	Rubiaceae
Herbs, epiphytes & climbers	<i>Wendlandia</i> sp.	Rubiaceae
	<i>Smilax</i> sp.	Smilacaceae
	<i>Curculigo</i> sp.	Hypoxidaceae
	<i>Calanthe</i> sp.	Orchidaceae
	Bambusoideae sp.	Poaceae
	<i>Isachne</i> sp.	Poaceae
	<i>Miscanthus floridulus</i> Warb. ex K.Schum. & Lauterb.	Poaceae
	Zingiberaceae sp.	Zingiberaceae
	<i>Tetracera</i> sp.	Dilleniaceae
Ferns & lower plants	Fabaceae sp.	Fabaceae
	<i>Pueraria</i> sp.	Fabaceae
	<i>Pteridium esculentum</i> (G.Forst.) Cockayne	Dennstaedtiaceae



**Figure 5.5** Modern pollen spectra from surface sediments at site Padi Bukit. Pollen taxa are colour-coded according to life-form. Relative abundance histograms for pollen types representing trees and shrubs are in dark green; those for herbs, epiphytes and climbers are in light green; ferns and lower plants are shown in yellow. Summary histograms for the various life-forms are shown in corresponding colours comprising the bottom three taxa.

### ***Sago Stand 2 (1065m)***

Site Sago Stand 2 occupies the sharp ridge of a lateral spur and the steep slopes falling from either side, just north of Pa' Dalih and off the unpaved logging road that connects Pa' Dalih with Bario and the rest of the Highlands. Soils at the site consist of organic silty loams underlying a thick layer of leaf litter. The vegetation that is supported here is mature secondary lower montane forest interspersed with many large hill sago palms (*Eugeissona utilis* Becc., Arecaceae) (Figure 5.6). Canopy height at this site is in excess of 20m, with many trees greater than 45cm diameter at breast height (dbh). The understorey consists largely of saplings of canopy taxa; groundcover is comprised primarily of herbaceous taxa of the pan-tropical/subtropical monocotyledonous order Zingiberales (ie *Costus* sp., Marantaceae sp., and Zingiberaceae sp.) (Table 5.4).



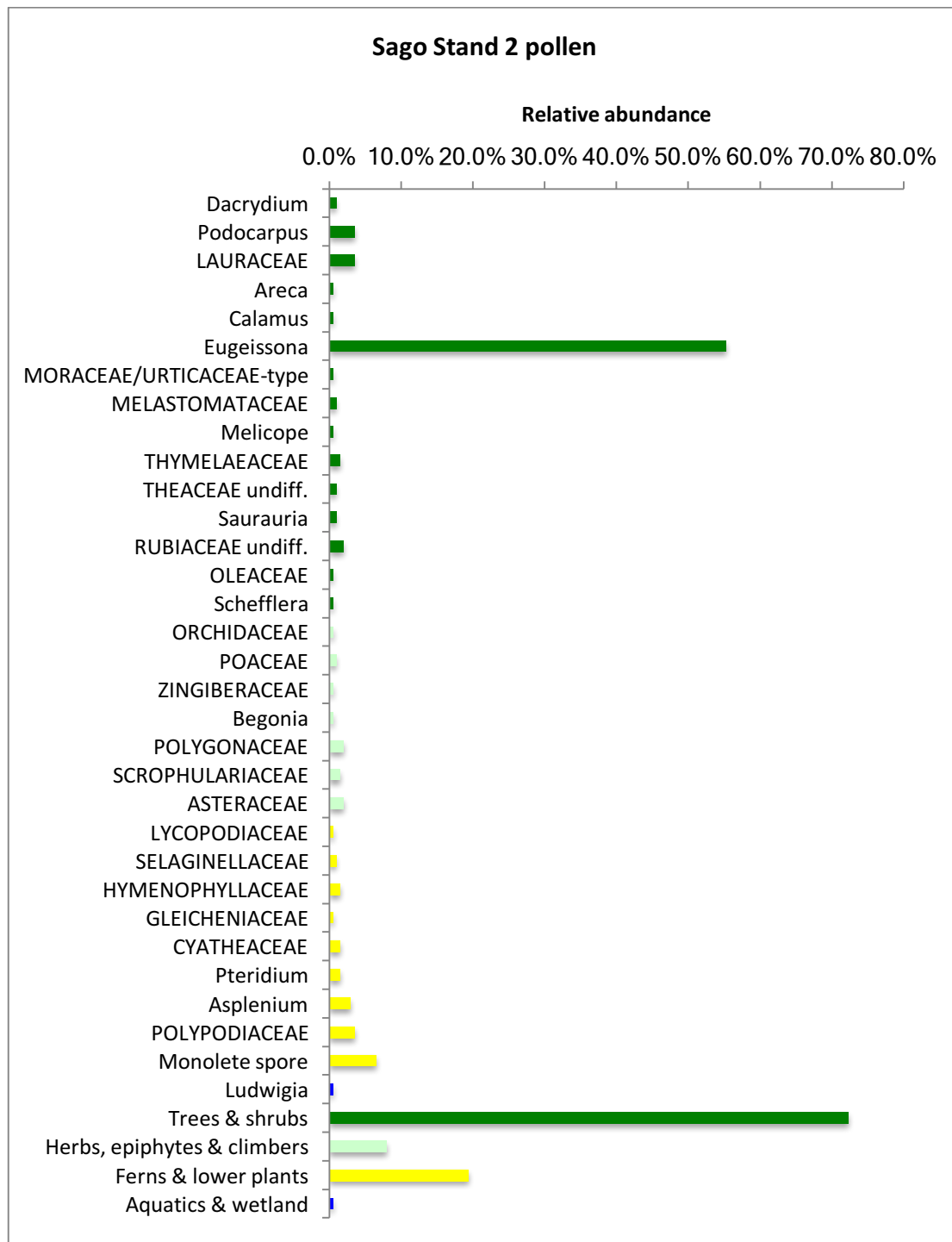
Figure 5.6 Looking downslope from ridge at site Sago Stand 2. Palm in centre of photo is *Eugeissona utilis* Becc., the hill sago palm., with one of our Kelabit guides from Pa' Dalih, Tadun Bala also known as Jeffrey Malang, in front right.

Tadun Bala, also known as Jeffrey Malang, our local guide from Pa' Dalih and informant for much of the land use histories for the southern sites sampled around Pa' Dalih, states that the hill sago at site Sago Stand 2 are not managed today, but may have been in the past. During our sampling visit, Jeffrey harvested a small young shoot from one of the sago palms. This sago shoot was later prepared back at the longhouse and served in a side-dish accompanying the main rice meal. This supports Janowski's (1991; 2003) observations that in contrast to their maintenance of paddy fields, very little labour, or even none at all, is invested by Kelabit in tending various sources of 'wild' plant foods such as these hill sago, though they are still collected. Indeed, wild foods collectively play a large role in modern Kelabit subsistence. Sites such as Sago Stand 2, that at the time of sampling also supported a fruiting *Baccaurea* Lour. tree (genus of the edible fruit tampoi), as well as individuals of *Cinnamomum* Schaeff. (source of cinnamon) and *Garcinia* L. (many local species produce wild mangosteens) (Table 5.4), represent a less intense land use than the paddy fields and orchards in and around Pa' Dalih.

The pollen assemblage from site Sago Stand 2 (Figure 5.7) is dominated by pollen from the summary grouping of 'Trees and shrubs'. This dominance is driven by the overwhelming percentage (nearly 60 per cent) of sago pollen (*Eugeissona*). At the time of sampling, this site supported multiple mature hill sago palms in flower. *Eugeissona utilis* Becc. (Arecaceae) produce huge vertical spike-like terminal inflorescences containing many flowers bearing large, robust pollen grains, so this sedimentary representation is unsurprising. The remainder of the pollen assemblage is quite diverse, largely reflecting the botanical taxon list. However, the fern spore assemblage contains many more taxa than were recorded in the non-exhaustive botanical survey.

**Table 5.4** Taxon list from the botanical survey of site Sago Stand 2. Taxa are grouped according to life-form, as denoted by left-hand column.

<b>Sago Stand 2</b>		
	<b>Taxon</b>	<b>Family</b>
<b>Trees &amp; shrubs</b>	<i>Cinnamomum</i> sp.	Lauraceae
	Lauraceae spp.	Lauraceae
	<i>Eugeissona utilis</i> Becc.	Areaceae
	<i>Leea</i> sp.	Vitaceae
	<i>Garcinia</i> sp.	Clusiaceae
	Euphorbiaceae sp.	Euphorbiaceae
	<i>Cratoxylum</i> sp.	Hypericaceae
	<i>Baccaurea</i> sp.	Phyllanthaceae
	<i>Parkia</i> sp.	Fabaceae
	<i>Anisophyllea</i> sp.	Anisophylleaceae
	Fagaceae sp.	Fagaceae
	<i>Syzygium</i> spp.	Myrtaceae
	Meliaceae sp.	Meliaceae
	<i>Clausena excavata</i> Burm.f.	Rutaceae
	<i>Saurauia</i> sp.	Actinidiaceae
	<i>Diospyros</i> sp.	Ebenaceae
	<i>Symplocos</i>	Symplocaceae
	<i>Gordonia</i> sp.	Theaceae
	Theaceae sp.	Theaceae
<b>Herbs, epiphytes &amp; climbers</b>	<i>Piper</i> sp.	Piperaceae
	<i>Amorphophallus</i> sp.	Araceae
	Araceae sp.	Araceae
	<i>Isachne</i> sp.	Poaceae
	<i>Costus</i> sp.	Costaceae
	Marantaceae sp.	Marantaceae
	Zingiberaceae sp.	Zingiberaceae
	Fabaceae sp.	Fabaceae
	<i>Phyllagathis</i> sp.	Melastomataceae
<b>Ferns &amp; lower plants</b>	<i>Selaginella</i> sp.	Selaginellaceae



**Figure 5.7** Modern pollen spectra from surface sediments at site Sago Stand 2. Pollen taxa are colour-coded according to life-form. Relative abundance histograms for pollen types representing trees and shrubs are in dark green; those for herbs, epiphytes and climbers are in light green; ferns and lower plants are shown in yellow; aquatics and wetland taxa are in blue. Summary histograms for the various life-forms are shown in corresponding colours comprising the bottom four taxa.

### **Alluvial Forest 3 (1073m)**

Site Alluvial Forest 3 (Figure 5.8) is a patch of mature riparian vegetation occupying an undulating floodplain of the Bayuh river, which is a tributary of the Dappur. This site is the lowest in elevation of the ten sites forming the northern cluster in closer proximity to Bario than to Pa' Dalih (Figure 5.1). The substrate at this site is of fine-grained alluvium devoid of the sands found at sites Alluvial Forests 1 and 2, suggesting lower energy floods when the Pa' Bayuh breeches its channel levees. Trees here form a canopy in excess of 30m in height, with an understorey of canopy saplings. This site is rich in palms (Arecaceae), including a few large *Eugeissona utilis* Becc., as well as other elements indicative of this site's transitional nature between the alluvial forest and lower montane forest types of Lim (2006), ie Lauraceae spp., Fagaceae sp., and *Shorea monticola* P.S.Ashton (Dipterocarpaceae) (Table 5.5). The primarily herbaceous groundcover, including the grasses (Bambusoideae sp. and Poaceae sp.), gingers (*Boesenbergia* sp. and *Globba* sp.), melastomes (*Phyllagathis* sp. and *Sonerila* sp.), fern flora, and sedge taxon (*Cyperus* sp.) are indicative of periodic inundation providing regular disturbance. Though this disturbance mechanism is not anthropogenic, nearby patches of lower montane forest that we traversed on our way to and from this site have been quite heavily logged in recent years.

In relation to the parent vegetation on site today, the pollen assemblage from site Alluvial Forest 3 (Figure 5.9) contains an over-representation of arboreal pollen ('Trees and shrubs' summary grouping) at the expense of herbaceous taxa ('Herbs, epiphytes, and climbers' summary grouping). Also of note are the usual suspects of anemophilous (wind-pollinated) elements of surrounding lower montane forest and *kerangas* communities, ie *Dacrycarpus*, *Dacrydium*, *Podocarpus*, *Castanopsis/Lithocarpus*-type, and *Gymnostoma*.

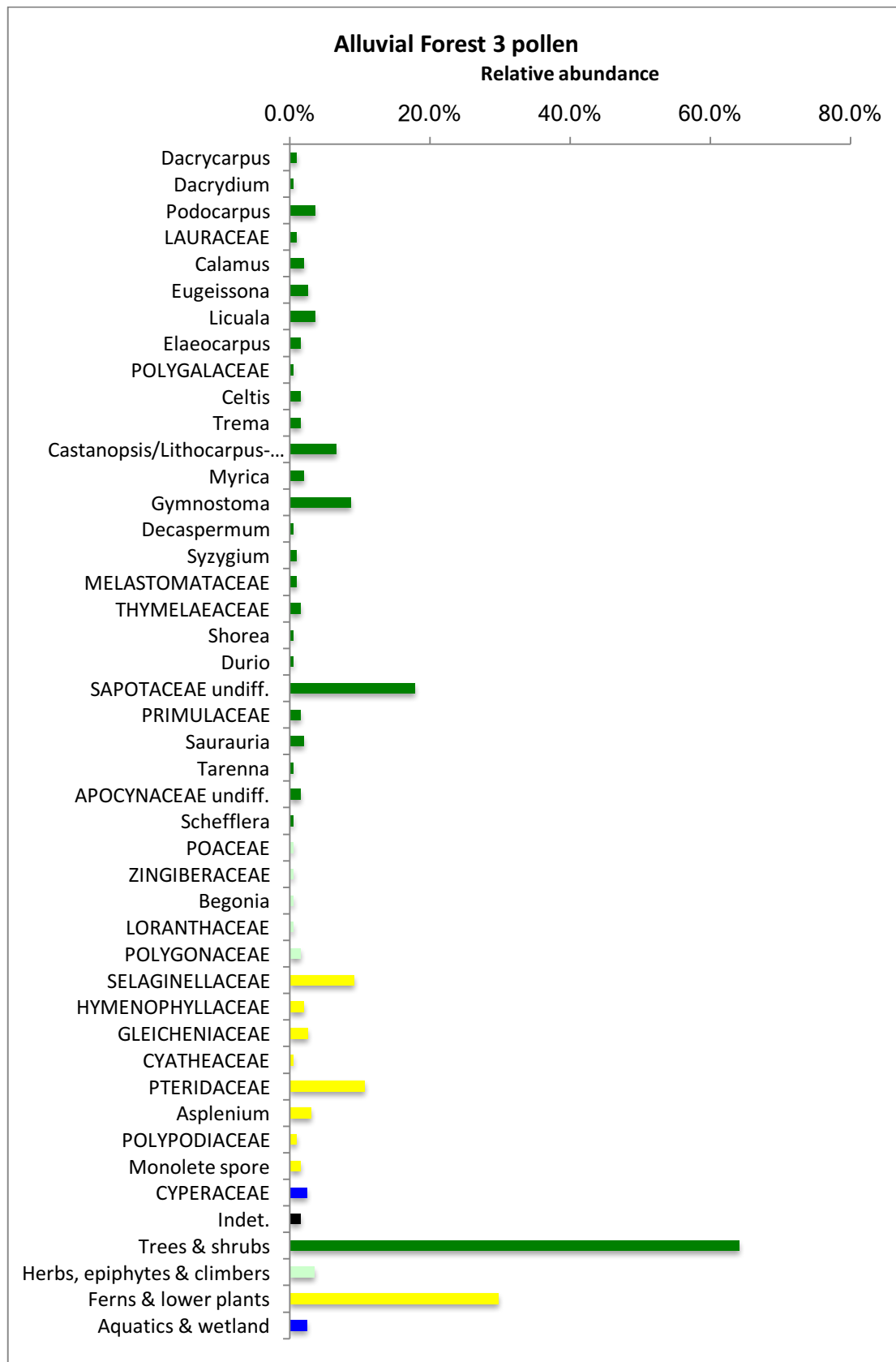




**Figure 5.8** Site Alluvial Forest 3. Palm in centre is *Eugeissona utilis* Becc. Note the relatively open structure of the vegetation with significant levels of light reaching the forest floor, as well as the predominantly bole-sized trees intermixed with occasional larger trees.

**Table 5.5** Taxon list from the botanical survey of site Alluvial Forest 3. Taxa are grouped according to life-form, as denoted by left-hand column.

<b>Alluvial Forest 3 vegetation</b>		
	<b>Taxon</b>	<b>Family</b>
<b>Trees &amp; shrubs</b>	Myristicaceae sp.	Myristicaceae
	Lauraceae spp.	Lauraceae
	<i>Freycinetia</i> sp.	Pandanaceae
	Arecoideae sp.	Arecaceae
	Calamoideae spp.	Arecaceae
	<i>Eugeissona utilis</i> Becc.	Arecaceae
	<i>Licuala</i> sp.	Arecaceae
	<i>Cratoxylum</i> sp.	Hypericaceae
	<i>Gomphia</i> sp.	Ochnaceae
	Fagaceae sp.	Fagaceae
	<i>Syzygium bankense</i> (Hassk.) Merr. & L.M. Perry	Myrtaceae
	<i>Toona sureni</i> (Blume) Merr.	Meliaceae
	<i>Shorea monticola</i> P.S. Ashton	Dipterocarpaceae
<b>Herbs, epiphytes &amp; climbers</b>	Orchidaceae spp.	Orchidaceae
	Bambusoideae sp.	Poaceae
	Poaceae sp.	Poaceae
	<i>Boesenbergia</i> sp.	Zingiberaceae
	<i>Globba</i> sp.	Zingiberaceae
	<i>Tetracera</i> sp.	Dilleniaceae
	<i>Pueraria</i> sp.	Fabaceae
	<i>Phyllagathis</i> sp.	Melastomataceae
	<i>Sonerila</i> spp.	Melastomataceae
<b>Ferns &amp; lower plants</b>	<i>Selaginella</i> spp.	Selaginellaceae
	<i>Cyathea</i> sp.	Cyatheaceae
	<i>Asplenium</i> sp.	Aspleniaceae
	<i>Lepisorus</i> sp.	Polypodiaceae
	<i>Selliguea triloba</i> (Houtt.) ex M.G. Price	Polypodiaceae
<b>Aquatics &amp; wetland</b>	<i>Cyperus</i> sp.	Cyperaceae



**Figure 5.9** Pollen spectra from site Alluvial Forest 3. Pollen taxa are colour-coded according to life-form. Histograms for pollen types representing trees & shrubs are in dark green; herbs, epiphytes & climbers in light green; ferns & lower plants in yellow; aquatics & wetland taxa in blue. Summary histograms for the various life-forms are shown in corresponding colours comprising the bottom four taxa.

### **Alluvial Forest 1 (1078m)**

Site Alluvial Forest 1 is a heavily disturbed patch of riparian vegetation adjacent to the Dappur river as it flows east of Bario. The site is reached via a 30-minute walk down a footpath east-southeast from the eastern end of the Bario airstrip (Figure 5.10). This footpath traverses land used patchily as orchards. An extensive area immediately surrounding the airstrip supports a thicket of bracken (*Pteridium esculentum* (G.Forst.) Cockayne). This appears to be the result of continued disturbance following localised removal of the naturally occurring *kerangas* vegetation that still remains in patches.

Once down at the river's edge, we sampled an area immediately behind the channel levee and just downstream from a disused wharf. A number of active human trails cross through the site, and there is much evidence for buffalo trample in flattened herbaceous groundcover and hollows made in the saturated floodplain sediments. The alluvial soils consist of fine sandy silts and clays. The vegetation supported at this site (Table 5.6) was recently opened to penetration by sunlight, as evidenced by the fallen tree bearing epiphytes. Groundcover is predominantly herbaceous, with grasses (*Bambusoideae* sp. and *Poaceae* sp.) and gingers (*Alpinia* sp.) the most conspicuous and abundant. The relatively low canopy of ~15m in height is composed of riparian *Syzygium* spp. (*Myrtaceae*), multiple *Ficus* spp. (*Moraceae*), and an individual of the sole non-mangrove genus of *Rhizophoraceae* that occurs in the Highlands (*Carallia* sp.). A number of smaller treelets of *Syzygium* sp. as well as *Ardisia* sp. (*Primulaceae*) comprise the understorey, supporting a tangle of climbers of *Smilax* sp. (*Smilacaceae*), *Tetracera* sp. (*Dilleniaceae*), and *Schefflera* sp. (*Araliaceae*), and numerous epiphytic orchids of various taxa (ie *Appendicula* sp., *Calanthe* sp., *Dendrochilum* sp., and multiple individuals identified only to family *Orchidaceae*).

The pollen assemblage from site Alluvial Forest 1 (Figure 5.11) closely mirrors the composition of the parent vegetation currently growing on site. However, as is appearing as a trend, sites supporting a vegetation with a mature canopy and diverse herbaceous groundcover seem to leave a palynological



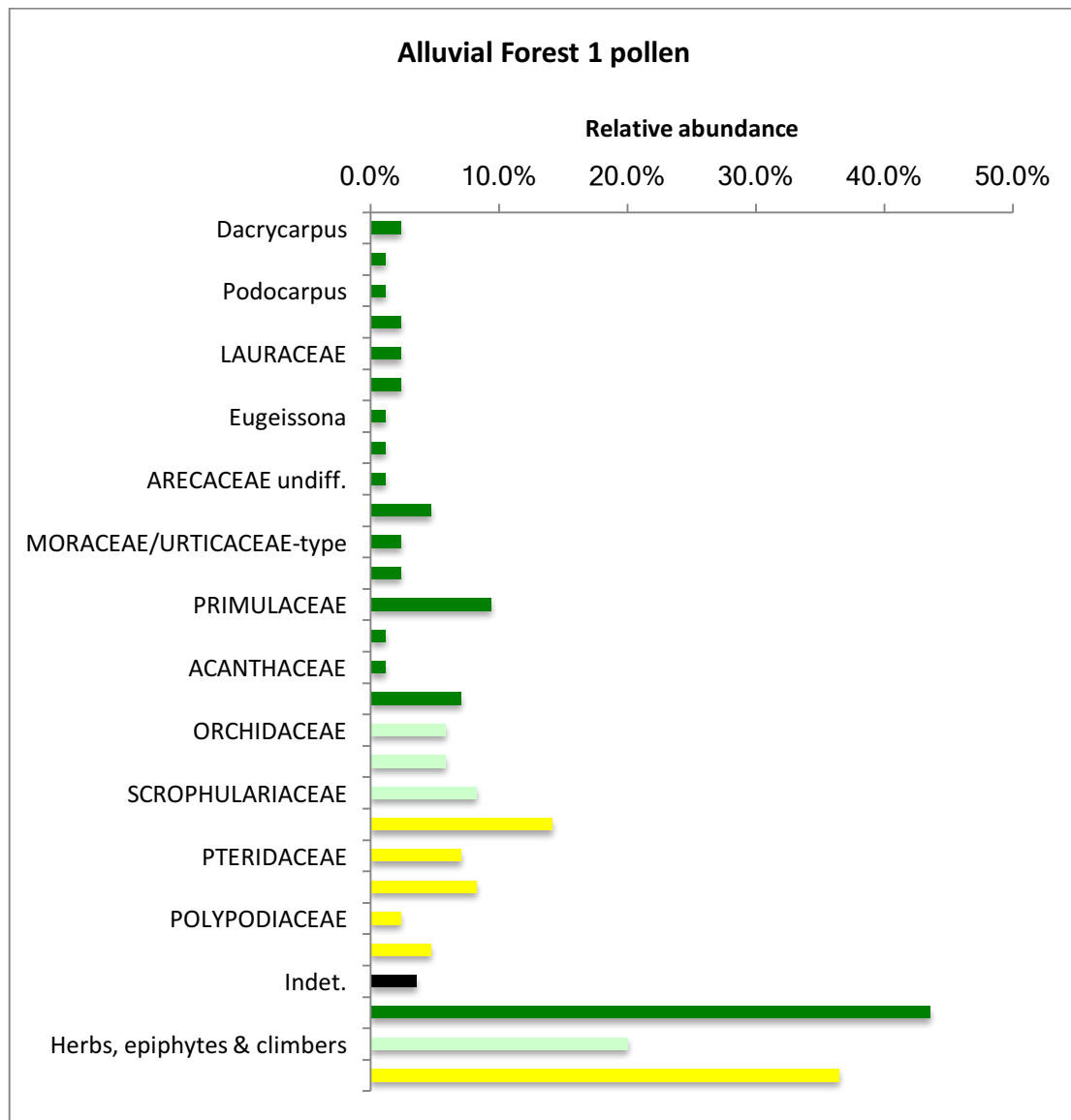
**Figure 5.10** Looking NW from site Alluvial Forest 1. The Dappur river is behind camera. Note open fern-dominated vegetation around the footpath, surrounded by relatively open structured alluvial forest on the adjacent floodplain.

fingerprint in which ‘Trees and shrubs’ are summarily over-represented whilst the ‘Herbs, epiphytes, and climbers’ summary grouping is under-represented. This can be attributed to a higher degree of anemophily (wind pollination) within canopy and sub-canopy taxa, combined with a parallel abundance of entomophily (insect pollination) amongst low-lying and prostrate forest herbs (Whitmore, 1984). The selective influence of the absence of wind as an available pollination vector within sheltered sub-canopy settings clearly drives this distribution of derived life history traits. Additionally, the higher diversity of fern taxa within the sedimentary pollen assemblage as compared with that of the vegetation currently growing on site appears also to be a trend. This suggests the hypothesis that fern spore assemblages across these sites are drawn from a larger source area than are the pollen assemblages of at least the entomophilous angiosperm taxa. Perhaps relative abundances of various fern spores and of anemophilous pollen types are providing an extra-local picture of vegetation,

whilst pollen spectra of the insect-pollinated herbaceous groundcover taxa reflect very localised vegetation.

**Table 5.6** Taxon list from the botanical survey of site Alluvial Forest 1. Taxa are grouped according to life-form, as denoted by left-hand column.

<b>Alluvial Forest 1 vegetation</b>		
	<b>Taxon</b>	<b>Family</b>
<b>Trees &amp; shrubs</b>	<i>Litsea garciae</i> Vidal	Lauraceae
	<i>Carallia</i> sp.	Rhizophoraceae
	<i>Ficus</i> spp.	Moraceae
	<i>Syzygium</i> spp.	Myrtaceae
	<i>Toona sureni</i> (Blume) Merr.	Meliaceae
	<i>Turpinia stipulacea</i> B.L. Linden	Staphyleaceae
	<i>Ardisia</i> sp.	Primulaceae
<b>Herbs, epiphytes &amp; climbers</b>	<i>Piper</i> sp.	Piperaceae
	<i>Smilax</i> sp.	Smilacaceae
	<i>Appendicula</i> sp.	Orchidaceae
	<i>Calanthe</i> sp.	Orchidaceae
	<i>Dendrochilum</i> sp.	Orchidaceae
	Orchidaceae spp.	Orchidaceae
	Bambusoideae sp.	Poaceae
	Poaceae sp.	Poaceae
	<i>Alpinia</i> sp.	Zingiberaceae
	<i>Tetracera</i> sp.	Dilleniaceae
	Vitaceae sp.	Vitaceae
	<i>Callerya nieuwenhuisii</i> (J.J. Sm.) Schot	Fabaceae
	<i>Aeschynanthus</i> sp.	Gesneriaceae
	<i>Lindernia</i> sp.	Linderniaceae
	<i>Schefflera</i> sp.	Araliaceae
<b>Ferns &amp; lower plants</b>	<i>Diplazium esculentum</i> (Retz.) Sw.	Athyriaceae



**Figure 5.11** Modern pollen spectra from surface sediments at site Alluvial Forest 1. Pollen taxa are colour-coded according to life-form. Relative abundance histograms for pollen types representing trees and shrubs are in dark green; those for herbs, epiphytes, and climbers are in light green; ferns and lower plants are shown in yellow. Summary histograms for the various life-forms are shown in corresponding colours comprising the bottom three taxa.



### ***Pa' Ramapuh Orchard (1079m)***

Site Pa' Ramapuh Orchard is a fruit tree orchard on the margins of the longhouse village of Pa' Ramapuh, that is itself one of the constituent Kelabit longhouse villages that make up the Bario area in the northern portion of the Kelabit Highlands. Dr Kit Pearce and her Kelabit husband own this particular orchard. The site is approximately 50 x 50m in area, and occupies a flat alluvial plain in a meander of the Pa' Ramapuh river. Soils at the site derive from clay alluvium. Wet rice paddies and secondary *kerangas* forest occupy the surrounding landscape.

The site supports a managed vegetation community with an open canopy of mature cultivated fruit trees ~ 20m in height; little understorey; and ground cover consisting largely of gingers (family Zingiberaceae), ferns, grasses (Poaceae), and other weedy herbaceous plants (Figure 5.12). The main cultivated fruit trees are durian (*Durio zibethinus* L., Malvaceae), tampoi (*Baccaurea macrocarpa* (Miq.) Müll.Arg., Euphorbiaceae), longan (*Dimocarpus longan* subsp. *malesianus* Leenh., Sapindaceae), and tarap (*Artocarpus odoratissimus* Blanco, Moraceae) (Table 5.7). Fruits of these cultivated trees are still collected, whilst the few remaining coffee plants (*Coffea arabica* L., Rubiaceae) from previous plantings are no longer harvested. Due to the active cultivation and harvesting of select taxa, as well as to the heavily managed nature of the surrounding landscape, this site can be placed just shy of the rice paddy sites at the end of the land use intensity gradient corresponding to the highest intensities.

'Ferns and lower plants' display dominant representation (nearly 60 per cent) amongst the summary groupings of the pollen assemblage from site Pa' Ramapuh Orchard (Figure 5.13). Many of the cultivated fruit tree taxa are also represented both in their respective individual histograms (ie Moraceae/Urticaceae-type, *Mangifera*, Sapindaceae, and *Durio*) and as constituent components of the 'Trees and shrubs' summary grouping that constitutes over one quarter of the total assemblage. The presence of



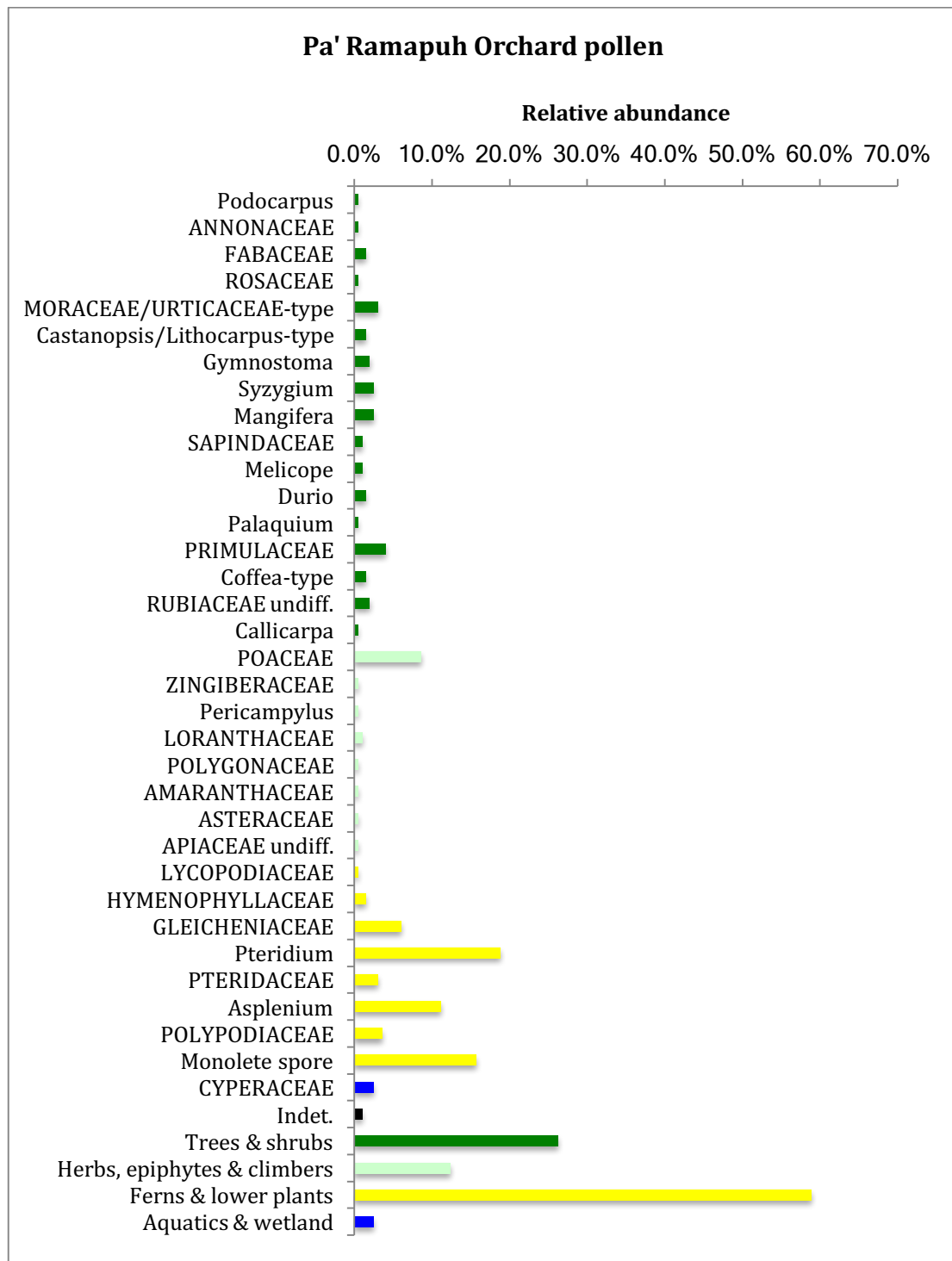


**Figure 5.12** Pa' Ramapuh Orchard site, showing open structure, mature fruit trees with many epiphytes, herbaceous ground cover, and sparse shrubby undergrowth.

Primulaceae (likely *Ardisia*), Poaceae, Zingiberaceae, *Pteridium*, and monolet spores in significant relative abundances indicate a frequently disturbed parent vegetation community. In concert with the representation of the extra-local wind-pollinated elements of the surrounding secondary *kerangas* and lower montane forests (*Castanopsis/Lithocarpus*-type and *Gymnostoma*), all of the above characteristics of the Pa' Ramapuh Orchard pollen assemblage align with the expected palynological signature of an open and intensively managed vegetation with many useful trees.

**Table 5.7** Taxon list from the botanical survey of site Pa' Ramapuh Orchard. Taxa are grouped according to life-form, as denoted by left-hand column.

Pa' Ramapuh Orchard vegetation		
	Taxon	Family
Trees & shrubs	<i>Litsea garciae</i> Vidal	Lauraceae
	<i>Elaeocarpus</i> sp.	Elaeocarpaceae
	<i>Mallotus paniculatus</i> (Lam.) Müll. Arg.	Euphorbiaceae
	<i>Baccaurea macrocarpa</i> (Miq.) Müll. Arg.	Phyllanthaceae
	<i>Carallia</i> sp.	Rhizophoraceae
	<i>Parkia speciosa</i> Hassk.	Fabaceae
	<i>Artocarpus odoratissimus</i> Blanco	Moraceae
	<i>Ficus</i> spp.	Moraceae
	<i>Syzygium</i> sp.	Myrtaceae
	<i>Mangifera foetida</i> Lour.	Anacardiaceae
	<i>Dimocarpus longan</i> subsp. <i>malesianus</i> Leenh.	Sapindaceae
	<i>Durio zibethinus</i> L.	Malvaceae
	<i>Symplocos fasciculata</i> Zoll.	Symplocaceae
Herbs, epiphytes & climbers	<i>Callicarpa</i> sp.	Lamiaceae
	<i>Coelogyne</i> sp.	Orchidaceae
	<i>Centotheca lappacea</i> (L.) Desv.	Poaceae
	<i>Setaria palmifolia</i> (J. Koenig) Stapf	Poaceae
	<i>Commelina paludosa</i> Blume	Commelinaceae
	<i>Alpinia</i> sp.	Zingiberaceae
	<i>Pericampylus</i> sp.	Menispermaceae
	Fabaceae sp.	Fabaceae
	<i>Pueraria</i> spp.	Fabaceae
	Urticaceae sp.	Moraceae
	<i>Rubus</i> sp.	Rosaceae
	<i>Medinilla</i> sp.	Melastomataceae
	<i>Cyathula prostrata</i> (L.) Blume	Amaranthaceae
Ferns & lower plants	<i>Polygonum</i> sp.	Polygonaceae
	<i>Elephantopus scaber</i> L.	Asteraceae
	<i>Asplenium</i> sp.	Aspleniaceae
	<i>Diplazium esculentum</i> (Retz.) Sw.	Athyriaceae
	<i>Stenochlaena palustris</i> (Burm. f.) Bedd.	Blechnaceae
	<i>Nephrolepis biserrata</i> (Sw.) Schott	Nephrolepidaceae



**Figure 5.13** Modern pollen spectra from surface sediments at site Pa' Ramapuh Orchard. Pollen taxa are colour-coded according to life-form. Relative abundance histograms for pollen types representing trees and shrubs are in dark green; those for herbs, epiphytes, and climbers are in light green; ferns and lower plants are shown in yellow. Summary histograms for the various life-forms are shown in corresponding colours comprising the bottom four taxa.

### ***Pa' Ramapuh Padi (1083m)***

Site Pa' Ramapuh Padi is a wet rice paddy field within the Kelabit longhouse village of Pa' Ramapuh. The field is bounded on two sides by a stream from which the paddy is irrigated. This field is situated amongst several other similar wet paddy fields, as well as the same secondary *kerangas* and lower montane forest that abuts site Pa' Ramapuh Orchard just up the road. Like site Pa' Ramapuh Orchard, this paddy field is owned and managed by Dr Kit Pearce and her Kelabit husband. According to Dr Pearce, one crop per year is planted in this field. It is left fallow for the remainder of the year. The rice crop at the site had been harvested in January/February, and the field was in a fallow state when we sampled and surveyed it in May 2013.

Soils at site Pa' Ramapuh Padi derive from saturated alluvial clays, supporting a predominantly herbaceous vegetation of annual regrowth. Taxa from the sedge and daisy families (Cyperaceae and Asteraceae, respectively) are the most conspicuous elements of the low-lying ground cover occurring on the site (Figure 5.14). Raised bunds bordering the paddy field, as well as scattered dry areas within the fallow paddy, support occasional perennial shrubs such as *Melastoma malabathricum* L. (Melastomataceae) (Table 5.8). Fewer of the common rice paddy weeds occur at this site than at site Pa' Dalih Padi. A number of factors probably contribute to this difference, with the role of herbicides undoubtedly playing at least a partial role. In Pa' Dalih, informants claim that neither paddy nor bunds are ever sprayed with herbicides or pesticides, whilst the bunds surrounding paddies in the Bario area are sprayed. The rice crop itself is not treated with chemicals, and is indeed marketed as organic Bario rice in lowland coastal markets such as Miri, but it is apparently seen as important to control weedy colonisation of intervening bunds.

The pollen assemblage from site Pa' Ramapuh Padi is very similar to that from site Pa' Dalih Padi (Figure 5.15). Of the summary groupings, 'Herbs, epiphytes, and climbers' is the most abundant, comprising 44 per cent of the total assemblage. This abundance is driven by the high values of grass pollen





**Figure 5.14** Site Pa' Ramapuh Padi, showing the wet paddy field in fallow, with herbaceous ground cover dominated by sedges (Cyperaceae spp.) and grasses (Poaceae spp.). Note perennial and annual shrubs and herbs on surrounding bunds and patches of at least seasonally dry soil.

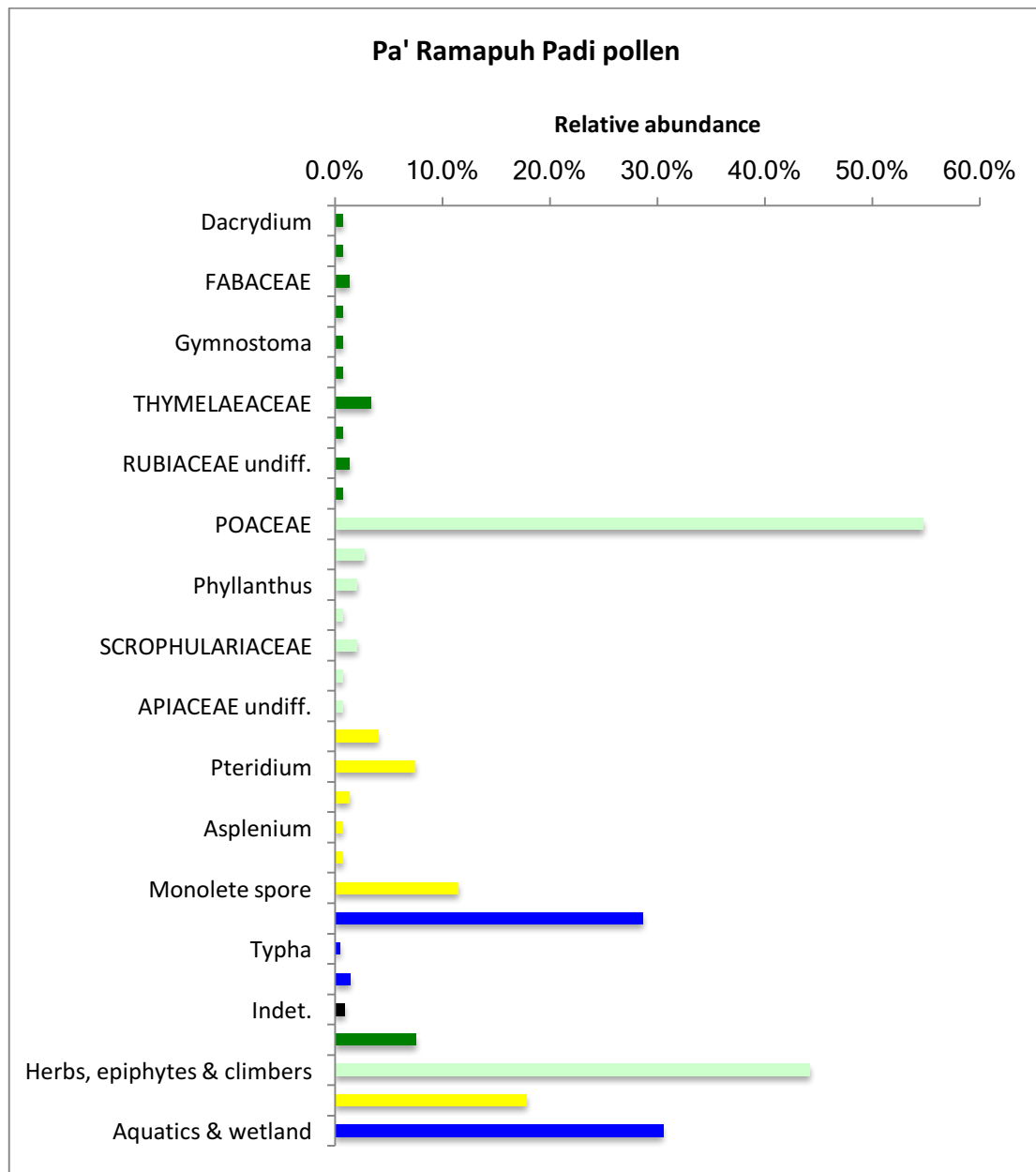
(Poaceae), with a surprisingly low contribution from daisies (Asteraceae) despite their representation by five taxa in the botanical survey data (*Ageratum conyzoides* (L.) L.; *Crassocephalum crepidioides* (Benth.) S.Moore; *Elephantopus scaber* L.; *Emilia sonchifolia* (L.) DC. ex DC.; and *Sphagneticola triloba* (L.) Pruski) (Table 5.8). The 'Aquatics and wetland' summary grouping also achieves high relative abundance, comprising 30 per cent of the total pollen assemblage. As in the assemblages from other sites that support vegetation communities of an open structure, the anemophilous taxa *Dacrydium* and *Gymnostoma* from surrounding *kerangas* forest are represented, though in low relative abundances. However, in contrast to the assemblage from site Pa' Dalih Padi in the southern Kelabit longhouse community of Pa' Dalih, the assemblage from site Pa' Ramapuh Padi in the Bario area of the northern Kelabit Highlands also includes anemophilous elements of lower montane forest, namely *Podocarpus*, *Castanopsis/Lithocarpus*-type, and Ericaceae. This difference is probably attributable to the greater proximity of lower montane forest to site

**Table 5.8** Taxon list from the botanical survey of site Pa' Ramapuh Padi. Taxa are grouped according to life-form, as denoted by left-hand column.

<b>Pa' Ramapuh Padi vegetation</b>		
	<b>Taxon</b>	<b>Family</b>
<b>Trees &amp; shrubs</b>	<i>Melastoma malabathricum</i> L.	Melastomataceae
	<i>Echinochloa crus-galli</i> (L.) P.Beauv.	Poaceae
<b>Herbs, epiphytes &amp; climbers</b>	<i>Isachne</i> sp.	Poaceae
	<i>Hypericum japonicum</i> Thunb.	Hypericaceae
	<i>Oldenlandia</i> sp.	Rubiaceae
	<i>Lindernia</i> sp.	Linderniaceae
	<i>Ageratum conyzoides</i> (L.) L.	Asteraceae
	<i>Crassocephalum crepidioides</i> (Benth.) S.Moore	Asteraceae
	<i>Elephantopus scaber</i> L.	Asteraceae
	<i>Emilia sonchifolia</i> (L.) DC. ex DC.	Asteraceae
	<i>Sphagneticola triloba</i> (L.) Pruski	Asteraceae
<b>Aquatics, swamp &amp; wetland</b>	<i>Cyperus digitatus</i> Roxb.	Cyperaceae
	<i>Cyperus</i> sp.	Cyperaceae
	<i>Eleocharis retroflexa</i> (Poir.) Urb.	Cyperaceae
	<i>Fimbristylis quinquangularis</i> (Vahl) Kunth	Cyperaceae
	<i>Fimbristylis</i> sp.	Cyperaceae
	<i>Rhynchospora colorata</i> (L.) H.Pfeiff.	Cyperaceae
	<i>Scirpus</i> sp.	Cyperaceae
	<i>Monochoria vaginalis</i> (Burm.f.) C.Presl	Pontederiaceae
	<i>Ludwigia octovalvis</i> (Jacq.) P.H.Raven	Onagraceae

Pa' Ramapuh Padi than to site Pa' Dalih Padi.

A taphonomic pattern is emerging that is qualitatively supported by the data presented thus far. At sites on which a vegetation community of relatively open structure is growing, the sedimentary pollen assemblage contains multiple representatives of wind-pollinated taxa. Composition and abundances of those elements seem to reflect proximity of the site to extra-local sources in various parent vegetation types. An example of this lies with the comparison drawn in the previous paragraph between the pollen assemblages from the two paddy field sites. This observation will become particularly relevant in interpretation of fossil assemblages in Chapter 6.



**Figure 5.15** Modern pollen spectra from surface sediments at site Pa' Ramapuh Padi. Pollen taxa are colour-coded according to life-form. Relative abundance histograms for pollen types representing trees and shrubs are in dark green; those for herbs, epiphytes, and climbers are in light green; ferns and lower plants are shown in yellow; aquatics and wetland taxa are in blue. Summary histograms for the various life-forms are shown in corresponding colours comprising the bottom four taxa.

### ***Kerangas 2 (1083m)***

Site Kerangas 2 is a patch of stunted *kerangas* forest occupying a medium slope along the path to Pa' Main. This site is one of the ten sites that form the northern cluster of sites surveyed whilst Dr Pearce and I were based out of Bario. On our approach to this site, we passed through some lower montane forest that had been heavily logged recently. However, our informants and guides for the day (Mustafa Raja Siwa from Bario and two men from Long Bawang, Indonesia who were presumably in Bario for seasonal work) claim that the particular patch of *kerangas* forest that we sampled has never been cut. As such, this site represents one of the 'naturally occurring' vegetation types common across the Kelabit Highlands, though it is in close proximity to some industrially logged lower montane forest.

Soils at the site consist of a dry, friable, and well-drained white sandy matrix derived from the hard white sandstone 20-30cm beneath the soil surface. This substrate supports a low and open vegetation with much sunlight penetrating to soil surface level (Figure 5.16). The largest trees (*Tristaniopsis* sp., Myrtaceae) at the time of sampling were five metres in height, whilst the majority of the open scrub was three metres or less in height. Taxonomic composition at this site (Table 5.9) is typical of *kerangas* forest (Whitmore, 1984) with its preponderance of ericaceous shrubs (*Rhododendron* spp. and *Vaccinium* sp.), pitcher plants (*Nepenthes stenophylla* Mast., Nepenthaceae), orchids (*Bromheadia* sp., Orchidaceae), and melastomes (*Melastoma* sp., Melastomataceae sp., and *Medinilla* sp.), as well as a common *kerangas* podocarp taxon, *Dacrydium* sp. Elements that set this site apart from site Kerangas 1 (description to follow) are the very low canopy stature, high degree of openness, and, thus, a much drier microclimate near the soil surface level. The site's low stature and ground cover dominated by *Pteridium esculentum* (G.Forst.) Cockayne provide causes to suspect somewhat recent disturbance, even in the face of the abovementioned anecdotal account that the plants on site have never been cut by people.



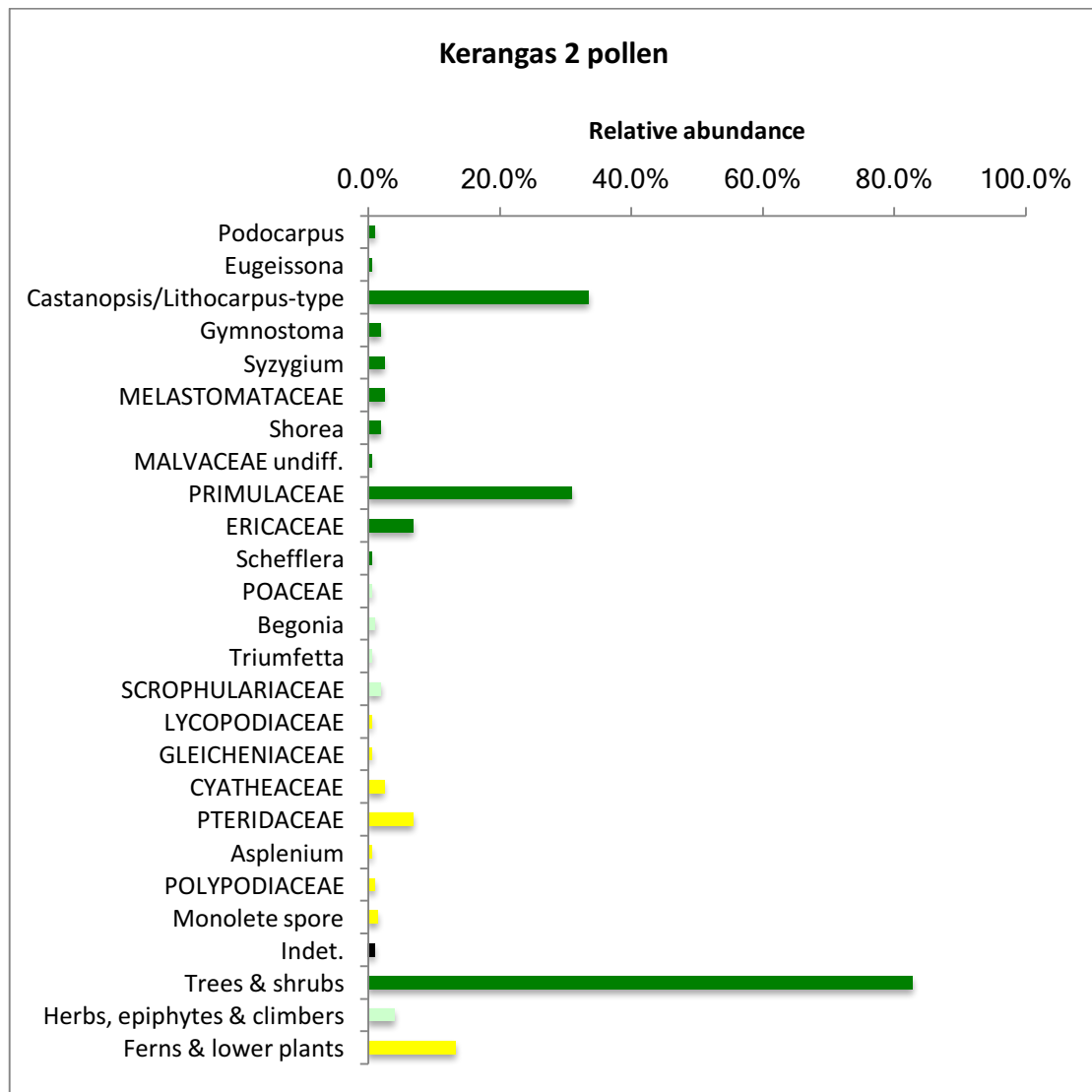


**Figure 5.16** Short stature with sparse open canopy and scrubby ericaceous understorey at site Kerangas 2. Note the shallow underlying yellow-orange sandy substrate overlain by a thin, spongy and dry humus layer.

Pollen from the ‘Trees and shrubs’ summary grouping dominates the assemblage from site Kerangas 2 (83 per cent) (Figure 5.17), whilst spores of ‘Ferns and lower plants’ show a significant representation at just over 13 per cent relative abundance. Pollen from herbaceous taxa are almost non-existent in this assemblage. At least two parallel processes are implicit in these data. Firstly, the local vegetation growing on site is itself dominated by hardier tree and shrub taxa due to the microclimate created by the open and low stature of the canopy, and to edaphic effects of the nutrient-poor and well-drained sandy soils. However, as has been mentioned in relation to the palynological signatures of all sites previously described that support open vegetation communities, over-representations of anemophilous taxa are also contributing to an exaggeration of the abundance of arboreal pollen at the expense of that of the typically entomophilous herbaceous plants.

**Table 5.9** Taxon list from the botanical survey of site Kerangas 2. Taxa are grouped according to life-form, as denoted by left-hand column.

<b>Kerangas 2 vegetation</b>		
	<b>Taxon</b>	<b>Family</b>
<b>Trees &amp; shrubs</b>	<i>Dacrydium</i> sp.	Podocarpaceae
	Lauraceae spp.	Lauraceae
	Calamoideae spp.	Arecaceae
	<i>Euthemis</i> sp.	Ochnaceae
	<i>Melastoma</i> sp.	Melastomataceae
	Melastomataceae spp.	Melastomataceae
	<i>Syzygium</i> sp.	Myrtaceae
	<i>Tristaniopsis</i> sp.	Myrtaceae
	<i>Rhododendron</i> spp.	Ericaceae
	<i>Vaccinium</i> sp.	Ericaceae
	<i>Ardisia</i> sp.	Primulaceae
<b>Herbs, epiphytes &amp; climbers</b>	<i>Madhuca</i> sp.	Sapotaceae
	<i>Urophyllum</i> sp.	Rubiaceae
	<i>Bromheadia</i> sp.	Orchidaceae
	<i>Medinilla</i> sp.	Melastomataceae
<b>Ferns &amp; lower plants</b>	<i>Nepenthes stenophylla</i> Mast.	Nepenthaceae
	<i>Schradera</i> sp.	Rubiaceae
	<i>Lycopodiella</i> sp.	Lycopodiaceae
	<i>Dicranopteris linearis</i> (Burm.f.) Underw.	Gleicheniaceae
	<i>Pteridium esculentum</i> (G.Forst.) Cockayne	Dennstaedtiaceae
	<i>Oleandra</i> sp.	Oleandraceae
	<i>Selliguea triloba</i> (Houtt.) ex M.G. Price	Polypodiaceae



**Figure 5.17** Modern pollen spectra from surface sediments at site Kerangas 2. Pollen taxa are colour-coded according to life-form. Relative abundance histograms for pollen types representing trees and shrubs are in dark green; those for herbs, epiphytes, and climbers are in light green; ferns and lower plants are shown in yellow. Summary histograms for the various life-forms are shown in corresponding colours comprising the bottom three taxa.

### ***Kerangas 1 (1098m)***

Like Kerangas 2, site Kerangas 1 is a patch of *kerangas* forest within the northern cluster of ten sites in the Bario area. This site is more northerly than Kerangas 2 (Figure 5.1). Due to the overall southward slope of the highland plateau, it is also at a slightly higher elevation and in closer proximity to the less disturbed lower montane forest communities on southern slopes of the Tama Abu range within Pulong Tau National Park that abuts Bario to the north. Site Kerangas 1 is surrounded in its immediate vicinity by what was once *Agathis* forest. However, due to the desirability of *Agathis borneensis* Warb. and *A. kinabaluensis* de Laub. (Araucariaceae) as sources of timber for Kelabit constructions (Christensen, 2002), many of these trees locally have been felled in the past 20 years. They continue to be cut, and locally few now remain. Despite being at similar elevations and of the same edaphically controlled *kerangas* forest type as site Kerangas 2, the structure and composition of the vegetation community at site Kerangas 1 differs from that at Kerangas 2 in a number of respects (Table 5.10). There is a bit of a chicken-and-egg scenario here, but two aspects of the vegetation community probably exert a positive feedback upon each other: the height and degree of openness of the canopy; as well as the apparent soil moisture content.

The sandy soils which characteristically support the edaphically controlled occurrence of *kerangas* forest across the highlands are here capped by about 10cm of sandy peat before grading into the white siliceous sands below. The canopy here is higher than at site Kerangas 2, reaching about 8-10m (Figure 5.18), and is dominated by *Agathis borneensis* Warb. (Araucariaceae), two podocarps (a *Dacrydium* sp. and a *Podocarpus* sp.), a number of myrtaceous tree taxa (three *Syzygium* spp. and a *Tristaniaopsis* sp.), and a few scattered oaks of the genus *Lithocarpus* Blume (Fagaceae). In addition to the canopy at site Kerangas 1 being taller, it is also slightly more closed than that at site Kerangas 2. Thus, the microclimate at soil surface level is more sheltered and moist. Along the small water-filled channels that criss-cross the gentle undulating slope of the forest floor occurs a *Sphagnum* sp. (Sphagnaceae), a *Selaginella* sp. (Selaginellaceae),





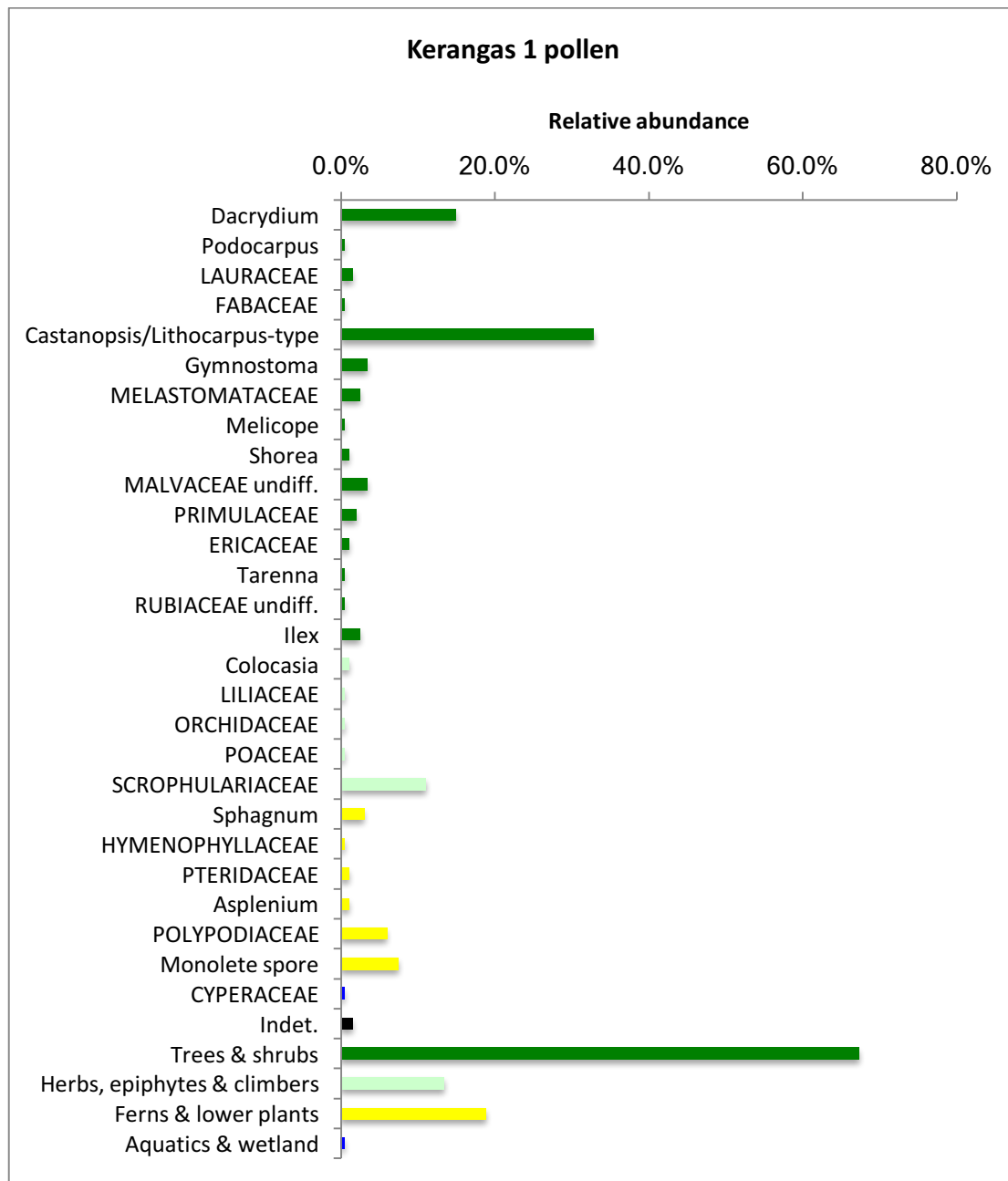
**Figure 5.18** Bole-sized treelets at site Kerangas 1 forming an open canopy of slightly higher stature than that at Kerangas 2, but with similar species composition in the understorey at both Kerangas sites consisting of largely ericaceous shrubs. Ground cover largely absent, with leaf litter dominated by fallen *Dacrydium* branchlets and bryophytes in channels of small shallow streamlets.

and other lower plants which display life history traits that are tied to wet or moist microenvironments. The same ericaceous shrub stratum (*Rhododendron* spp. and *Vaccinium* sp.) exists here as at site Kerangas 2, along with the pitcher plants (*Nepenthes* sp., Nepenthaceae) and melastomes (*Melastoma malabathricum* L. and *Medinilla* sp.) that are so indicative of *kerangas* forest associations (Pearce, 2006).

**Table 5.10** Taxon list from the botanical survey of site Kerangas 1. Taxa are grouped according to life-form, as denoted by left-hand column.

<b>Kerangas 1 vegetation</b>		
	<b>Taxon</b>	<b>Family</b>
<b>Trees &amp; shrubs</b>	<i>Agathis borneensis</i> Warb.	Araucariaceae
	<i>Dacrydium</i> sp.	Podocarpaceae
	<i>Podocarpus</i> sp.	Podocarpaceae
	Lauraceae sp.	Lauraceae
	<i>Pandanus</i> sp.	Pandanaceae
	<i>Garcinia</i> sp.	Clusiaceae
	<i>Euthemis minor</i> Jack	Ochnaceae
	<i>Lithocarpus</i> sp.	Fagaceae
	<i>Melastoma malabathricum</i> L.	Melastomataceae
	<i>Syzygium bankense</i> (Hassk.) Merr. & L.M.Perry	Myrtaceae
	<i>Syzygium</i> spp.	Myrtaceae
	<i>Tristaniopsis</i> sp.	Myrtaceae
	<i>Melanochyla</i> sp.	Anacardiaceae
	<i>Rhododendron</i> spp.	Ericaceae
	<i>Vaccinium</i> sp.	Ericaceae
	<i>Ardisia</i> sp.	Primulaceae
	<i>Gaertnera</i> sp.	Rubiaceae
<b>Herbs, epiphytes &amp; climbers</b>	Araceae sp.	Araceae
	<i>Smilax</i> sp.	Smilacaceae
	<i>Dianella</i> sp.	Asphodelaceae
	<i>Dendrochilum</i> sp.	Orchidaceae
	<i>Dilochia</i> sp.	Orchidaceae
	<i>Trichotosia</i> sp.	Orchidaceae
	<i>Racemobambos</i> sp.	Poaceae
	<i>Medinilla</i> sp.	Melastomataceae
	<i>Nepenthes</i> sp.	Nepenthaceae
	<i>Schradera</i> sp.	Rubiaceae
<b>Ferns &amp; lower plants</b>	<i>Sphagnum</i> sp.	Sphagnaceae
	<i>Selaginella</i> sp.	Selaginellaceae
	<i>Oleandra</i> sp.	Oleandraceae
	<i>Selliguea triloba</i> (Houtt.) ex M.G.Price	Polypodiaceae

The surface sediment pollen assemblage from site Kerangas 1 (Figure 5.19) is conspicuously similar to that from Kerangas 2 in its dominance by the ‘Trees and shrubs’ summary grouping. This grouping includes taxa of the *kerangas* canopy flora as well as extra-local anemophilous taxa. Notable minor differences, however, between the pollen assemblages from the two *kerangas* sites sampled are the higher percentages in the Kerangas 1 assemblage of pollen from herbaceous taxa (13.4 per cent versus 3.9 per cent in the Kerangas 2 assemblage) and of spores from the ‘Ferns and lower plants’ summary grouping (18.8 per cent compared with 13.3 per cent from Kerangas 2). These contrasts



**Figure 5.19** Modern pollen spectra from surface sediments at site Kerangas 1. Pollen taxa are colour-coded according to life-form. Relative abundance histograms for pollen types representing trees and shrubs are in dark green; those for herbs, epiphytes and climbers are in light green; ferns and lower plants are shown in yellow; aquatics and wetland taxa are in blue. Summary histograms for the various life-forms are shown in corresponding colours comprising the bottom four taxa.

likely derive from the differences in canopy structure and soil surface level microenvironments mentioned above.

### ***Sago Stand 1 (1183m)***

Whilst covering roughly the same area (~500m<sup>2</sup>) as the other 15 sites sampled, site Sago Stand 1 actually comprises three small adjacent sub-areas that are all managed by the same landowner (father of Bulan Radu, one of our Kelabit guides and informants from Bario). The site occupies the steep basal portion of a slope at the toe of the Tama Abu Mountains immediately west of Bario Asal longhouse (Figure 5.1).

The lowest of the three sub-areas at site Sago Stand 1, just above the break in slope with the alluvial plain on which the town of Bario is situated, is currently used as sheep pasture with a few scattered fruit trees (*Mangifera* sp., Anacardiaceae; *Artocarpus odoratissimus* Blanco, Moraceae) (Table 5.11). Previously, this portion of the site supported lower montane forest which was subsequently felled and burnt. Hill padi was then planted, followed by pineapples that were no longer growing on site at the time of our botanical survey. Ground cover on this lowest portion consists mainly of an unidentified grass (Poaceae sp.) and scattered bracken (*Pteridium esculentum* (G.Forst.) Cockayne, Dennstaedtiaceae). At the top of this is a small mixed stand of trees planted 14 years ago to be used for timber. Taxa identified in this portion were: an *Agathis* sp. (Araucariaceae); *Gymnostoma sumatranum* (Jung. ex de Vriese) L.A.S.Johnson (Casuarinaceae); a *Palaquium* sp. (Sapotaceae); and a *Shorea* sp. (Dipterocarpaceae). At the top of site Sago Stand 1 is Bulan Radu's grandfather's managed stand of hill sago palms (Figure 5.20), kept to supply the longhouse with roofing material. This is the largest and most botanically diverse of the three sub-areas so a more detailed description follows.

Substrate at the steeply sloping site Sago Stand 1 consists of orange clays covered by a thin layer of peat. At the time of sampling, this peat was dissected by shallow, ephemeral water-courses that resulted from the previous night's rains, thus exposing the underlying orange clays. Vegetation supported on this upper portion of the site consists of a relatively closed canopy of *Syzygium* sp. (Myrtaceae) with scattered *Eugeissona utilis* Becc. (Arecaceae) and *Pandanus* sp. (Pandanaceae), reaching a height of about 10m. Conspicuous climbers amongst





**Figure 5.20** Dense tangle of climbers, treelets, fronds from *Eugeissona utilis* Becc. hill sago palms amongst medium boles of surrounding secondary lower montane forest at the steeply sloping site Sago Stand 1.

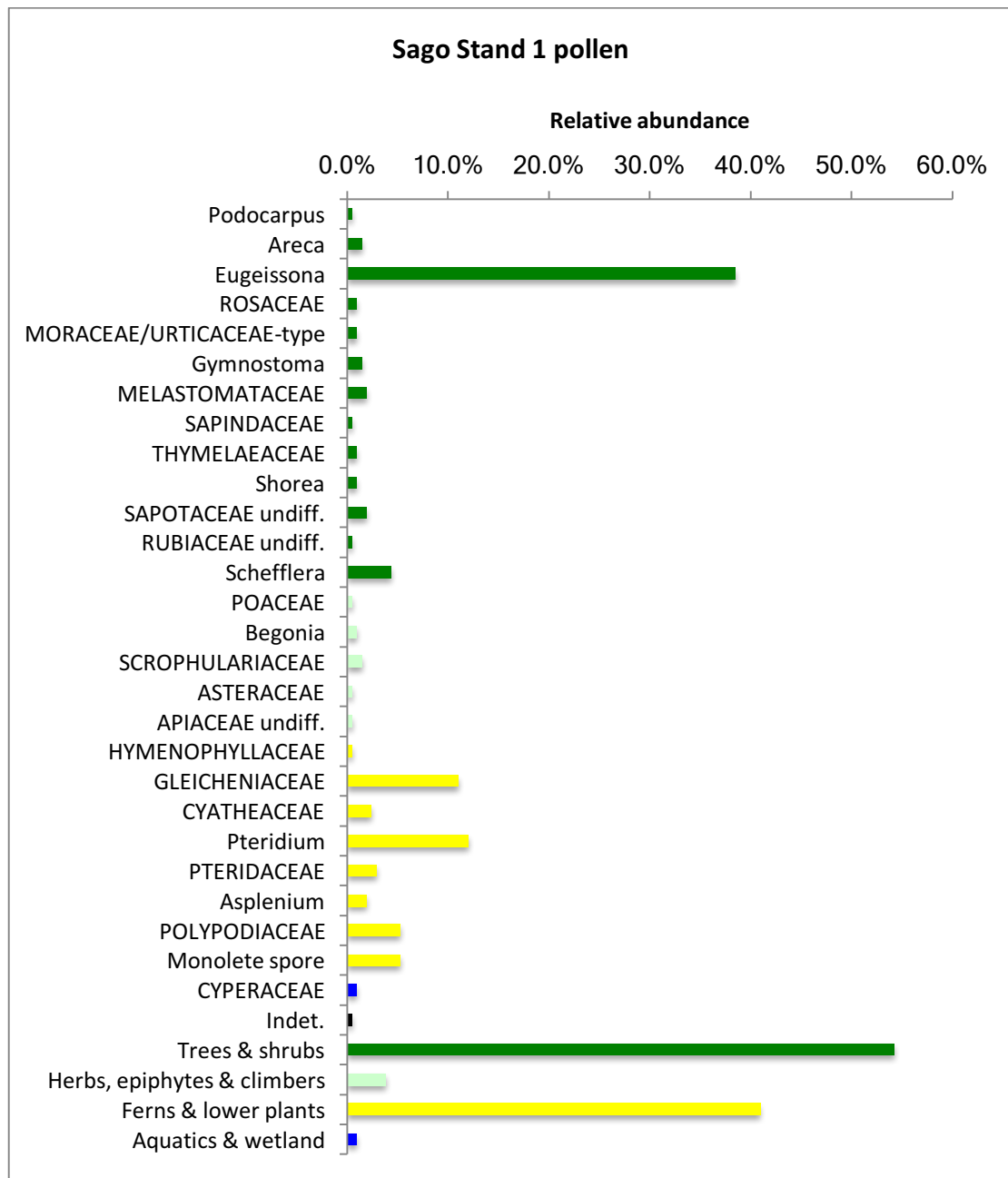
this relatively low, closed canopy were a climbing aroid (*Scindapsus treubii* Engl.) and a *Smilax* sp. (Smilacaceae). Ground cover consists largely of a ginger (Zingiberaceae sp.), a sedge (*Scleria purpurascens* Steud., Cyperaceae), the fern *Selliguea triloba* (Houtt.) ex M.G.Price (Polypodiaceae), and a lycopod (*Lycopodiella cernua* (L.) Pic.Serm.).

The dominant elements of the surface sediment pollen assemblage from site Sago Stand 1 (Figure 5.21) are pollen from hill sago (*Eugeissona*), as well as spores from the open landscape fern taxa *Pteridium* and Gleicheniaceae. In regard to the summary groupings, 'Ferns and lower plants' are well represented (41 per cent of the assemblage), reflecting the abovementioned open landscape taxa combined with a number of minor elements from within the sheltered and moist microenvironment at the soil surface level beneath the relatively closed canopy of the managed sago stand. Another indicator of this moist microenvironment and peaty topsoil layer is the minor representation of a sedge

**Table 5.11** Taxon list from the botanical survey of site Sago Stand 1. Taxa are grouped according to life-form, as denoted by left-hand column.

Sago Stand 1 vegetation		
	Taxon	Family
Trees & shrubs	<i>Agathis</i> sp.	Araucariaceae
	<i>Lindera pipericarpa</i> Boerl.	Lauraceae
	<i>Pandanus</i> sp.	Pandanaceae
	<i>Eugeissona utilis</i> Becc.	Arecaceae
	<i>Artocarpus odoratissimus</i> Blanco	Moraceae
	<i>Ziziphus</i> sp.	Rhamnaceae
	<i>Gymnostoma sumatranum</i> (Jungh. ex de Vriese) L.A.S. Johnson	Casuarinaceae
	<i>Anerincleistus</i> sp.	Melastomataceae
	<i>Melastoma malabathricum</i> L.	Melastomataceae
	<i>Ochthocharis</i> sp.	Melastomataceae
	<i>Syzygium</i> sp.	Myrtaceae
	<i>Mangifera</i> sp.	Anacardiaceae
	<i>Palaquium</i> sp.	Sapotaceae
	<i>Shorea</i> sp.	Dipterocarpaceae
	<i>Eurya acuminata</i> DC.	Pentaphylacaceae
	<i>Ardisia</i> sp.	Primulaceae
Herbs, epiphytes & climbers	<i>Schima wallichii</i> Choisy	Theaceae
	Rubiaceae sp.	Rubiaceae
	<i>Scindapsus treubii</i> Engl.	Araceae
	<i>Smilax</i> sp.	Smilacaceae
	<i>Scleria purpurascens</i> Steud.	Cyperaceae
	Poaceae sp.	Poaceae
Ferns & lower plants	Zingiberaceae sp.	Zingiberaceae
	<i>Hedyotis</i> sp.	Rubiaceae
	Gesneriaceae sp.	Gesneriaceae
	<i>Lycopodiella cernua</i> (L.) Pic.Serm.	Lycopodiaceae
	<i>Pteridium esculentum</i> (G.Forst.) Cockayne	Dennstaedtiaceae
	<i>Selliguea triloba</i> (Houtt.) ex M.G.Price	Polypodiaceae

taxon (Cyperaceae), probably *Scleria purpurascens* that was noted in the botanical survey. One final note of interest is that, within this relatively closed canopy setting, little input from extra-local anemophilous taxa was tallied (ie no pollen from *Dacrydium*, *Dacrycarpus*, or *Castanopsis/Lithocarpus*-type) save for very minor representation of *Podocarpus* (0.5 per cent) and *Gymnostoma* (1.4 per cent).



**Figure 5.21** Modern pollen spectra from surface sediments at site Sago Stand 1. Pollen taxa are colour-coded according to life-form. Relative abundance histograms for pollen types representing trees and shrubs are in dark green; those for herbs, epiphytes, and climbers are in light green; ferns and lower plants are shown in yellow; aquatics and wetland taxa are in blue. Summary histograms for the various life-forms are shown in corresponding colours comprising the bottom four taxa.

### ***Lower Montane Forest (1310m)***

Site Lower Montane Forest is located on the east-facing slopes of the Tama Abu Range just west-northwest from Bario, within a narrow valley incised by a stream flowing off these mountains and into the alluvial landscape of the Bario area. This site is situated along the path from Bario up to an anthropogenic feature in the ridge-top vegetation called the Millennium Kawang (discussed below). We sampled site Lower Montane Forest on our way between sites Sago Stand 1 and Kawang (Figure 5.1). According to Dr Pearce, as indicated by the preponderance of epiphytes and mosses growing on trunks of mature trees (Figure 5.22), the vegetation supported at this site is actually transitional between two climatically controlled vegetation types: lower montane forest (LMF) and upper montane forest (UMF).

Soils at site Lower Montane Forest consist of alluvial clays and silts near the stream channel, with an adjacent moist sandy loam derived from sandstone parent material and decaying vegetal matter from the vegetation growing on site. The vegetation community (Table 5.12) consists of a tall (25-30m) and open canopy (open relative to other patches of lower montane forest observed by Dr Pearce throughout her experience in the Kelabit Highlands) of mature trees of typical LMF associations (Lim, 2006; Pearce, 2006): *Elaeocarpus* sp. (Elaeocarpaceae); *Lithocarpus* sp. (Fagaceae); *Toona sureni* (Blume) Merr. (Meliaceae); and *Shorea platyclados* Slooten ex Endert (Dipterocarpaceae). Many of these canopy trees reached 60cm in diameter at breast height. As mentioned above, a rich epiphyte flora was present, including a number of fern taxa (*Asplenium* sp., *Drynaria quercifolia* (L.) J.Sm., and other unidentified pteridophytes), a couple of pandans (*Freycinetia* sp. and *Pandanus epiphyticus* Martelli), an orchid (Orchidaceae sp.), and a number of mosses and lichens. A distinct understorey was conspicuously absent, whilst ground cover consisted exclusively of herbaceous plants. Taxa represented in this non-woody low-lying stratum include various aroids (*Alocasia* sp. and a couple of unidentified Araceae spp.), a ginger of the genus *Etlingera* Giseke (Zingiberaceae), and an unidentified taxon of the nettle family (Urticaceae sp.; an *Elatostema* sp. and a *Pilea* sp. were noted along the path en route to this site).



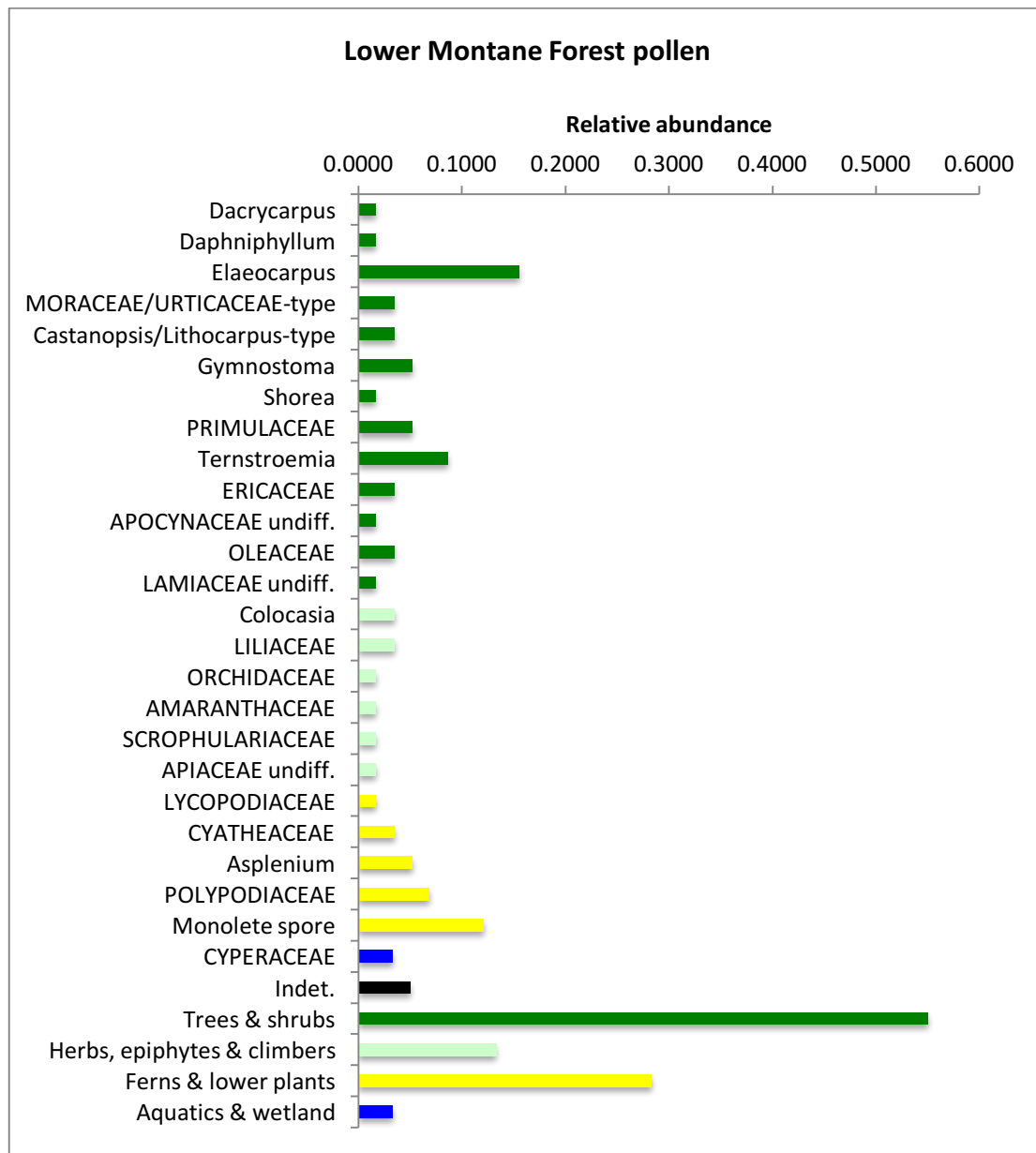


**Figure 5.22** Scattered large trees amongst mainly bole-sized trees forming the relatively open canopy at site Lower Montane Forest. Note the abundance of epiphytes and climbers, as well as exclusively herbaceous ground cover.

The palynological signature of site Lower Montane Forest (Figure 5.23) is characterised by a dominance of pollen from the ‘Trees and shrubs’ summary grouping (55 per cent). An examination of the constituent taxa of this summary grouping reveals that, in addition to the arboreal canopy taxa, many shrubby taxa are represented palynologically despite their absence in the vegetation growing immediately on site. Given the noted openness of the vegetation as well as the patterns observed within the data from other sites supporting open vegetation communities, the presence of pollen from shrubby taxa such as *Ericaceae* and *Ternstroemia* can probably be explained as extra-local inputs from surrounding *kerangas* and true lower montane forest patches. Herbaceous taxa, as well as ferns and lower plants, are quite well represented (13.33 per cent and 28.33 per cent, respectively), which reflect the taxonomic composition of the parent vegetation growing on site. However, in this moist yet relatively open setting, anemophilous taxa seem to be over-represented whilst the largely entomophilous herbaceous ground cover taxa are under-represented.

**Table 5.12** Taxon list from the botanical survey of site Lower Montane Forest. Taxa are grouped according to life-form, as denoted by left-hand column.

Lower Montane Forest vegetation		
	Taxon	Family
Trees & shrubs	Annonaceae sp.	Annonaceae
	<i>Elaeocarpus</i> sp.	Elaeocarpaceae
	<i>Macaranga gigantifolia</i> Merr.	Euphorbiaceae
	<i>Lithocarpus</i> sp.	Fagaceae
	<i>Toona sureni</i> (Blume) Merr.	Meliaceae
	<i>Shorea platyclados</i> Slooten ex Endert	Dipterocarpaceae
	Sapotaceae sp.	Sapotaceae
	<i>Teijsmanniodendron</i> sp.	Lamiaceae
Herbs, epiphytes & climbers	<i>Alocasia</i> sp.	Araceae
	Araceae spp.	Araceae
	<i>Freycinetia</i> sp.	Pandanaceae
	<i>Pandanus epiphyticus</i> Martelli	Pandanaceae
	<i>Curculigo</i> sp.	Hypoxidaceae
	Orchidaceae sp.	Orchidaceae
	<i>Etlingera</i> sp.	Zingiberaceae
	Urticaceae sp.	Urticaceae
	<i>Cyrtandra</i> sp.	Gesneriaceae
Ferns & lower plants	<i>Asplenium</i> sp.	Aspleniaceae
	<i>Drynaria quercifolia</i> (L.) J.Sm.	Polypodiaceae



**Figure 5.23** Modern pollen spectra from surface sediments at site Lower Montane Forest. Pollen taxa are colour-coded according to life-form. Relative abundance histograms for pollen types representing trees and shrubs are in dark green; those for herbs, epiphytes, and climbers are in light green; ferns and lower plants are shown in yellow; aquatics and wetland taxa are in blue. Summary histograms for the various life-forms are shown in corresponding colours comprising the bottom four taxa.

### ***Bukit Kelit (1357m)***

Site Bukit Kelit occupies a ridge top just below a summit of the same name, which rises above the Kelapang river south of the village of Pa' Dalih (Figure 5.1). This site is located off the logging road from Pa' Dalih in the southern Kelabit Highlands down to the coastal town of Miri. We reached the site via an hour's walk up a scrub-covered illegal logging skid track made seven years ago. The ridge top on which the site Bukit Kelit is located is used by the elders of Pa' Dalih as a hunting track and as a local *Agathis* reserve (probably *A. borneensis* Warb., according to Dr Pearce) which is an important source of dammar resin (Christensen, 2002). Similar to site Lower Montane Forest, site Bukit Kelit is of a transitional nature between the lower montane and upper montane forests of Lim (2006) and Pearce (2006).

One reason that Dr Pearce considers the vegetation on site to represent a transitional form between LMF and UMF is the lack of true soil to a considerable depth (greater than ten cm). Instead, the upper substrate into which plants at the site grow is a mixture of fine rootlets and humus. Both Lim (2006) and Pearce (2006) note this feature as characteristic of topsoils into which upper montane forest and upper *kerangas* forest grow at the highest elevations of mountains surrounding the upland plateaux. They attribute this lack of a true soil to the limitation imposed on decay processes by the altitudinal depression in temperature. Another reason to denote this site as transitional is, like at site Lower Montane Forest, the trunks of many of the mature trees house lichens and mosses. Still, site Bukit Kelit supports a 20-30m high canopy of lower montane elements (Figure 5.24) such as *Agathis borneensis* Warb. (Araucariaceae), *Shorea venulosa* G.H.S.Wood ex Meijer (Dipterocarpaceae), and Myrtaceae spp. (probably *Tristaniaopsis* Brongn. & Gris), with an understorey of *Lithocarpus* sp. (Fagaceae), *Syzygium bankense* (Hassk.) Merr. & L.M.Perry (Myrtaceae), and saplings of canopy taxa (Table 5.13). Ground cover consists of three species of arecoid palms (Arecoidae spp.), along with a number of herbaceous plants including a pandan (*Pandanus* sp.), a sedge (*Mapania* sp., Cyperaceae), and a ginger (Zingiberaceae sp.). A number of 'strangler' figs (*Ficus* sp., Moraceae), an Annonaceae sp., and *Schefflera* sp. (Araliaceae) were conspicuous climbers.



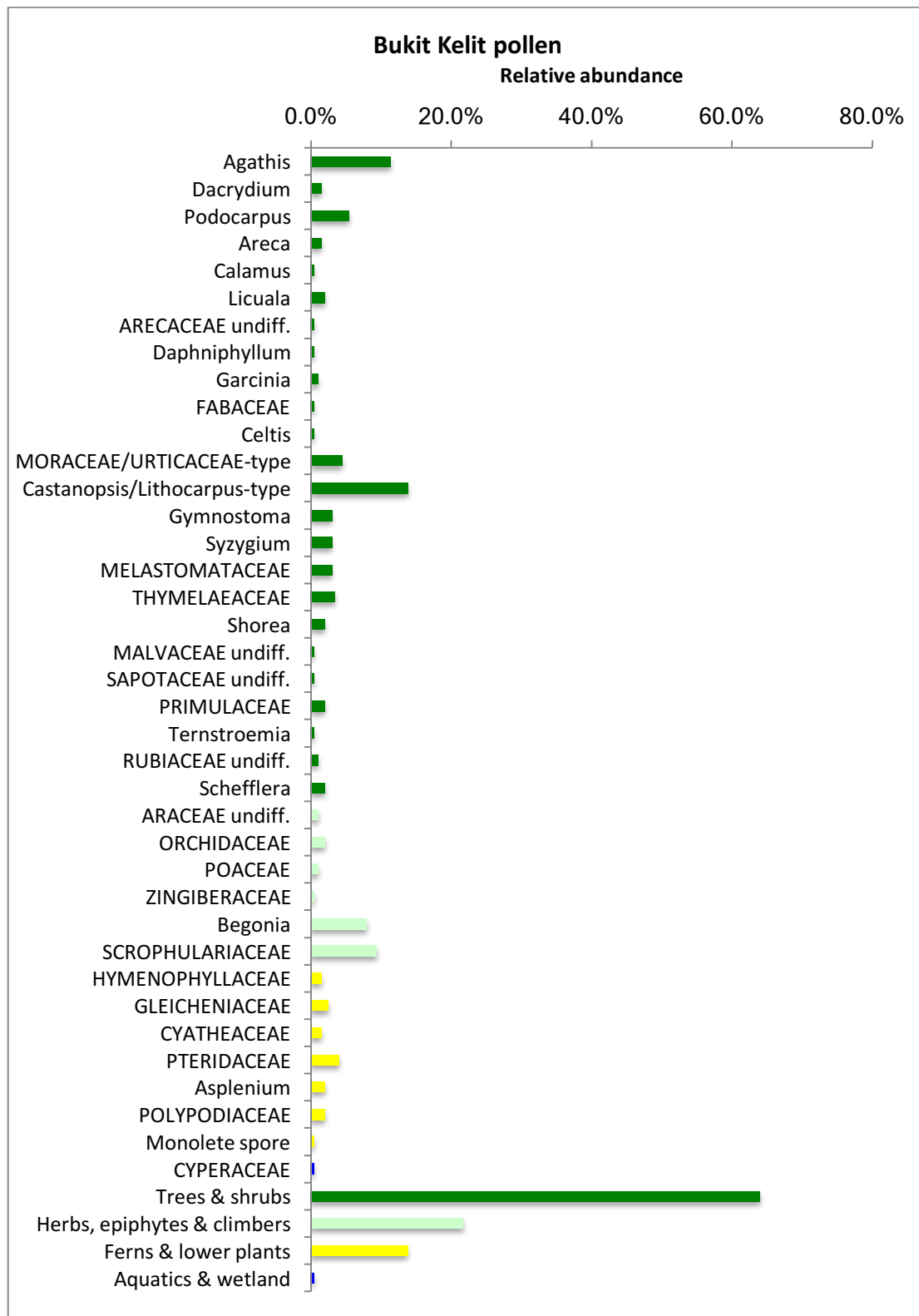


**Figure 5.24** Dr Kit Pearce peering up the trunk of a large mature *Agathis borneensis* Warb. at site Bukit Kelit. Note the abundance of mature trees, thick leaf litter, understorey of saplings, and sparse herbaceous ground cover.

The pollen assemblage from site Bukit Kelit (Figure 5.25) is highly diverse, especially across the ‘Trees and shrubs’ summary grouping. As has been the case at all the forested sites described thus far, this summary grouping is the most abundant within the Bukit Kelit assemblage, at 64 per cent. However, the palynological richness amongst this summary grouping surpasses that from the other forest sites. Wind-pollinated taxa not noted in the botanical survey are represented (ie *Dacrydium*, *Podocarpus*, and *Gymnostoma*) reflecting the somewhat open structure of the vegetation on site, as well as the proximity of *kerangas* and lower montane forest communities. The features of the pollen assemblage that most markedly separate it from that of Lower Montane Forest, though, are: the significant representation of *Agathis* pollen (11.4 per cent of the assemblage) reflecting the presence of trees from that genus in the parent vegetation growing on site; and the much reduced representation of taxa from the ‘Ferns and lower plants’ summary grouping, perhaps reflecting the better drained soil at site Bukit Kelit than at Lower Montane Forest.

**Table 5.13** Taxon list from the botanical survey of site Bukit Kelit. Taxa are grouped according to life-form, as denoted by left-hand column.

<b>Bukit Kelit vegetation</b>		
	<b>Taxon</b>	<b>Family</b>
<b>Trees &amp; shrubs</b>	<i>Agathis borneensis</i> Warb.	Araucariaceae
	<i>Illicium</i> sp.	Schisandraceae
	Lauraceae sp.	Lauraceae
	<i>Pandanus</i> sp.	Pandanaceae
	Arecoideae spp.	Arecaceae
	<i>Calophyllum</i> sp.	Clusiaceae
	<i>Garcinia</i> sp.	Clusiaceae
	<i>Ficus</i> sp.	Moraceae
	<i>Lithocarpus</i> sp.	Fagaceae
	Myrtaceae spp.	Myrtaceae
	<i>Syzygium bankense</i> (Hassk.) Merr. & L.M.Perry	Myrtaceae
	Meliaceae sp.	Meliaceae
	<i>Shorea venulosa</i> G.H.S.Wood ex Meijer	Dipterocarpaceae
	Sapotaceae sp.	Sapotaceae
	<i>Symplocos johniana</i> Stapf.	Symplocaceae
	Theaceae sp.	Theaceae
	<i>Gaertnera</i> sp.	Rubiaceae
<b>Herbs, epiphytes &amp; climbers</b>	Annonaceae sp.	Annonaceae
	<i>Scindapsus glaucescens</i> (Engl. & K.Krause) Alderw.	Araceae
	Orchidaceae sp.	Orchidaceae
	<i>Mapania</i> sp.	Cyperaceae
	Zingiberaceae sp.	Zingiberaceae
	<i>Schradera</i> sp.	Rubiaceae
<b>Ferns &amp; lower plants</b>	<i>Schefflera</i> sp.	Araliaceae
	<i>Dicranopteris linearis</i> (Burm.f.) Underw.	Gleicheniaceae
	<i>Oleandra</i> sp.	Oleandraceae



**Figure 5.25** Modern pollen spectra from surface sediments at site Bukit Kelit. Pollen taxa are colour-coded according to life-form. Relative abundance histograms for pollen types representing trees and shrubs are in dark green; those for herbs, epiphytes, and climbers are in light green; ferns and lower plants are shown in yellow; aquatics and wetland taxa are in blue. Summary histograms for the various life-forms are shown in corresponding colours comprising the bottom four taxa.

### ***Kawang (1434m)***

Highest in elevation of all the 16 sites sampled in the present study, site Kawang is a patch of regrowth on a ridge top in the Tama Abu range west-northwest from Bario along the path that leads to Pa' Tik (Figure 5.26). The patch of regrowth is the result of a localised anthropogenic clearance in the otherwise little-disturbed lower and upper montane forests that occupy these elevations. The site name is the Kelabit word for a notch cut in the forest on a prominent ridge to commemorate an auspicious occasion. This particular *kawang* is called in Bario the Millennium Kawang, and was cut in 2000 to celebrate the turn of the new millennium. *Kawang* are one of many forms of *etuu*, or marks in the landscape which are usually long-lasting and are made intentionally to signify that Kelabit people live in and have altered the landscape, and therefore have the right to use the land and its resources (Janowski & Langub, 2011). Ecologically, this site is little different to a swidden clearance for hill paddy, except that the land has not been subsequently planted with crops.

The thin, silty loam soils at site Kawang support a ground cover of regrowth taxa consisting primarily of an unidentified prostrate grass and bracken (*Pteridium esculentum* (G.Forst.) Cockayne) on the gently sloping ridge top (Table 5.14). Lower down, where the gradient steepens and the vegetation grades into lower montane forest that escaped the effects of the chainsaw, a *Globba* sp. (Zingiberaceae), *Piper* sp. (Piperaceae), a rattan (Calamoideae sp.), *Vernonia arborea* Buch.-Ham. (Asteraceae), and *Macaranga gigantifolia* Merr. (Euphorbiaceae) occur. Beyond this is typical lower montane forest with a canopy of two arboreal taxa of the family Annonaceae (*Goniothalamus* sp. and an unidentified taxon), two trees of the Lauraceae (a *Cinnamomum* sp. and an unidentified taxon), *Lithocarpus* sp. (Fagaceae), and *Palaquium* sp. (Sapotaceae), as well as a *Syzygium* sp. (Myrtaceae) in the understorey.

Palynologically, this vegetation leaves a different signature than is expected (Figure 5.27). Grass pollen (Poaceae) is only a very minor component of the assemblage (2.4 per cent), whilst grains of the *Castanopsis/Lithocarpus*-



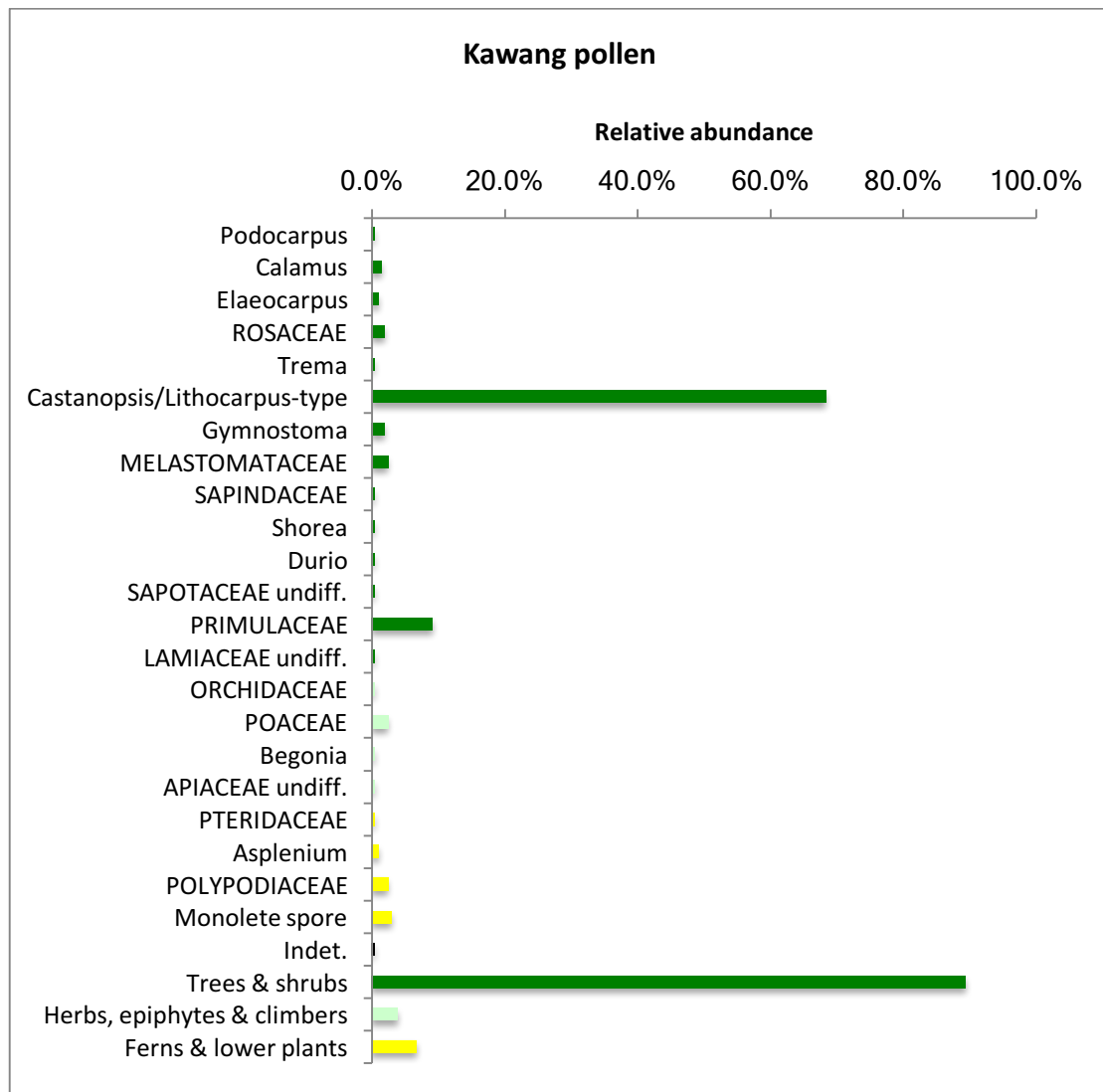
**Figure 5.26** Anthropogenic clearing at site Kawang on a ridge in the Tama Abu overlooking the town of Barrio from the west. Vegetation in the clearing itself dominated by pioneering species, whilst surrounding communities reflect the site's elevation near the upper extent of lower montane forest.

type dominate (68.3 per cent). Not a single pollen grain from the family Asteraceae was tallied despite the occurrence of many large *Vernonia arborea* in the vegetation growing immediately on site, and despite the ubiquity of pollen produced by taxa of that family. However, the dominance of *Castanopsis/Lithocarpus*-type pollen combined with minor representation of extra-local anemophilous taxa (*Podocarpus* and *Gymnostoma*), disturbance indicators (*Trema*, Melastomataceae, and Primulaceae (probably *Ardisia*)), as well as lower montane forest elements (*Elaeocarpus*, Sapindaceae, *Shorea*, *Durio*, and Sapotaceae undiff.), distinguish this assemblage as derived from an open patch of disturbed lower montane forest surrounded by intact forest.

**Table 5.14** Taxon list from the botanical survey of site Kawang. Taxa are grouped according to life-form, as denoted by left-hand column.

<b>Kawang vegetation</b>		
	<b>Taxon</b>	<b>Family</b>
<b>Trees &amp; shrubs</b>	Annonaceae sp.	Annonaceae
	<i>Goniothalamus</i> sp.	Annonaceae
	<i>Cinnamomum</i> sp.	Lauraceae
	Lauraceae sp.	Lauraceae
	Calamoideae sp.	Arecaceae
	<i>Ploiarium</i> sp.	Bonnetiaceae
	<i>Macaranga gigantifolia</i> Merr.	Euphorbiaceae
	<i>Flacourtia</i> sp.	Salicaceae
	<i>Lithocarpus</i> sp.	Fagaceae
	<i>Syzygium</i> sp.	Myrtaceae
	<i>Palaquium</i> sp.	Sapotaceae
	<i>Vernonia arborea</i> Buch.-Ham.	Asteraceae
<b>Herbs, epiphytes &amp; climbers</b>	<i>Piper</i> sp.	Piperaceae
	<i>Globba</i> sp.	Zingiberaceae





**Figure 5.27** Modern pollen spectra from surface sediments at site Kawang. Pollen taxa are colour-coded according to life-form. Relative abundance histograms for pollen types representing trees and shrubs are in dark green; those for herbs, epiphytes, and climbers are in light green; ferns and lower plants are shown in yellow. Summary histograms for the various life-forms are shown in corresponding colours comprising the bottom three taxa.

**\*Pa' Dalih Orchard (985m)**

Site Pa' Dalih Orchard is a grove of fruit trees (Figure 5.28) just behind the longhouse on the edge of the southern Kelabit village of Pa' Dalih. The site is adjacent to the Kelapang river which flows just east of the settlement. This orchard is the locale from which Samantha Jones extracted her PDH 223 core (Jones, 2012) during her PhD research a few years prior to our sampling for the present study.



**Figure 5.28** Open grove of fruit trees comprising site Pa' Dalih Orchard, on the southern fringe of the village of Pa' Dalih just off the path to the disused missionary airstrip. The Pa' Kelapang immediately to the east and wet padi to the west surround the site. This is the locale of Jones' (2013) PDH 223.

Soil at the site consists of an alluvial clay loam. Cultivated fruit trees form an open canopy about 10m high with bole diameters at breast height ~20-30cm. Significant fruit tree taxa noted were: *Artocarpus odoratissimus* Blanco (Moraceae); *Dimocarpus longan* subsp. *malesianus* Leenh. (Sapindaceae); *Baccaurea macrocarpa* (Miq.) Müll.Arg. (Phyllanthaceae); *Nephilium ramboutanake* (Labill.) Leenh. (Sapindaceae); and two species of durian (*Durio zibethinus* L.,



**Table 5.15** Taxon list from the botanical survey of site Pa' Dalih Orchard. Taxa are grouped according to life-form, as denoted by left-hand column.

Pa' Dalih Orchard vegetation		
	Taxon	Family
Trees & shrubs	Euphorbiaceae sp.	Euphorbiaceae
	<i>Baccaurea macrocarpa</i> (Miq.) Müll.Arg.	Phyllanthaceae
	<i>Carallia</i> sp.	Rhizophoraceae
	Fabaceae sp.	Fabaceae
	<i>Pueraria</i> sp.	Fabaceae
	<i>Artocarpus odoratissimus</i> Blanco	Moraceae
	<i>Ficus</i> spp.	Moraceae
	Urticaceae sp.	Urticaceae
	<i>Lithocarpus</i> sp.	Fagaceae
	<i>Melastoma</i> sp.	Melastomataceae
	<i>Syzygium</i> spp.	Myrtaceae
	<i>Turpinia</i> sp.	Staphyleaceae
	<i>Mangifera</i> sp.	Anacardiaceae
	<i>Clausena excavata</i> Burm.f.	Rutaceae
	<i>Melicope</i> sp.	Rutaceae
	<i>Dimocarpus longan</i> subsp. <i>malesianus</i> Leenh.	Sapindaceae
	<i>Nephelium ramboutan-ake</i> (Labill.) Leenh.	Sapindaceae
	<i>Durio graveolens</i> Becc.	Malvaceae
	<i>Durio zibethinus</i> L.	Malvaceae
	<i>Barringtonia</i> sp.	Lecythidaceae
	Rubiaceae sp.	Rubiaceae
Herbs, epiphytes & climbers	<i>Alocasia</i> sp.	Araceae
	<i>Curculigo</i> sp.	Hypoxidaceae
	<i>Isachne</i> sp.	Poaceae
	<i>Phrynium maximum</i> Blume	Marantaceae
	Zingiberaceae sp.	Zingiberaceae
	<i>Tetracera</i> sp.	Dilleniaceae
	<i>Urena lobata</i> L.	Malvaceae
	<i>Elephantopus scaber</i> L.	Asteraceae
Ferns & lower plants	<i>Diplazium esculentum</i> (Retz.) Sw.	Athyriaceae
	<i>Nephrolepis biserrata</i> (Sw.) Schott	Nephrolepidaceae
Aquatics & wetland	<i>Scleria</i> sp.	Cyperaceae

the widely cultivated species; and *D. graveolens* Becc., a wild species native to these highland forests and which produces sought-after fruit) (Table 5.15). Beneath this edible canopy, an understorey of common alluvial and lower montane forest, as well as pioneer, taxa occur (ie *Carallia* sp., Rhizophoraceae; *Ficus* spp., Moraceae; *Lithocarpus* sp., Fagaceae; *Barringtonia* sp., Lecythidaceae; and *Melicope* sp., Rutaceae). The herbaceous ground cover was dominated by a grass species of the genus *Isachne* R.Br., as well as the fern *Nephrolepis biserrata* (Sw.) Schott. Also noted were scattered occurrences of *Alocasia* sp. (Araceae), *Urena lobata* L. (Malvaceae), and the widespread weed *Elephantopus scaber* L. (Asteraceae).

***\*Ruma Ma'on Dakah (1000m)***

Site Ruma Ma'on Dakah (Figure 5.29) is one of many sites of previous Kelabit longhouse settlements scattered throughout the highlands (Lloyd-Smith *et al.*, 2013), next to which remain fruit trees that had been planted when the site was in use. Combined with oral histories alluding to the past use of this site, it is indeed also the presence of a few select taxa of fruit trees that identify this site as the location of a former longhouse.



**Figure 5.29** Vegetation at site Ruma Ma'on Dakah, comprising mature alluvial forest with planted and previously cultivated fruit trees scattered throughout. Note the open structure and herbaceous ground cover.

It is unfortunate that neither site Pa' Dalih Orchard nor site Ruma Ma'on Dakah produced usable pollen assemblages. Complete datasets from these two sites would have provided for an interesting comparison, with the potential to shed light on the diachronic evolution of the palynological signature of a specific land use system. Both sites occupy nearly identical physiographic settings, situated as they are on low terrace-like formations adjacent to active river floodplains. However, it is probably owing to this physiography that

Table 5.16 Taxon list from the botanical survey of site Ruma Ma'on Dakah. Taxa are grouped according to life-form, as denoted by left-hand column.

Ruma Ma'on Dakah vegetation		
	Taxon	Family
Trees & shrubs	Lauraceae sp.	Lauraceae
	<i>Pandanus</i> sp.	Pandanaceae
	<i>Calamus</i> spp.	Arecaceae
	<i>Eugeissona utilis</i> Becc.	Arecaceae
	<i>Helicia robusta</i> R.Br. ex Blume	Proteaceae
	<i>Garcinia</i> sp.	Clusiaceae
	Euphorbiaceae sp.	Euphorbiaceae
	<i>Macaranga</i> sp.	Euphorbiaceae
	<i>Carallia</i> sp.	Rhizophoraceae
	Fabaceae sp.	Fabaceae
	<i>Artocarpus odoratissimus</i> Blanco	Moraceae
	<i>Ficus</i> sp.	Moraceae
	<i>Lithocarpus</i> sp.	Fagaceae
	<i>Syzygium</i> spp.	Myrtaceae
	<i>Camptosperma</i> sp.	Anacardiaceae
	<i>Mangifera foetida</i> Lour.	Anacardiaceae
	<i>Semecarpus</i> sp.	Anacardiaceae
	<i>Chisocheton</i> sp.	Meliaceae
	Meliaceae sp.	Meliaceae
	<i>Dimocarpus longan</i> subsp. <i>malesianus</i> Leenh.	Sapindaceae
	<i>Durio zibethinus</i> L.	Malvaceae
	<i>Saurauia</i> sp.	Actinidiaceae
	<i>Symplocos</i> sp.	Symplocaceae
	Theaceae sp.	Theaceae
Herbs, epiphytes & climbers	<i>Piper</i> sp.	Piperaceae
	<i>Curculigo</i> sp.	Hypoxidaceae
	<i>Isachne</i> sp.	Poaceae
	<i>Pseudechinolaena</i> sp.	Poaceae
	<i>Setaria palmifolia</i> (J.Koenig) Stapf	Poaceae
	Zingiberaceae spp.	Zingiberaceae
	Vitaceae sp.	Vitaceae
Ferns & lower plants	<i>Selaginella</i> sp.	Selaginellaceae
Aquatics & wetland	<i>Scleria</i> sp.	Cyperaceae

modern pollen rain is not preserved in the surface soils for any significant length of time. The botanical taxon list from site Ruma Ma'on Dakah (Table 5.16) is not markedly different to that of site Pa' Dalih Orchard. Key fruit tree taxa which signify the site's history are: *Artocarpus odoratissimus* Blanco (Moraceae); *Mangifera foetida* Lour. (Anacardiaceae); *Dimocarpus longan* subsp. *malesianus* Leenh. (Sapindaceae); and *Durio zibethinus* L. (Malvaceae).



**\*Alluvial Forest 2 (1072m)**

Site Alluvial Forest 2 occupies an undulating floodplain adjacent to and about six metres above the Dappur River on the southern edge of the cluster of ten sites in the northern portion of the study area near Bario (Figure 5.1). The site supports a fairly open alluvial forest vegetation community. Canopy height is ~15-16m, with an understorey of scattered trees and a dense herbaceous ground flora (Figure 5.30). Soil at this site consists of a moist, organic-rich loam with a sandy alluvium component.



**Figure 5.30** Patch of open gallery forest comprising site Alluvial Forest 2. Similar to other sites sampled which support alluvial forest communities, the canopy is open and ground cover is comprised of herbaceous plants and ferns.

Typical riparian taxa of the genera *Syzygium* Gaertn. (Myrtaceae) and *Carallia* Roxb. (Rhizophoraceae), alongside an unidentified Meliaceae sp., a *Sterculia* sp. (Malvaceae), and *Symplocos fasciculatus* Zoll. (Symplocaceae) comprise the canopy (Table 5.17). Understorey components recorded were a *Saurauia* sp. (Actinidiaceae), *Pandanus* sp. (Pandanaceae), an arecoid palm (Arecoideae sp.), *Helicia robusta* (Roxb.) R.Br. ex Blume (Proteaceae), as well as

**Table 5.17** Taxon list from the botanical survey of site Alluvial Forest 2. Taxa are grouped according to life-form, as denoted by left-hand column.

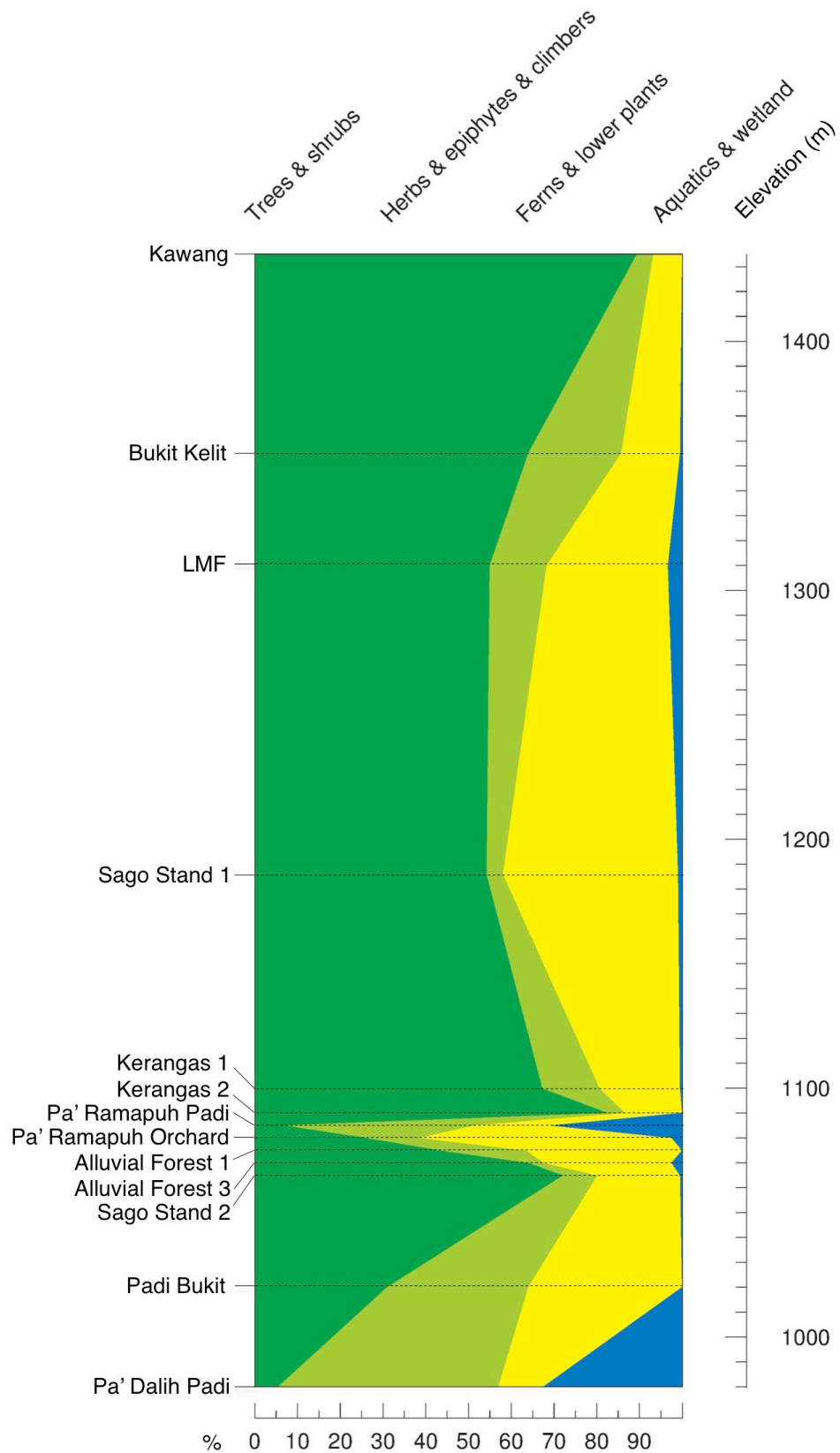
<b>Alluvial Forest 2 vegetation</b>		
	<b>Taxon</b>	<b>Family</b>
<b>Trees &amp; shrubs</b>	<i>Pandanus</i> sp.	Pandanaceae
	<i>Arecoideae</i> sp.	Arecaceae
	<i>Helicia robusta</i> (Roxb.) R.Br. ex Blume	Proteaceae
	<i>Garcinia</i> sp.	Clusiaceae
	<i>Euphorbiaceae</i> sp.	Euphorbiaceae
	<i>Carallia</i> sp.	Rhizophoraceae
	<i>Rinorea</i> sp.	Violaceae
	<i>Syzygium</i> sp.	Myrtaceae
	<i>Meliaceae</i> sp.	Meliaceae
	<i>Sterculia</i> sp.	Malvaceae
	<i>Saurauia</i> sp.	Actinidiaceae
	<i>Symplocos fasciculata</i> Zoll.	Symplocaceae
	<i>Gordonia</i> sp.	Theaceae
	<i>Rubiaceae</i> spp.	Rubiaceae
<b>Herbs, epiphytes &amp; climbers</b>	<i>Dioscorea</i> sp.	Dioscoreaceae
	<i>Smilax</i> sp.	Smilacaceae
	<i>Orchidaceae</i> sp.	Orchidaceae
	<i>Poaceae</i> sp.	Poaceae
	<i>Etlingera</i> spp.	Zingiberaceae
	<i>Tetracera</i> sp.	Dilleniaceae
	<i>Vitaceae</i> sp.	Vitaceae
	<i>Pueraria</i> sp.	Fabaceae
	<i>Ficus</i> sp.	Moraceae
	<i>Rubus</i> sp.	Rosaceae
<b>Ferns &amp; lower plants</b>	<i>Scrophulariaceae</i> sp.	Scrophulariaceae
	<i>Selaginella</i> sp.	Selaginellaceae
<b>Aquatics &amp; wetland</b>	<i>Scleria</i> sp.	Cyperaceae

multiple shrubby *Rubiaceae* spp. The herbaceous ground cover was dominated by gingers (*Etlingera* spp., Zingiberaceae), a *Selaginella* sp. (Selaginellaceae), and a sedge of the genus *Scleria* P.J.Bergius (Cyperaceae), whilst a number of climbers were also recorded (*Dioscorea* sp., Dioscoreaceae; *Smilax* sp., Smilacaceae; *Tetracera* sp., Dilleniaceae; a *Vitaceae* sp.; *Pueraria* sp., Fabaceae). Compositionally, the vegetation at site Alluvial Forest 2 is more similar to that at site Alluvial Forest 3 than at Alluvial Forest 1. This relationship undoubtedly reflects the degrees of disturbance at each of these sites, as site Alluvial Forest 1 was by far the most impacted (human footpaths and buffalo trample throughout) of the alluvial forest sites.

### 5.2.2 *Surface sediment samples*

As the palynological assemblages from the 13 pollen-yielding sites of the 16 sites sampled have been presented individually above, this subsection will treat those 13 assemblages in aggregate as an entire dataset. A summary diagram is presented first, with the 13 usable assemblages arranged by elevation from lowest at the base to highest at the top. Certain patterns are visible in these data when arranged in such a manner, relating to the effect of temperature upon vegetation as well as the altitudinal concentration of modern human activity. An additional summary diagram of these same data is then presented, this time with the sites arranged along the qualitatively assessed gradient in land use intensity, thus revealing additional patterns and insights. Graphical representations of multivariate statistical comparisons between assemblages are then presented in the forms of: a dichotomously branching dendrogram; and a principal component analysis (PCA) plot. The dendrogram provides justification for grouping similar assemblages into clusters, whilst the PCA aids in explaining given variables' importances to the structure and patterning in the data. This section concludes with comments on how this modern dataset can aid in interpretation of fossil palynological sequences.

When the summary pollen data from the 13 modern sites that yielded usable assemblages are arranged according to the elevation of the site from which they come (Figure 5.31), a couple of general patterns can be observed. Firstly, the sites are not evenly distributed across the elevation range that they collectively span. Whilst all of the sites occur within the 900-1800m elevation band corresponding to climatically controlled lower montane forest (Lim, 2006; Pearce, 2006), nine of the 13 sites (69.2 per cent) occur within the lowest 121 of the 457m (26.5 per cent) total altitudinal range sampled. This largely reflects the elevations of the bases from which sampling trips embarked (the settlements of Bario and Pa' Dalih) and of the altitudinal concentration of modern settlements which largely occupy the lower-lying alluvial floodplains of the plateau drainages. Secondly, the wet rice paddy sites (Pa' Dalih Padi and Pa' Ramapuh Padi) form marked breaks in otherwise relatively smooth curves, namely in

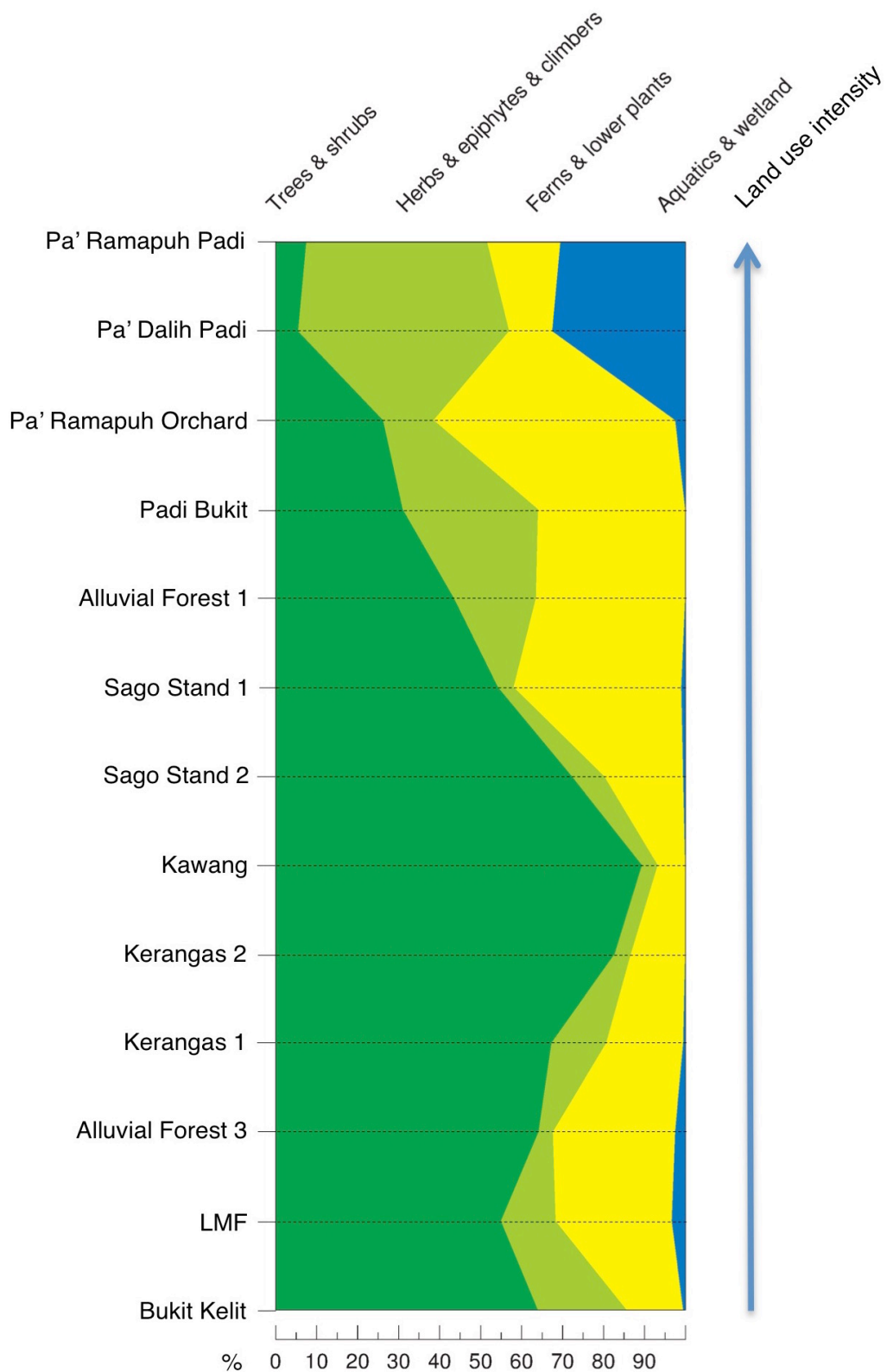


**Figure 5.31** Summary diagram for the 13 pollen-bearing surface sample assemblages. Vertical axis represents elevation; relative abundances (%) are shown along the horizontal axis. Summary groupings are colour-coded: Trees and shrubs – dark green; Herbs – light green; Ferns – yellow; Aquatics – blue.

relation to those sites' abundance of pollen from 'Aquatics and wetland' taxa and scarcity of pollen from the 'Trees and shrubs' summary grouping. In general, though, the trends visible when the data are displayed in such a manner are not very clear.

When the same summary data are displayed along a qualitatively assessed gradient in land use intensity (Figure 5.32), relative abundance of pollen from the 'Trees and shrubs' summary grouping is revealed to be a reasonable proxy for land use intensity, exhibiting a negative correlation. Two primary factors were considered in the qualitative assessments of land use intensities at each site, based upon accounts from local informants: degree of vegetation modification; and duration of that human intervention in normal plant growth processes. Degrees of modification encompass: wholesale clearance (as in the paddy fields and site Kawang), selective harvesting of entire individuals (as in the *Agathis* and dipterocarps from forests surrounding sites Kerangas 1 and Alluvial Forest 3, respectively, logged for timber), as well as harvesting of plant parts whilst leaving individual plants intact (as in harvesting from fruit trees at site Pa' Ramapuh Orchard and from other sites, as well as harvesting of vegetable 'cabbages' from various fern and angiosperm taxa). Duration of human intervention ranges from: a one-off clearance of forest from site Kawang with no continued modification to vegetation; through swidden clearance at site Padi Bukit followed by continued harvesting of various plant resources of the different seral stages through which the regrowth passes; through to maintenance of an open and cultivated landscape, as at the wet rice paddy sites. Placed qualitatively along a gradient in land use intensity using these factors, the upper eight sites as displayed in Figure 5.32 (Kawang up through Pa' Ramapuh Padi) represent the sites characterised by increasing human impact. The lower five sites (Kerangas 2 down through Bukit Kelit) represent the 'natural' vegetation communities sampled, organised according to observations relating to human impact on nearby forest. Relative abundances of the different summary groupings within the pollen assemblages from this latter





**Figure 5.32** Summary diagram of assemblages from the 13 pollen-yielding surface samples. Sites are arranged along a y-axis that represents a gradient in land use intensity, assessed qualitatively. The order in which sites are placed along this gradient is significant; spacing between sites is not.

subset of sites reflect edaphic differences rather than human modification of vegetation.

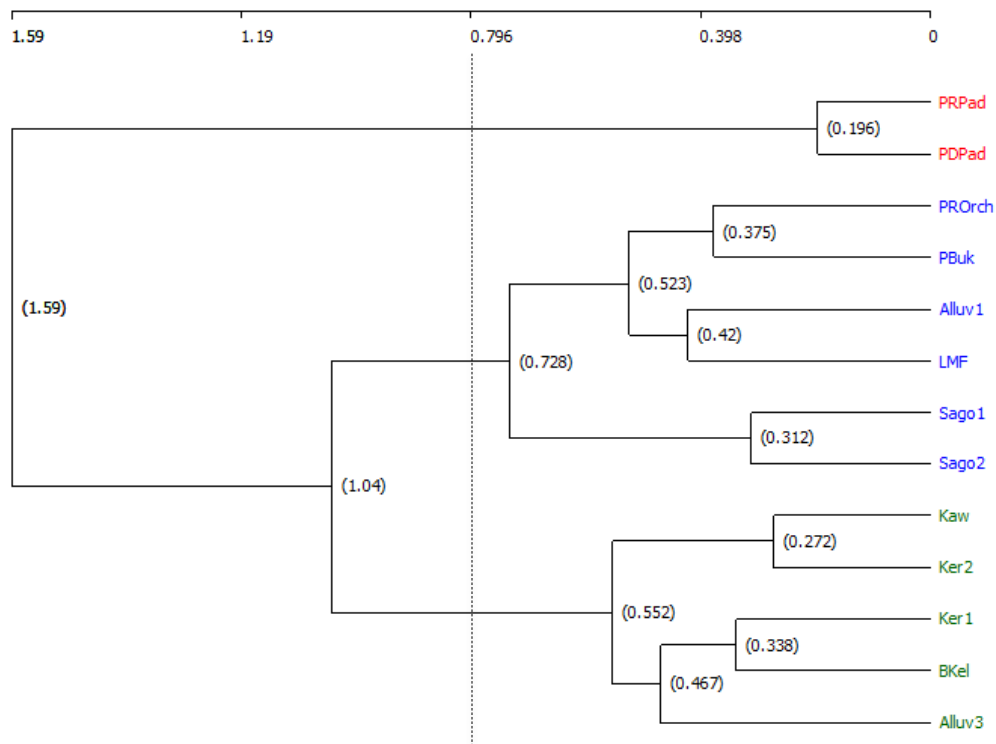
### **5.2.3 Multivariate statistics**

The following two subsections provide empirical clarification of the internal structure within the modern pollen dataset that previously has been described either as individual sites in isolation or in qualitative terms. Much like with the summary diagrams presented above, graphical results of the clustering analysis and principal component analysis plot enable the dataset to be viewed in its entirety, thus facilitating inter-site comparisons and multi-taxa ecological interpretations.

#### ***Clustering***

A Ward's hierarchical agglomerative clustering analysis (Ward, 1963) was performed on the dataset comprising the 13 pollen assemblages that have been presented individually and in summary in the previous sections of this chapter. A Bray-Curtis similarity measure for inter-site comparisons was selected based upon clarity of output amongst iterative trials of a number of different options provided within PISCES Conservation Ltd.'s Community Analysis Package 5.0 software (Seaby *et al.*, 2014).

The dendrogram output from the clustering analysis is presented in Figure 5.33. A dotted line appears at the midway point (0.796) of the range of Bray-Curtis similarity scores between pairs of sites across the dataset. This line is used as an arbitrary cut-off to define groupings of sites that bear similar pollen assemblages. The branchings to the left of this line, corresponding to nodes with similarity scores greater than 0.796, define the three primary groups of sites; branchings to the right of this line describe intra-group relationships. Abbreviated site names appear along the right side of Figure 5.33 at the end of their respective terminal branches. These site name abbreviations are colour-coded according to the site groupings just described. These same colour-coded groupings are used again in the principal component analysis plot in the following sub-section.



**Figure 5.33** Dendrogram output of Ward's hierarchical agglomerative clustering analysis on the 13 surface sediment pollen assemblages from the Kelabit Highlands. Bray-Curtis similarity scores are shown in brackets to the right of corresponding nodes. Colour-coded groups are defined by all adjacent samples connected by a node with Bray-Curtis score <0.796 (50 per cent of range of similarity scores across dataset). Abbreviations: "PRPad" – Pa' Ramapuh Padi; "PDPad" – Pa' Dalih Padi; "PROrch" – Pa' Ramapuh Orchard; "PBuk" – Padi Bukit; "Alluv1" – Alluvial Forest 1; "LMF" – Lower Montane Forest; "Sago1" – Sago Stand 1; "Sago2" – Sago Stand 2; "Kaw" – Kawang; "Ker2" – Kerangas 2; "Ker1" – Kerangas 1; "Bkel" – Bukit Kelit; "Alluv3" – Alluvial Forest 3.

Two aspects of the dendrogram (Figure 5.33) merit special notes. Firstly, the independently derived and empirically generated order of the sites within and across groupings largely mirrors that of the qualitatively assessed position of each site along the land use intensity gradient as presented in Figure 5.32. This result provides quantitative support for those land use intensity assessments. Secondly, with one exception (site Lower Montane Forest, or "LMF"), the groupings of similar pollen assemblages align with similarities in ecologies and land use histories as recorded in the field and described within the individual site treatments. This supports the implicit claim that the arbitrarily placed cut-off at the midpoint of the range of Bray-Curtis similarity scores across the dataset has real world ecological meaning. The uppermost grouping, comprising the two rice paddy sites (denoted by red abbreviated site names), represents the most intense land use, with pollen assemblages distinct from those from the other 11 sites. The middle group (denoted by blue abbreviated

site names), comprising six sites, exhibits a gradient in degree of human modification from highest at the top (“PROrch”) to lowest at the bottom (“Sago2”). The basal group of five sites, shown with green abbreviated site names, can be conceptualised as the sites supporting ‘natural’ vegetation types. Based upon the qualitative assessments of land use intensity presented in the previous section, site Lower Montane Forest is placed amongst this final group of ‘natural’ sites. This singular mismatch between the qualitative and quantitative assessments in the case of this particular site could reflect: an artefact of the occurrence of wind-pollinated plants in the vegetation growing on site at LMF, whilst the palynological representations of anemophilous taxa in assemblages from other sites mark artificial opening of on-site vegetation combined with extra-local pollen sources; or, an error in the qualitative assessment of the land use intensity at site Lower Montane Forest, as no local informant was present during sampling of this particular site.

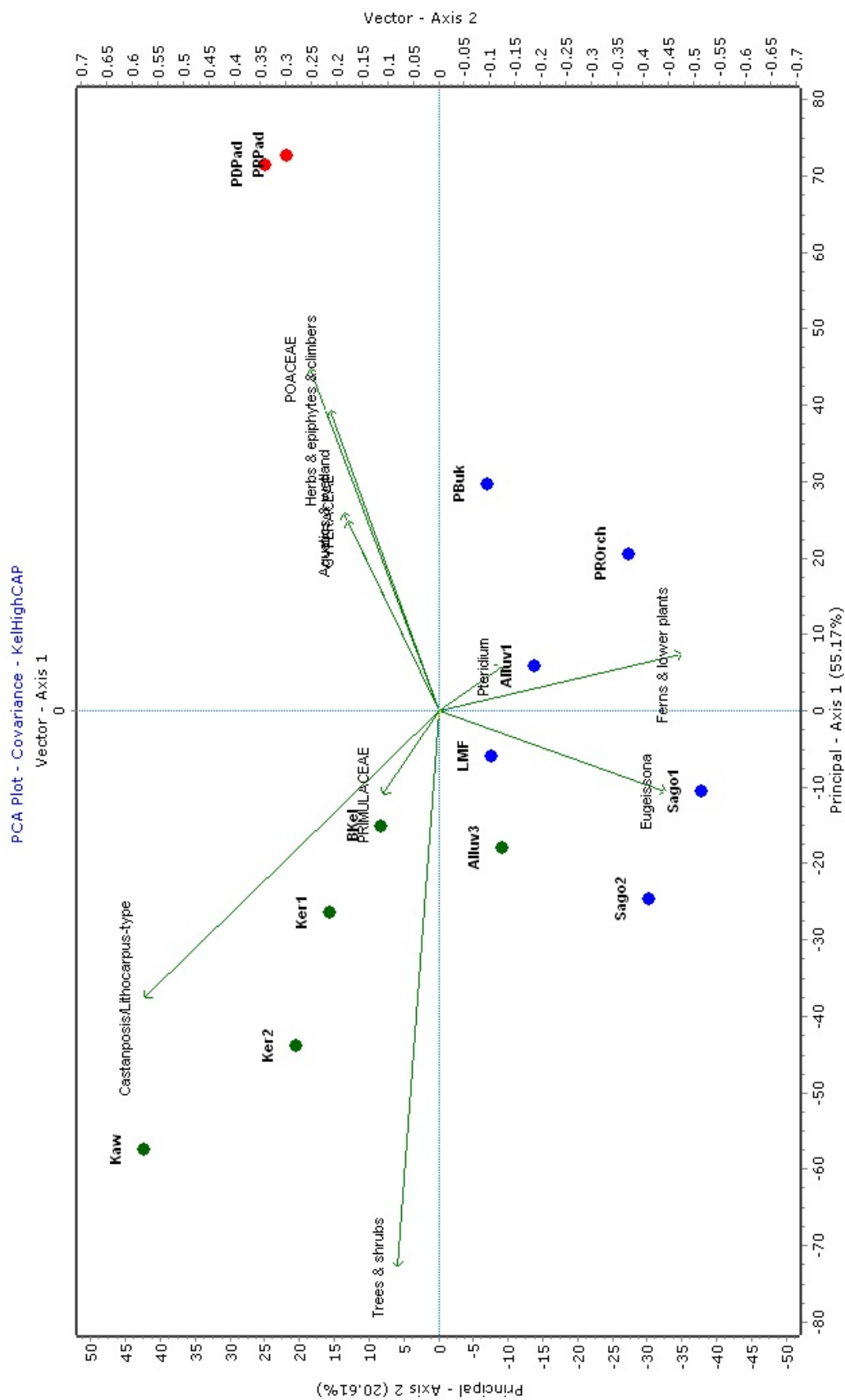
### ***Ordination***

Principal component analysis (PCA) provides an alternative graphical representation of patterns within the multivariate dataset comprising the 13 usable multi-taxa pollen assemblages from the suite of sites sampled. PCA is one of the oldest and most frequently used methods of multivariate ordination for community ecology datasets (Seaby and Henderson, 2014). Its purposes are to graphically represent in multidimensional space the relationships between samples and to offer suggestions as to which variables might have the most explanatory power for describing those relationships. In the case of the present study, output of the PCA is plotted in two-dimensional space whose axes are defined not by tangible characteristics or variables, but rather by abstract statistical measures relating to patterns of variance amongst the individual variables and between samples. Samples here refer to surface sediment pollen assemblages; variables refer to the constituent pollen taxa that make up those assemblages, expressed in terms of their relative abundances.

In the PCA plot presented here (Figure 5.34), each of the 13 pollen assemblages appear as filled circles of the colour corresponding to the same

groups as described above in the clustering analysis. Site name abbreviations appear in bold black text above the corresponding circle. Green vectors radiating outward from the Cartesian origin represent the explanatory power of individual pollen taxa in driving the relationships between assemblages from different sites. The length and direction of these vectors is significant. Longer vectors have more explanatory power than shorter ones; and the component of any given vector that is parallel to either axis represents the magnitude of influence of the variable represented by that vector upon the placement of a given sample along that axis. For example, in Figure 5.18, the ‘Trees and shrubs’ vector is long, nearly parallel to Axis 1 (which, as stated in brackets in the axis title, describes 55.17 per cent of the variance in the data), and orientated in a direction corresponding to negative values along that axis. Therefore, a given site’s relative abundance of pollen from ‘Trees and shrubs’ is inversely proportional to where that site is placed along Axis 1 in the PCA plot presented here.

The two wet rice paddy sites, Pa’ Dalih Padi (“PDPadi”) and Pa’ Ramapuh Padi (“PRPadi”), comprise Group 1 and are colour-coded with red circles. The assemblages from these sites plot in the upper-right quadrant of the PCA diagram in Figure 5.34, with moderate length vectors corresponding to “Poaceae”, “Herbs, epiphytes, and climbers”, “Cyperaceae”, and “Aquatics and wetland” pointing towards these samples. This suggests that the pollen assemblages from the wet paddy sites are distinct from the remaining 11 assemblages, and that that distinctiveness is driven by their relative abundances of pollen from plants that are common to and diagnostic of this decidedly anthropogenic landscape (ie grasses and sedges). Group 2, the constituent assemblages from which are shown with blue circles, are somewhat diffusely spread around the zero point along Axis 1 whilst slightly below zero with respect to Axis 2. These sites comprise the remaining sites that have been impacted to varying degrees by humans and/or their livestock. Three vectors point in the general direction of this diffuse cluster, with the primary component of each paralleling Axis 2. The vector representing “*Eugeissona*” is the longest and, unsurprisingly, points between the two sites described as managed stands of sago. The “Ferns and lower plants” summary taxon also appears to have



**Figure 5.34** PCA plot of the thirteen Kelabit Highlands surface sediment pollen assemblages. Sites' assemblages are represented by filled circles, colour-coded by group and labelled above; important pollen taxa are shown as vectors. Axis 1 describes 55.17% of the variance, whilst Axis 2 encompasses 20.61%.

significant explanatory power in describing the position of sites with respect to Axis 2. Ferns often suggest repeated disturbance. Finally, the third group of assemblages, represented in Figure 5.34 by dark green dots, consists of assemblages from sites that support various 'natural' vegetation types. Since all sites occur within the elevation band of lower montane forest (Lim, 2006; Pearce, 2006), it is unsurprising that the two longest vectors in the PCA plot are those representing pollen from the common LMF elements of "*Castanopsis/Lithocarpus*-type" and "Trees and shrubs", and which bracket the Group 3 sites.

From the PCA plot, a few conclusions can be drawn. The "Trees and shrubs" summary grouping appears to have the most explanatory power in describing the relationships between pollen assemblages from different sites. This conclusion is supported by the corresponding vector's length and its near-parallel orientation with the primary axis, Axis 1, which explains 55.17 per cent of the variance in the dataset. An interpretation suggested by this, and in combination with the knowledge derived from the botanical and palynological classifications of each individual site, is that, in relation to the modern landscape, relative abundance of surface sediment pollen from the "Trees and shrubs" summary grouping can be used with a good degree of confidence as a negatively correlated proxy for modern land use intensity. A second conclusion suggested by these data is that the palynological signature of the modern form of intensive wet rice cultivation practiced across the Kelabit Highlands today is quantitatively distinctive and, hence, conspicuous in sedimentary records.

### 5.3 Conclusion

The botanical taxon lists of modern plants growing at each of the sites sampled, alongside their respective pollen assemblages extracted from the corresponding surface sediments, have been presented here in detail by individual site. The results of this presentation have been to define 'palynological signatures' for the suite of human ecologies extant today across the Kelabit Highlands. Comparison of the botanical and palynological data have revealed the taphonomic influences of vegetation community structure and of pollination

vectors, with over-representation of wind-pollinated taxa from extra-local sources in the sediments of sites which support on-site vegetation of an either naturally or anthropogenically open structure. The data from local informants pertaining to land use histories have facilitated the qualitative placement of each site along a gradient in land use intensity. Multivariate statistical analyses have shown that sites within the modern landscape that support various vegetation types and land uses can be distinguished from the sedimentary pollen signature that they leave in the ground. At the elevation and climatic ranges spanned by the suite of sites sampled for the present study, the relative abundance of pollen from trees and shrubs appears to be a strong negatively-correlated proxy for human land use intensity.

The chapter to follow (Chapter 6) will apply the data and conclusions derived in the present chapter in order to refine interpretations of a series of fossil pollen records from the Kelabit Highlands. Pollen sequences from five cores will be analysed, thus demonstrating the modern analogue approach described in Chapters 3 and 4. The initial core to be presented and examined in such a manner was analysed by myself; the remaining four cores were analysed by a CRF colleague, Dr Samantha Jones, during her PhD research (Jones, 2012). Since detection of past human land use is the primary aim of the present study, the mid-late Holocene portions of these records are the focus of the chapter to follow.



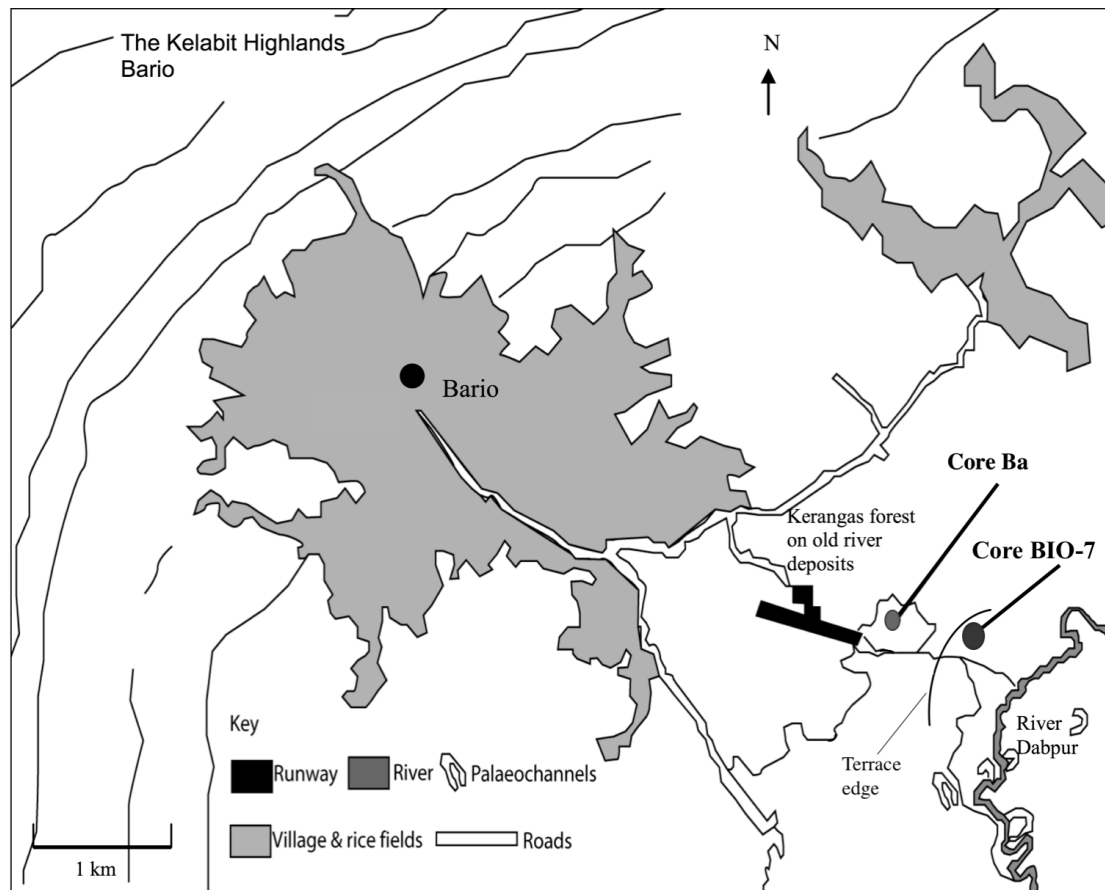
## **6 Fossil pollen results and comparisons with modern analogues from the Kelabit Highlands, Sarawak**

### **6.1 Introduction**

The primary focus of this chapter is application of the modern analogue training set presented in Chapter 5 to fossil pollen sequences from the Kelabit Highlands. The aim is to reveal potential signatures of various past land uses and ecologies within the pollen assemblages from sediment cores that diachronically transect local depositional histories. Holocene portions of five fossil sequences are presented in the following sections. Original data from the first core (BIO-7) are presented in full, followed by multivariate statistical comparison with the modern analogue dataset. With permission from the original pollen analyst, Samantha Jones, data from four of her previously analysed pollen cores (Jones, 2012) are presented in summary next, with application of the modern training set applied to each individually. The chapter closes with landscape-scale interpretations of the results in the context of the existing data and results from other aspects of the cultural and environmental histories revealed by previous Cultured Rain Forest project (CRF) work.

### **6.2 BIO-7 core sequence**

Original data from the BIO-7 sediment core are presented in detail below. As described in Chapter 4, this core was extracted from the infill of a palaeochannel of the Dappur river just east of the airstrip in Bario within the northern portion of the Kelabit Highlands, and just below the terrace into which Samantha Jones drilled her 'Ba' core (Figure 6.1). Core lithology and chronology, which includes physical analyses such as loss-on-ignition, magnetic susceptibility, and microcharcoal counts, are presented first; palynological analysis of fossil assemblages follow, comprising a stratigraphic pollen diagram as well as statistical analyses which justify diagram



**Figure 6.1** Map of Bario area showing location of the BIO-7 coring site in relation to Jones' (2012) 'Ba' core and to other elements of the physical landscape and built environment. Elevation of Bario is 1070m above sea level. Lines west and north of Bario represent sandstone ridges, not topographic contours. Modified from Jones (2012).

zonation and support interpretations of diachronic vegetation changes. Closing this section is the modern analogue analysis of fossil assemblages from the BIO-7 core via ordination alongside the modern training set.

### 6.2.1 Lithology

Graphical representation of the lithological sequence across the depth of the BIO-7 core appears along the left margin of the stratigraphic pollen diagram in section 6.2.2 (Figure 6.5; pp. 214-6). Brief descriptions of the constituent sedimentary units and their respective depths beneath the modern ground surface are presented in this subsection. These same data are summarised in Table 6.1 (top of next page).

**Table 6.1** Lithological descriptions of sedimentary units comprising the BIO-7 core. Shading represents the dark brown colour (10YR/3/2) and organic appearance of all but the lowest unit.

Depth (cm)	Description
0 - 7	Dark brown partially-humified organic detritus & organic silts; roots
7-27	Brown organic silts with few roots; darkening with depth
27-33	Brown organic silts with many roots
33-36	Brown organic silts with few roots
36-47	Dark brown partially-humified organic detritus & organic silts; crumbly
47-55	Brown organic silts
55-68	White / light brown sandy silts; heavily compacted

Total depth of the BIO-7 core extends 68cm down from the modern surface. Visual inspection of the sequence suggests only two constituent sedimentary units: a 13cm-thick basal unit (68-55cm depth) of off-white to lightbrown (10YR/8/2) mineral sand; and an upper, brown (10YR/3/2) organic unit comprising the overlying 55cm of the core. However, tactile examination during subsampling for pollen revealed subtle changes within this upper organic portion relating to density of fine rootlets (mostly dead and decomposing, but in the upper 7cm probably representing penetration by living roots from the modern ground surface) and matrix structure. The contact between the basal mineral sands and the overlying organic strata appeared diffuse at the time of laboratory-based sediment description and subsampling for pollen. Soils supporting many Bornean montane *kerangas* forest communities, such as those communities remaining in patches today within the vicinity of the present coring site, consist of a layer of raw hummus capping well-drained, nutrient-poor white siliceous sands (podzolised humult sands of Ashton, 2014). Whilst the upper portion of the BIO-7 core contains what are clearly depositional units of varying properties, the basal sands and overlying few centimetres of organic detritus may represent a buried soil of the type which supports montane *kerangas* forest, rather than representing a clear stratigraphic discontinuity or marked change in depositional environment.

### 6.2.2 Chronology

Two Accelerator Mass Spectrometry (AMS) radiocarbon age determinations provide chronological control for the BIO-7 sequence (Table 6.2). These two ages were provided by different laboratories due to resources and connections available at the time: the upper age comes from Beta Analytic, Inc in Miami; the basal age comes from the <sup>14</sup>CHRONO Centre for Climate, the Environment and Chronology at the Queen's University Belfast.

Table 6.2 Radiocarbon chronology for BIO-7 core sequence.

Depth (cm)	<sup>14</sup> C age	2-σ Calibrated	Material	Reference
20-19	8520±30 BP	9540-9485 cal BP	Fine organics	Beta-396778
68-67	3606±35 BP	4066-3833 cal BP	Wood fragment	UBA-19813

The basal age of 4066-3833 cal BP comes from a single large wood fragment embedded within the basal silicate sandy silt unit (Table 6.1). The upper age of 9540-9485 cal BP, interpreted to be a result of reworked material, comes from the fine organic fraction of a 1cm thick slice of bulk sediment from 20-19cm depth. These two depths were selected for radiocarbon age determinations based upon availability of datable material as well as perceived relevance to the chronology of environmental changes represented by the sediment sequence. Specifically, the basal AMS sample was placed as it is due to the fortuitous occurrence of a single wood fragment embedded in a stratigraphically secure context within the silicate sands at the base of the core. It thus provides a maximum age for the sequence in which we can be relatively confident. Placement of the upper AMS age was selected after palynological analysis in order to first identify portions of the sequence which contain changes that might have bearing on the aims of this research, namely related to signatures of past human-environment interactions. As will be described in the following section, the pollen assemblages from the uppermost four subsamples (above 22cm depth) represent a discrete palynological zone(s) defined by aspects that suggest human modification of vegetation. The interest in constraining the age of this change was determined to be great enough to justify allocation of limited resources to a bulk sediment AMS age. This gamble did not pay off.

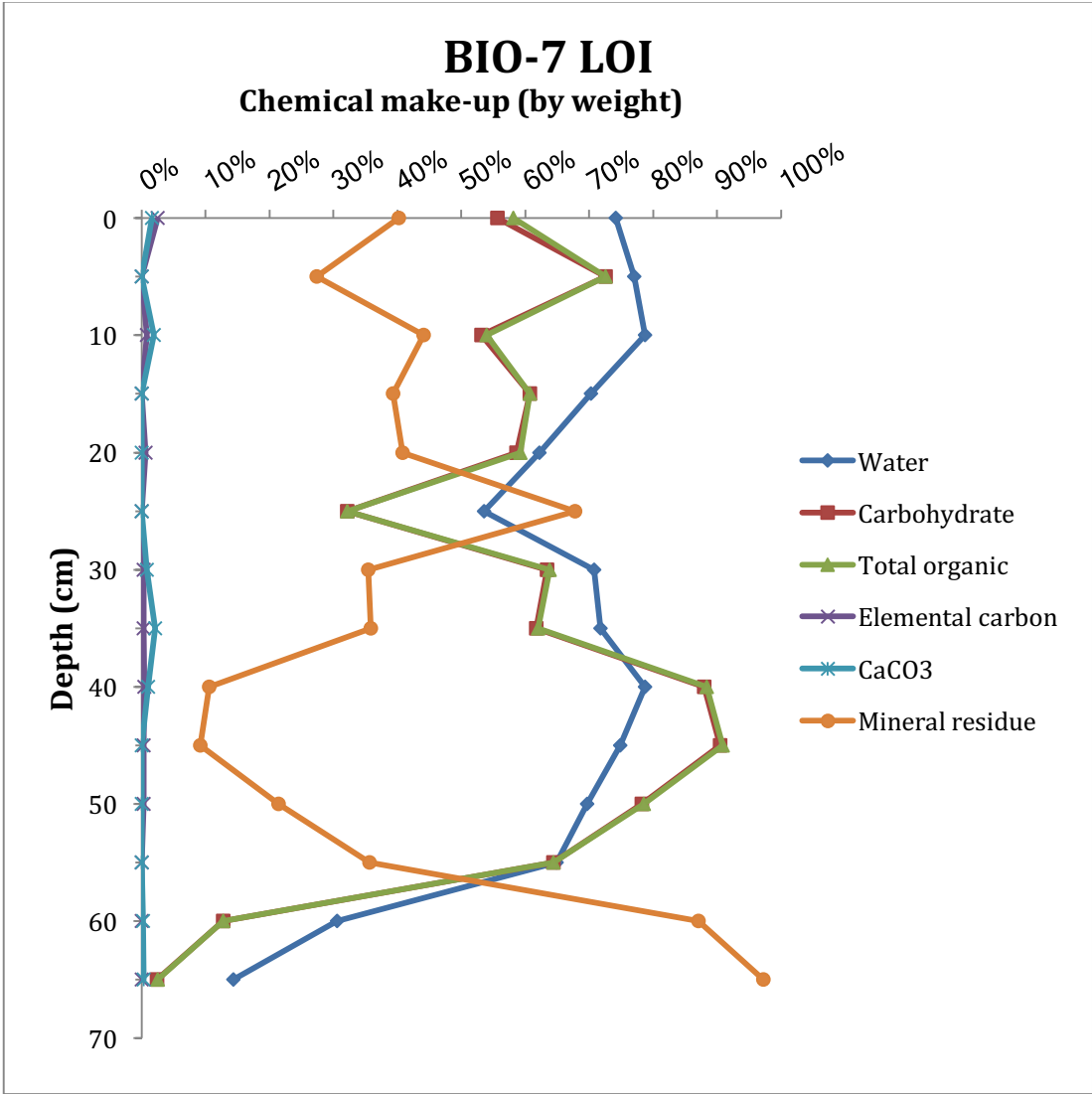
Given more resources, as well as the availability of datable material within stratigraphically secure contexts, additional AMS ages on individual organic fragments (ie single pieces of wood, seeds, or charcoal) would be desirable. Targeted portions of the sequence would be: the lithological change between the basal sands and the overlying organics; the discrete band of mineral-enriched sediments at 25cm depth; and from near the surface to determine the temporal span of the depositional sequence. As it stands, and based upon the physical and palynological proxies analysed as well as the nature of the material dated, the basal age of 4066-3833 cal BP is interpreted to be secure, whilst the upper age at 20-19cm depth of 9540-9485 cal BP is considered to come from reworked material, perhaps due to colluvial redeposition of older organics. This interpretation will be expanded upon below, and situated within the context of existing chronologies from other sequences from previous CRF work. The geographically closest analogue is Jones' (2012) Ba-1.

### ***Loss On Ignition (LOI)***

Further data pertaining to physical properties and chemical make-up are revealed by the loss-on-ignition (LOI) analysis. A few obvious trends are visible in the data (Figure 6.2). Values for both elemental carbon (charcoal) and calcium carbonate ( $\text{CaCO}_3$ ) are negligible throughout, with a minor increase in elemental carbon in the uppermost subsamples. This is as expected, given both the largely silicate sandstone surficial geology within the catchment as well as the perhumid aseasonal moisture regime and, hence, low susceptibility to natural fire of most of the vegetation on the montane plateau. Related to the minor amount of elemental carbon is the coupling of the total organics with the carbohydrates curves. This is showing that the relative quantity of decaying plant material (carbohydrate) throughout the BIO-7 sequence largely represents the total organic fraction of the sediments at any given depth.

More informative, yet unsurprising, is the positive correlation between total organics and water content (linear regression yields an  $r^2 = 0.804$ ) as well as the negative correlation between mineral residue and water content (linear  $r^2 = 0.818$ ). This demonstrates the sponge-like function of the organic fraction of

sediments, and, by extension, the effect of soil organic content upon moisture availability to the ecologies a given soil supports. In relation to the lithological



**Figure 6.2** Loss-On-Ignition data for BIO-7 sequence, showing basal mineral sandy unit, gradual transition to overlying organic units and discrete mineral pulse at 25cm depth.

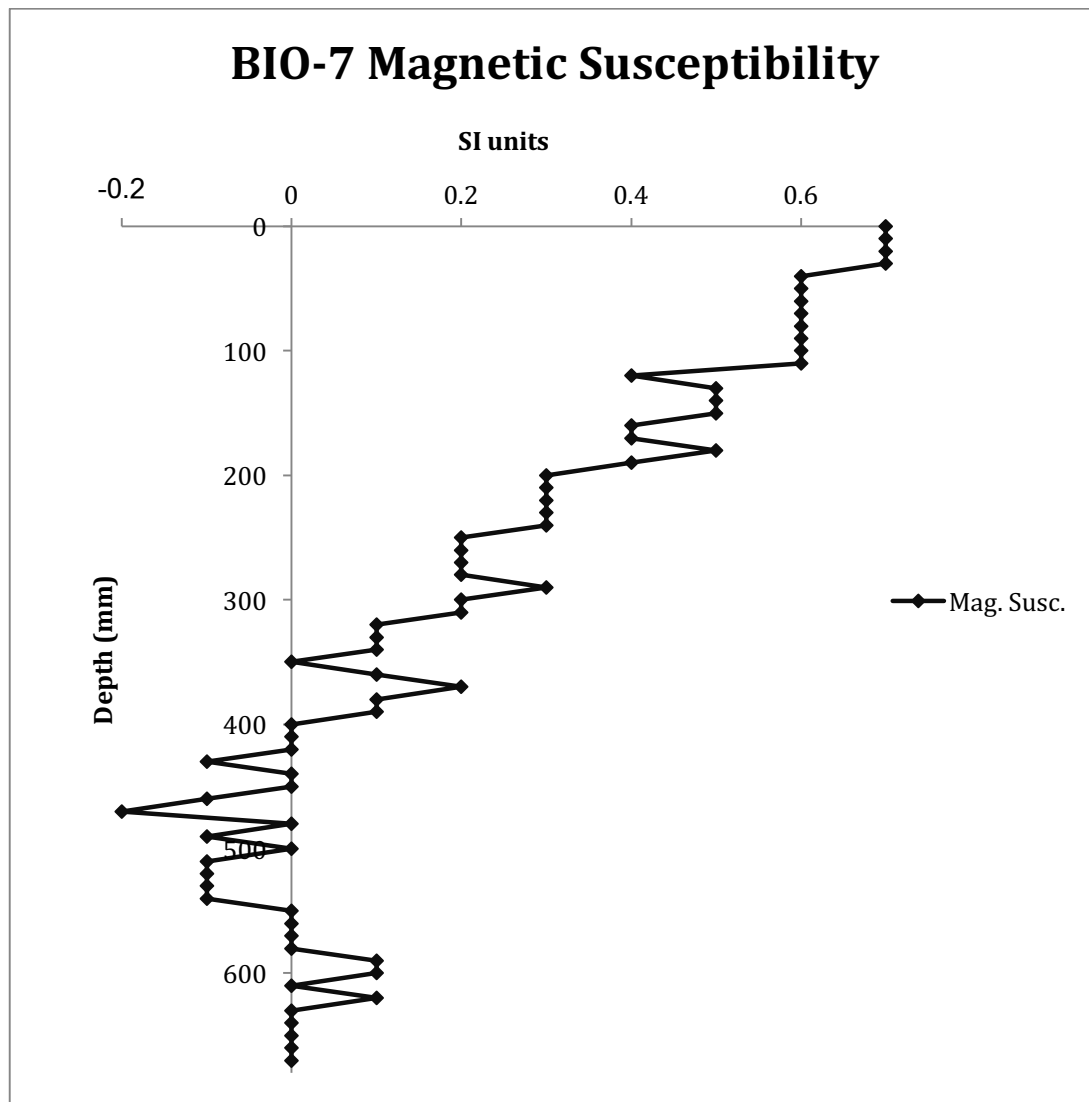
changes with depth, the associated change from the sandy basal unit to the overlying organic units between the 60cm and 55cm depth measurements is clear, as is the gradual change associated with what was described above as a diffuse contact between these units. However, the subsample at 25cm depth appears to show a pulse of mineral deposition. This coincides with, or immediately overlies, a unit of increased density of fine rootlets (33-27cm depth; Table 6.1). This increase in density of rootlets could represent a decrease in

sedimentation rate during which time plant growth increased on what was then the soil surface. This may have then been followed by a pulse of increased sedimentation from changes within the catchment which appear to have increased fluvial activity or sediment load of the Dappur river. Magnetic susceptibility, microcharcoal counts, radiocarbon chronology, and pollen assemblages can potentially shed additional light here.

### ***Magnetic susceptibility***

Magnetic susceptibility measurements were taken every centimetre throughout the depth of the BIO-7 core. Data are presented in Figure 6.3 below. The range of values, displayed in SI units (Blundell, 2001), throughout the sequence are consistent with the lithology described above, consisting of non- or weakly magnetic components. The basal unit of mineral sands appears to consist mainly of the magnetically neutral quartz (silicate). The predominant trend in magnetic susceptibility measurements across the depth of the core is the low-magnitude but continual rise from near the base of the organic portion through to the modern soil surface. The lack of impact that the pulse of mineral input at ~25cm depth, identified in the LOI analyses above, has upon this general trend of increasing magnetic susceptibility with decreasing depth suggests that this pulse is also composed of non-ferrous silicate sands, perhaps from the same source as the basal sediments.

In concert with the lithological data, the magnetic susceptibility curve suggests leaching of nanometre-sized particles of ferromagnetic material from the surface or shallow subsurface from a source that did not play a role in the deposition of lower layers. Two possible interpretations are offered here, representing two different potential sources of ferromagnetic material into the surface levels of the deposit. Firstly, the surficial geology of the northern and western portions of the Kelabit Plateau, within which the BIO-7 site sits, as well as that of the Tama Abu range which marks the elevated northern and western boundaries of the plateau, consists of the upper Miocene Meligan Formation of orthoquartzite sandstones (Singh, 1999). This sandstone unit overlies the Oligocene-lower Miocene Setap Shale in the west and the Kelabit Formation of



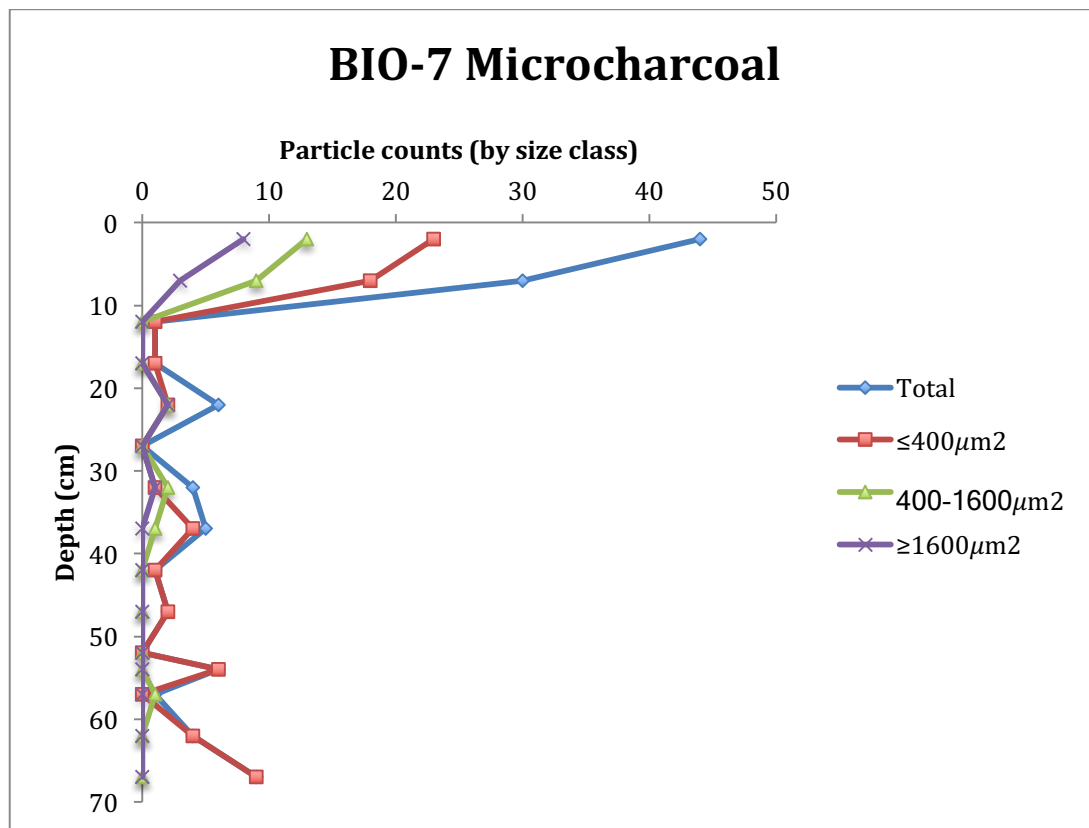
**Figure 6.3** Magnetic susceptibility curve for the BIO-7 sediment core. Note the moderate values throughout; magnetically-neutral basal portion; and steady increase up through the organic upper layers.

the same age in the east and south of the Plateau. This latter unit consists predominantly of mudstones with lenses of sandstone and impure limestone (Singh, 1999) and is of importance in interpretation of three of the four previously published sequences described in section 6.3. During their 1998 expedition to the Plateau to document its natural history ahead of the proposed gazetting of Pulong Tau National Park, the Miri Branch of the Malaysian Nature Society noted ‘continental red beds’ containing iron oxides abutting the Kelabit Formation mudstones further to the east (Malaysian Nature Society, Miri Branch, 1999). This area is in the upstream direction from the BIO-7 coring site. Industrial logging in recent decades across the highlands may have liberated



some of these sediments which were then fluvially transported to and deposited during overbank flow at the BIO-7 coring site in a palaeochannel of the Dappur.

Alternatively, or perhaps in addition to the above, Cornell and Schwertmann (2003) describe a process by which species of iron oxides common in topsoils of mild, humid environments (goethite, lepidocrocite and/or ferrihydrite) such as those of the perhumid montane tropics are transformed into the ferromagnetic maghemite through heating in the presence of fire. Microscopic charcoal abundance, which is widely used as a proxy for local and regional burning (Patterson III *et al.*, 1987), throughout the BIO-7 sequence is low, except for in the uppermost subsample (Figure 6.4). Modern increases in burning associated with clearance of vegetation for agriculture or construction (ie of the nearby Barrio airstrip, built in the 1960s) could, via their secondary production of maghemite, be responsible for the heightened magnetic signature of the upper levels of this sequence. The steady decline in magnetic susceptibility



**Figure 6.4** Microcharcoal abundance throughout the BIO-7 sequence, grouped into particle size-classes. Note the marked increase in microcharcoal particles of all size-classes in the uppermost subsamples, implying unprecedented modern increases in both local and regional burning.

with depth could then be attributed to active podzolization and leaching of iron oxides down the sediment profile.

### **6.2.3 *Palynology***

Pollen assemblages, expressed in relative abundances (per cent of main pollen sum for the corresponding stratigraphic level) of identified pollen types, from the 15 subsamples analysed across the depth of the BIO-7 sequence are presented below in three different graphical formats: a stratigraphic pollen diagram; a dichotomously branching dendrogram; and a Principal Component Analysis (PCA) plot of a multivariate ordination. The same dataset is presented in each of these graphical formats, representing alternative visualisations of the multivariate pollen data from the BIO-7 core.

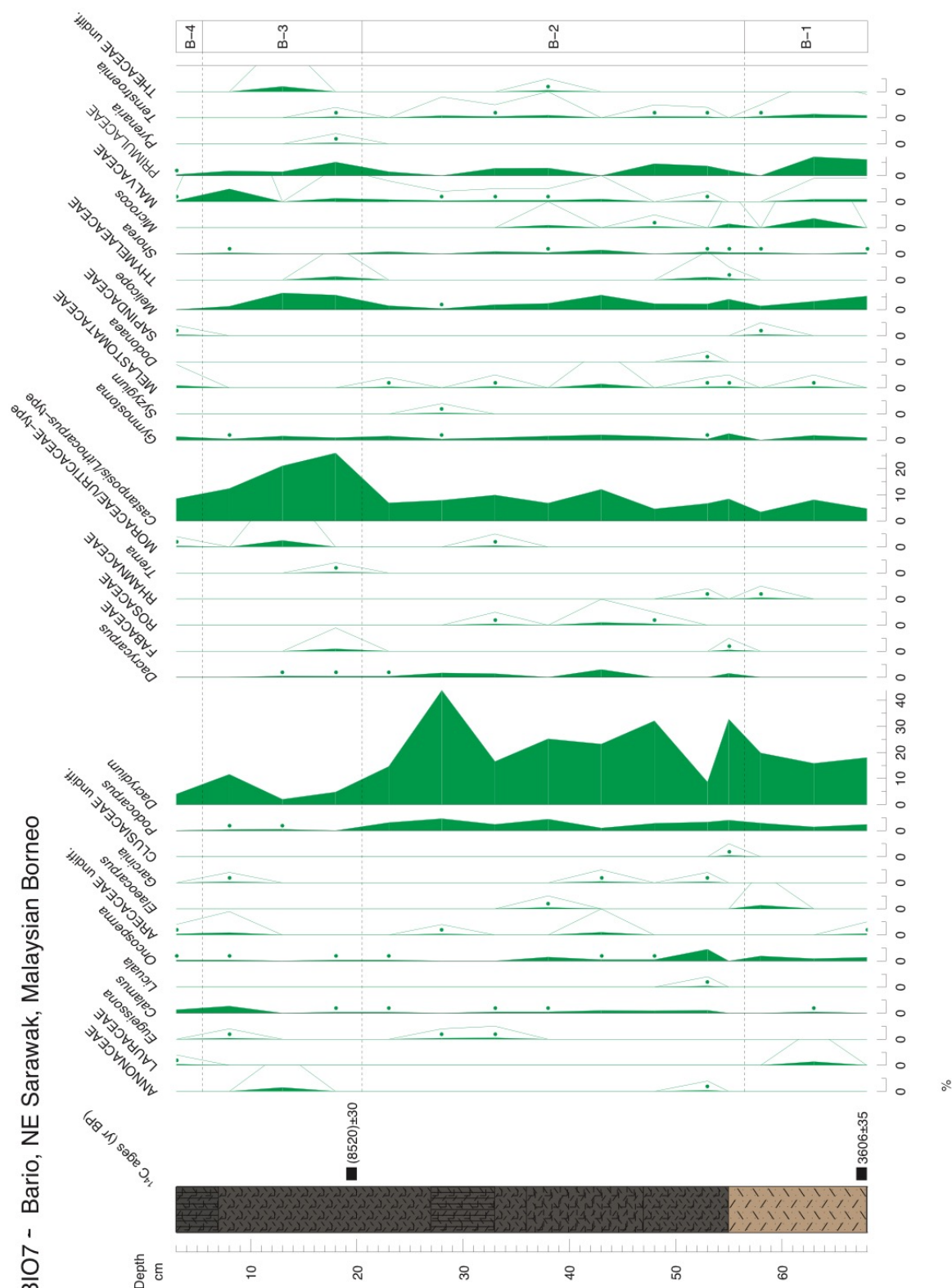
#### ***Pollen diagram***

The stratigraphic pollen diagram presented in Figure 6.5 (split across pages 212-4, and labelled a, b, and c, respectively) consists of columns representing (from left to right): the vertical axis, which depicts depth from the modern soil surface, and is expressed in centimetres; a sediment column, which is colour-coded according to the two Munsell soil colours observed in the core and described in section 6.2.1 above, and variously cross-hatched according to the lithological units defined in Table 6.1; radiocarbon chronology provided by the two AMS age determinations described in section 6.2.2, which are depicted as black rectangles at their respective depths and expressed in uncalibrated radiocarbon years before present (note the upper age, which is considered to represent older reworked material, is in brackets); curves for individual pollen types comprising the bulk of the diagram, and which are expressed in relative abundances (per cent of main pollen sum for a given stratigraphic level); and zonation notation, representing groupings of statistically similar pollen assemblages from adjacent stratigraphic levels, supported by the dendrogram which appears along the right margin of the third page of the diagram (Figure 6.5c; p. 214).

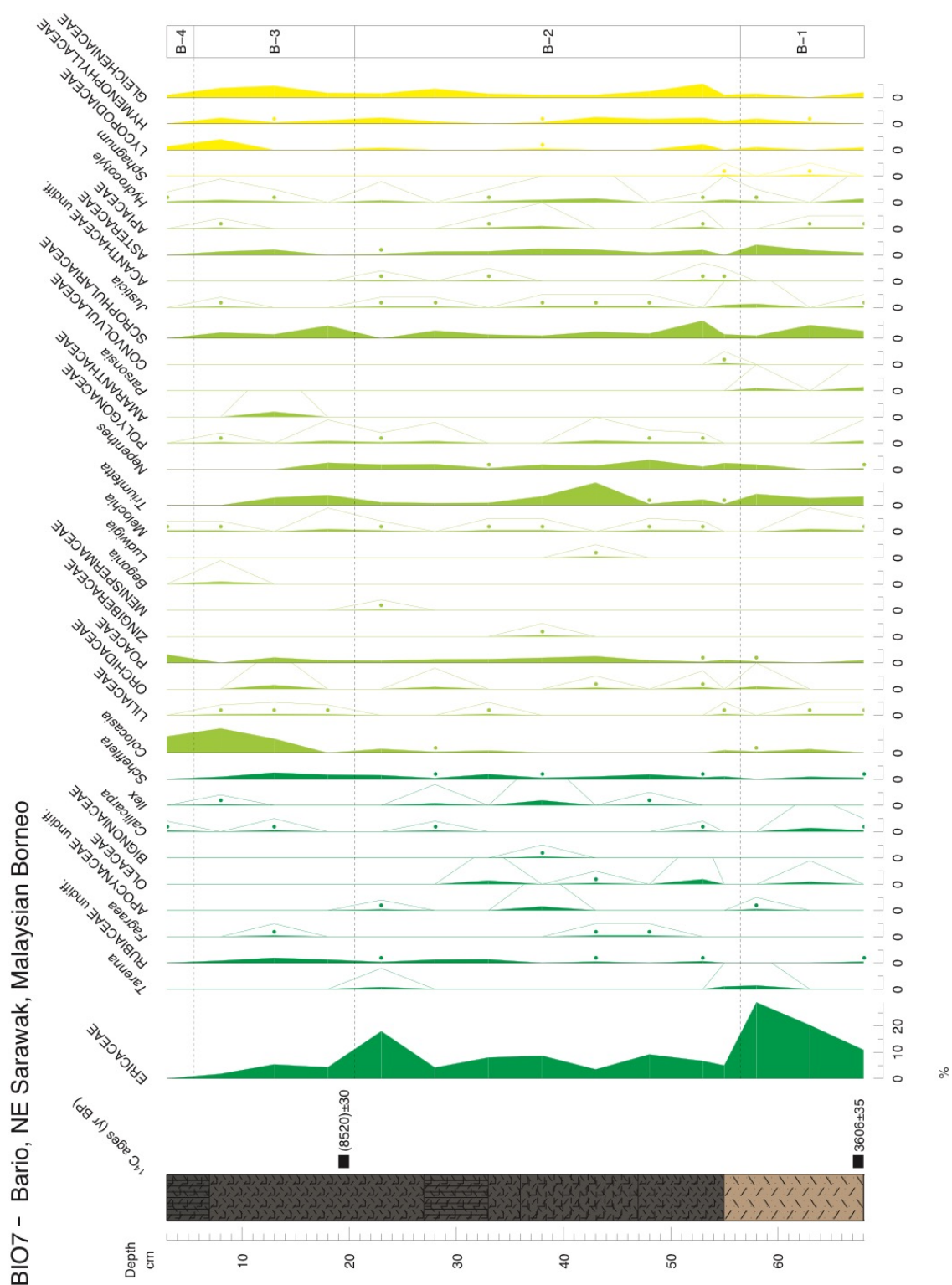
Curves for the individual pollen types are colour-coded according to life form, following the same colour scheme used in the modern assemblages

presented in Chapter 5. 'Trees and shrubs' are coloured dark green; 'Herbs, epiphytes, and climbers' are light green; 'Ferns and lower plants' are yellow; and 'Aquatics and wetland taxa' are blue. Thin outline curves for the less abundant pollen types represent a 10x exaggeration of their actual relative abundances so as to aid in visualisation of subtler changes; for the same reason, non-zero values that amount to less than one per cent of the pollen sum are marked by dots. The order, from left to right, in which the various pollen types are shown is organised at two levels: firstly, by life form, colour-coded as described above; and secondly, within each of these life form groupings, pollen types are listed with those from the most ancestral lineages first and with those from progressively more derived lineages following to the right, *sensu* APG III (APG III, 2009). The life form groupings have ecological meaning, in that their summary relative abundances suggest the architecture of the vegetation community on-site at the time they were deposited, and thus also imply the localised microenvironments and degrees of disturbance within those communities. The phylogenetic arrangement within each of these life form groupings does not have a direct ecological basis. This system was implemented as a means of applying a less arbitrary standard than a simple alphabetical order.

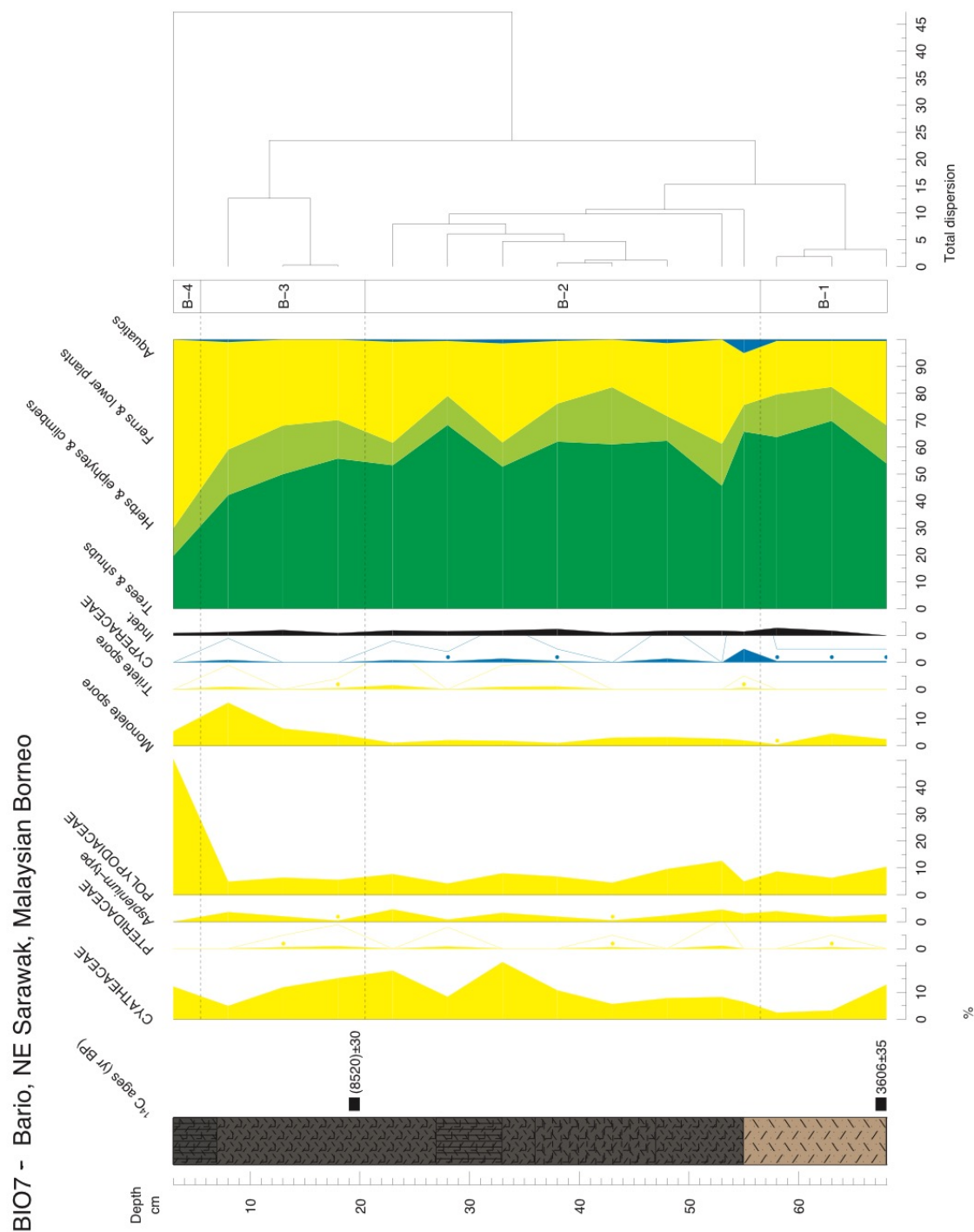
When reading the pollen diagram, two approaches are complementary. Firstly, each horizontal level should be conceptualised as a multi-year slice in time rather than as a snapshot, as each subsample has a certain thickness that likely incorporates multiple years' worth of deposition. In this sense, each level consists of the respective relative abundances of the constituent pollen types which, in aggregate as a taphonomically-filtered assemblage, represent the vegetation across that span of time. Additionally, each column represents the changes through time in the relative abundance of the corresponding pollen type. Using the former approach, the paragraphs to follow contain descriptions of the constituent BIO-7 pollen assemblages (horizontal levels), grouped by pollen zones (right column of pollen diagram) and moving from the base to the top of the sequence and, hence, from the past forward in time.



**Figure 6.5a** Page 1 of BIO-7 pollen diagram. Sediment column and chronology at left. Filled curves represent relative (per cent) abundances of individual pollen taxa, colour-coded by life form: trees and shrubs in dark green. Outline curves show 10x exaggeration; dots represent non-zero values less than one per cent. Pollen zone boundaries denoted by dashed horizontal lines, with zonation notation at right.



**Figure 6.5b** Page 2 of BIO-7 pollen diagram. Sediment column and chronology at left. Filled curves represent relative (per cent) abundances of individual pollen taxa, colour-coded by life form: trees and shrubs in dark green; herbs, epiphytes, and climbers in light green; ferns and lower plants in yellow. Outline curves show 10x exaggeration; dots represent non-zero values less than one per cent. Pollen zone boundaries denoted by dashed horizontal lines, with zonation notation at right.



**Figure 6.5c** Page 3 of BIO-7 pollen diagram. Sediment column and chronology at left. Filled curves represent relative (per cent) abundances of individual pollen taxa, colour-coded by life form: trees and shrubs in dark green; herbs, epiphytes, and climbers in light green; ferns and lower plants in yellow; aquatics and wetland taxa in blue. Outline curves show 10x exaggeration; dots represent non-zero values less than one per cent. Pollen zone boundaries denoted by dashed horizontal lines, with zonation notation and CONISS dendrogram at right

***Pollen Zone B-1: 4066-? cal BP (68-57cm depth)***

The basal pollen zone (B-1) consists of the three subsamples from within the siliceous sandy silt unit at the base of the core. These subsamples immediately overlie the only stratigraphically secure radiocarbon age of 4066-3833 cal BP from the base of the BIO-7 sequence. Zone B-1 is dominated by *kerangas* forest elements and by disturbance indicators. The basal assemblage from 67.5cm depth consists mostly of pollen from Trees and shrubs (54 per cent), with moderate representation of Ferns and lower plants (31 per cent). Predominant individual pollen types within this basal assemblage are the *kerangas* heath treelet and shrub taxa of *Dacrydium* (20 per cent) and Ericaceae (11 per cent), with minor but significant values for the palm genus *Oncosperma*, the temperate southern hemisphere conifer *Podocarpus*, the drought-tolerant and nitrogen-fixing heath forest element *Gymnostoma*, as well as possible disturbance indicators such as *Melicope*, *Microcos*, Primulaceae, and *Triumfetta*. The pteridophyte component of this basal assemblage is dominated by Cyatheaceae and Polypodiaceae. Notable changes across zone B-1 are the steady rise in abundance of Ericaceae pollen (from 11 to 29 per cent) and less pronounced drop in spores from tree ferns in family Cyatheaceae.

The pollen assemblages across zone B-1 appear to reflect the presence of frequently disturbed montane *kerangas* heath forest growing atop well-drained, acidic, and nutrient-poor silicate sandy soils. Moderate abundances of the wind-pollinated lower montane tropical oak genera of *Castanopsis* and *Lithocarpus* suggest lower montane forest nearby, perhaps on the slopes of the Tama Abu range abutting the Bario area to the north and west. Apart from the two uppermost subsamples of the BIO-7 sequence, the highest microcharcoal counts of the smallest size-class ( $\leq 400\mu\text{m}^2$ ; Figure 6.4) were recorded in the basal subsample. This may indicate heightened regional burning at this time, perhaps related to ENSO-induced drought and exacerbated by low moisture retention of freely draining sandy soils.

### ***Pollen Zone B-2: 57-20cm depth***

The only age from the BIO-7 sequence in which we can have confidence is the basal age of 4066-3833 cal BP. If we assume both a linear sedimentation rate (though the lithology suggests that this may *not* have been the case) and that the top of the core represents modern deposition, then the portion of the core encompassed by zone B-2 (57-20cm depth) would have been deposited between about 3400-1200 cal BP. Both of these assumptions are speculative.

Zone B-2 consists of eight pollen assemblages. Variability internal to this zone exceeds that of the other zones, most noticeably in the fluctuations of the negatively correlated relative abundances of pollen from the summary groupings of 'Trees and shrubs' and 'Ferns and lower plants'. Relative abundance of pollen from 'Trees and shrubs' remained between 52-62 per cent in six of the eight assemblages within this zone, whilst values for 'Ferns and lower plants' in those same six assemblages stayed between 25-35 per cent. However, at 52.5cm depth, there was a short-lived drop in the relative abundance of Trees and shrubs to 45 per cent which coincided with an increase in Ferns and lower plants to their maximum value for the zone at 39 per cent. In contrast, Trees and shrubs reached their highest value (68 per cent) for zone B-2 at 27.5cm depth whilst Ferns and lower plants were at their lowest at 20 per cent. Other minor though notable changes in the summary abundances were the small peak of pollen from 'Aquatics and wetland taxa' at the expense of Ferns and lower plants in the lowest subsample from this zone (54.5cm depth), as well as the small increase in pollen from 'Herbs, epiphytes, and climbers' at 42.5cm depth, again at the expense of Ferns and lower plants.

Individual taxa that drove the trends in the summary groupings just described appear to be: the podocarps *Dacrydium* and *Podocarpus*, as well as the heath family Ericaceae amongst the Trees and shrubs; and pteridophyte families of Cyatheaceae and Polypodiaceae amongst the Ferns and lower plants. The only pollen type attributed to the 'Aquatics and wetland taxa' is Cyperaceae, so the aforementioned peak in this summary grouping at 54.5cm depth was entirely accounted for by a peak in sedge pollen. Within the herbaceous taxa, *Triumfetta*



showed a distinct peak at 42.5cm along with a minor increase in grass (Poaceae) pollen above its very small values throughout, whilst pollen from Scrophulariaceae increased in the 52.5cm depth assemblage. These trends and changes, in concert with the lithological and LOI data described in section 6.2, suggest changes in local vegetation driven by edaphic development and hydrological fluctuations, potentially also exacerbated by disturbance whether of climatic or anthropic origin.

#### ***Pollen Zones B-3 & B-4: 20-0cm depth***

The upper two pollen zones, B-3 and B-4, comprising assemblages from the uppermost four subsamples, are treated together here. As will be demonstrated in the following sections, the assemblage from the uppermost subsample is statistically distinct enough to merit the assignment of its own zone (B-4). In line with the same speculative assumptions described in the previous section regarding chronology (linear sedimentation rate and modern surface), these upper four assemblages were notionally produced by the vegetation communities of the past 1200 years. The AMS radiocarbon age of 9540-9485 cal BP on the fine organic fraction of a bulk sediment sample came from 20-19cm depth, but is interpreted to represent old organic material transported into the site. No sharp breaks in lithology (Table 6.1), in magnetic susceptibility (Figure 6.3), nor in microcharcoal counts (Figure 6.4) occur at this depth. However, the LOI data (Figure 6.2) suggest a pulse of mineral deposition centred around 25cm depth within the visually uniform upper 55cm of organic sediments. Additionally, as described in the following paragraph, zones B-3 and B-4 consist of pollen assemblages that depart significantly from those of the underlying zones. Indeed, it was these significant palynological changes that drove the selection of 20-19cm depth for placement of the second of the two AMS age determinations.

The most marked feature of the palynological changes across these upper zones is the steady decline in pollen from Trees and shrubs and parallel sustained increase in representation of Ferns and lower plants. Assemblages from the three levels that constitute zone B-3 (17.5cm, 12.5cm, and 7.5cm

depths) also displayed slightly elevated values for Herbs, epiphytes, and climbers relative to those of the rest of the core. The most striking changes in the relative abundances of individual pollen types were the huge increase in the tropical lower montane forest oak genera of *Castanopsis/Lithocarpus* (pollen from these two genera are nearly indistinguishable) in concert with attendant decreases in the *kerangas* forest canopy southern hemisphere conifers *Dacrydium*, *Dacrycarpus*, and *Podocarpus* as well as Ericaceae heath. Subtler changes were marked by the slight upticks in pollen from Moraceae/Urticaceae, *Melicope*, Malvaceae, Primulaceae, *Schefflera*, *Calamus*, *Colocasia*, *Triumfetta*, Scrophulariaceae, Amaranthaceae, and Asteraceae, whilst *Nepenthes*, *Microcos*, and Oleaceae were either not tallied or reduced in abundance across these upper levels. The assemblage from 2.5cm depth, comprising the sole subsample within zone B-4, was dominated by spores from the fern family Polypodiaceae. Additionally, microcharcoal counts across all size-classes dramatically increased in the uppermost two levels (7.5cm and 2.5cm depths; Figure 6.4, p. 208).

These changes in pollen assemblages and microcharcoal counts across the upper 20cm of the BIO-7 sequence suggest both localised and regional disturbance combined with the disappearance of the *kerangas* forest that previously occupied the site. The increase in lower montane forest elements, namely the tropical oaks, is interpreted to result from a spatial broadening in source area of pollen deposited at the BIO-7 site due to structural opening of the on-site vegetation following disappearance of the local *kerangas* forest. As has been shown by the modern botanical and palynological data presented in Chapter 5, pollen assemblages deposited beneath vegetation of a more open structure contain significant components of more widespread and often wind-pollinated taxa of surrounding lower montane forest. The increases in *Colocasia* (taro) in these upper levels, combined with the dramatic rises in Polypodiaceae and microcharcoal, lend a distinct air of intensive human intervention in what appears to previously have been edaphic, hydrological, and climatic drivers of change amongst a developing *kerangas* forest growing atop an increasingly podzolised substrate.

## **Zonation**

Zonation of the pollen diagram is based upon a multivariate statistical method of cluster analysis called Constrained Incremental Sums of Squares, or CONISS (Grimm, 1987). This method is similar to the agglomerative cluster analysis performed on the modern pollen data presented in Chapter 5, except that CONISS compares adjacent multivariate samples which, in the case of the multi-taxa assemblages of fossil pollen from the BIO-7 vertical sediment sequence, means subsamples of consecutive depths. Such a method of cluster analysis is designed specifically to identify zones within stratigraphic sequences that consist of adjacent levels with high measures of similarity relative to other levels. CONISS is one of the optional graphical outputs built into the pollen plotting program, *psimpoll* (Bennett, 2008), with which the stratigraphic pollen diagrams in this study were produced. As such, the primary choice that the analyst must arbitrarily make is specification of the number of desired zones. In effect, recalling the description in Chapter 5 of the arbitrary placement of the vertical dotted line in Figure 5.33 (p 197) to delineate a cut-off which defines significant branchings of the dendrogram, by changing the number of requested zones in a CONISS analysis, the analyst is moving that dotted line either up or down the clustering hierarchy (left or right, as the branchings are orientated horizontally).

The CONISS dendrogram along the right margin of Figure 6.5c, when viewed in isolation from the pollen diagram, does not imply a set number of zones. Based upon a few iterative runs of alternatives, four zones were selected. However, as can be observed in the structure of the CONISS dendrogram, two zones may be equally justifiable, thus splitting the sequence into: the lower 11 subsamples, which are interpreted to represent development of montane *kerangas* heath over active podzols; overlain by the upper four subsamples, which suggest a more open and heavily disturbed local environment surrounded regionally by lower montane forest. The uppermost level, dominated by Polypodiaceae spores, remains distinct, though zones traditionally consist of multiple assemblages.

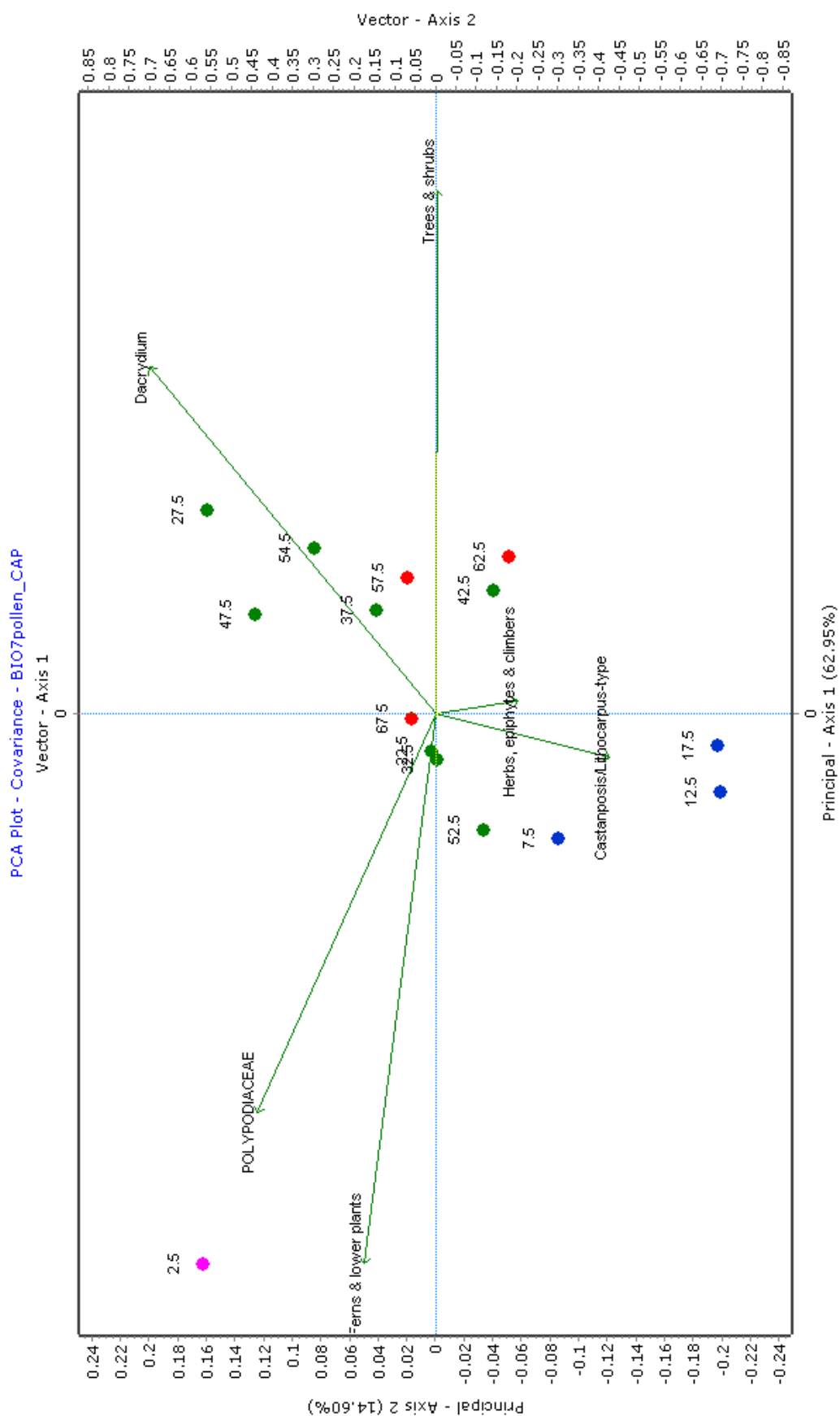
The following ordination and brief description show a third alternative visualisation of the BIO-7 pollen data.

### ***Ordination***

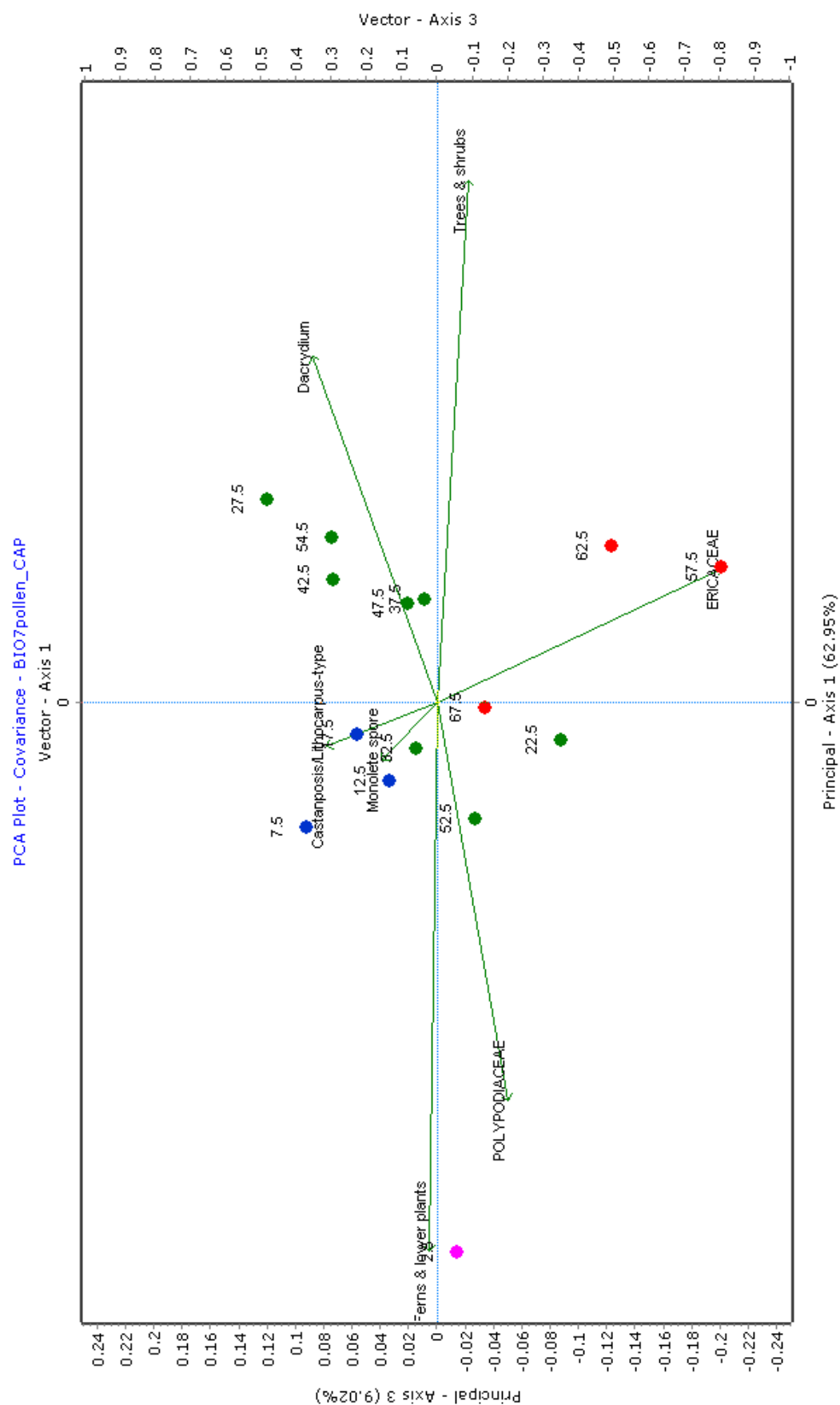
Principal Component Analysis (PCA) covariance plots are presented below (Figures 6.6 and 6.7) as a third alternative graphical representation of the BIO-7 pollen data. The utility of this visualisation of the structure in the dataset lies in its potential to reveal which variables (in the case of pollen data such as the BIO-7 assemblages, 'variables' equate to pollen taxa) are most important in determining the patterns within and relationships between assemblages. This can, in turn, feed back into a better understanding of the pollen diagram, as the PCA plots may act to highlight certain key taxa, the relative abundance with depth curves of which can then be re-examined with greater appreciation of their respective influence.

The two PCA plots presented below (Figures 6.6 and 6.7) together display the data situated along the first three axes of the ordination. With a bit of mental spatial manipulation, these data can be imagined in a single three-dimensional space. In Figure 6.6, the horizontal dimension is defined by Axis 1, which accounts for 62.95 per cent of the variance in the data, whilst Axis 2, encompassing 14.60 per cent of the variance, defines the vertical. Similarly, the horizontal dimension of the plot in Figure 6.7 is again provided by the principal axis of the ordination, whilst Axis 3 (9.02 per cent of the variance) defines the vertical. In aggregate, these three axes encompass 86.57 per cent of the variance in the dataset, so the respective positions of assemblages relative to one another within the three-dimensional space defined by these three axes provide a high-fidelity depiction of the patterning and structure internal to the pollen data.

Of particular note in both Figures are the long, horizontal, nearly anti-phase vectors representing the summary groupings of 'Trees and shrubs' (pointing to the right from the origin) and 'Ferns and lower plants' (to the left). This suggests that the position of a given assemblage (filled coloured circles with depth labels above) along the principal horizontal axis is driven by the degree of openness of the vegetation community growing on-site at the time the



**Figure 6.6** PCA covariance plot of BIO-7 pollen data. The primary ordination axis (Axis 1) is displayed along the horizontal and accounts for 62.95 per cent of the variance; Axis 2 (14.6 per cent of the variance) provides the vertical scale. Filled circles represent individual pollen assemblages, labelled by depth and colour-coded according to pollen zone (B-1 in red; B-2 in green; B-3 in blue; B-4 in pink). Vectors show influential variables.



**Figure 6.7** PCA covariance plot of BIO-7 pollen data. The primary ordination axis (Axis 1) is displayed along the horizontal and accounts for 62.95 per cent of the variance; Axis 3 (9.02 per cent of the variance) provides the vertical scale. Filled circles represent individual pollen assemblages, labelled by depth and colour-coded according to pollen zone (B-1 in red; B-2 in green; B-3 in blue; B-4 in pink). Vectors show influential variables.

sediments from which the assemblage derives were deposited. Assemblages that appear to the left of the central origin represent more open vegetation due to their high relative abundances of Ferns and lower plants at the expense of Trees and shrubs, whilst assemblages produced by more closed canopy communities appear to the right of the central origin. A general trend, then, is revealed in that the lower, and hence older, assemblages of zones B-1 (red circles) and B-2 (green circles) imply a more forested landscape, whilst those of the upper two zones (B-3 in blue circles, and B-4 in pink) suggest an opening of the vegetation. Note also the distinct position and extreme distance separating the uppermost assemblage (from 2.5cm depth, in pink) from the other assemblages.

#### **6.2.4 Modern analogue analysis**

In this subsection, the modern training set presented in Chapter 5 is applied to the BIO-7 fossil sequence described across the preceding subsections. This modern analogue analysis of the BIO-7 fossil data aims to reveal potential signatures of land use within the record of past vegetation changes contained in the fossil sequence. Comparative analysis is achieved through the same multivariate statistical technique of ordination just used to compare the various assemblages internal to the BIO-7 record with one another. Within and amongst the paragraphs below, two PCA plots are presented of an ordination in which the modern dataset presented in Chapter 5 is included alongside the fossil assemblages from the BIO-7 sequence. In so doing, spatial proximities between modern and fossil assemblages within the resultant PCA plot reveal whether the fossil assemblages are statistically similar to any of the modern analogues. It is argued here that such multivariate statistical similarity between a given fossil pollen assemblage and that from one of the modern land uses sampled suggests the past presence of similar human-mediated vegetation communities (cf Faegri & Iversen, 1989, p. 186). The results below support the assertion that such an approach lends to a more nuanced interpretation of human signatures in fossil pollen records.

In a similar manner to the PCA plots for the previous ordination which included only the BIO-7 fossil assemblages, the following two plots (Figures 6.8

and 6.9) use colour-coded symbols to represent assemblages from either: individual levels of the BIO-7 sequence (filled circles); or individual sites in the modern landscape (filled triangles). The circles representing the BIO-7 fossil assemblages are colour-coded, as in Figures 6.6 and 6.7, according to the four pollen zones defined in previous subsections. The filled triangles, representing assemblages from the modern sites, are colour-coded in Figures 6.8 and 6.9 according to the three groupings relating to land use intensity as described in Chapter 5. Due to the incorporation of 13 additional assemblages into the ordination for the modern analogue analysis, the total variance across this broadened dataset has increased. As a result, the component axes of the two PCA plots (Figures 6.8 and 6.9) have changed from those of the previous ordination that compared only the BIO-7 assemblages with one another. These new PCA plots are defined by: a principal axis (Axis 1) that accounts for 41.59 per cent of the variance across the dataset; Axis 2 which encompasses 19.06 per cent of the variance; and Axis 3 that displays 11.06 per cent of the variance.

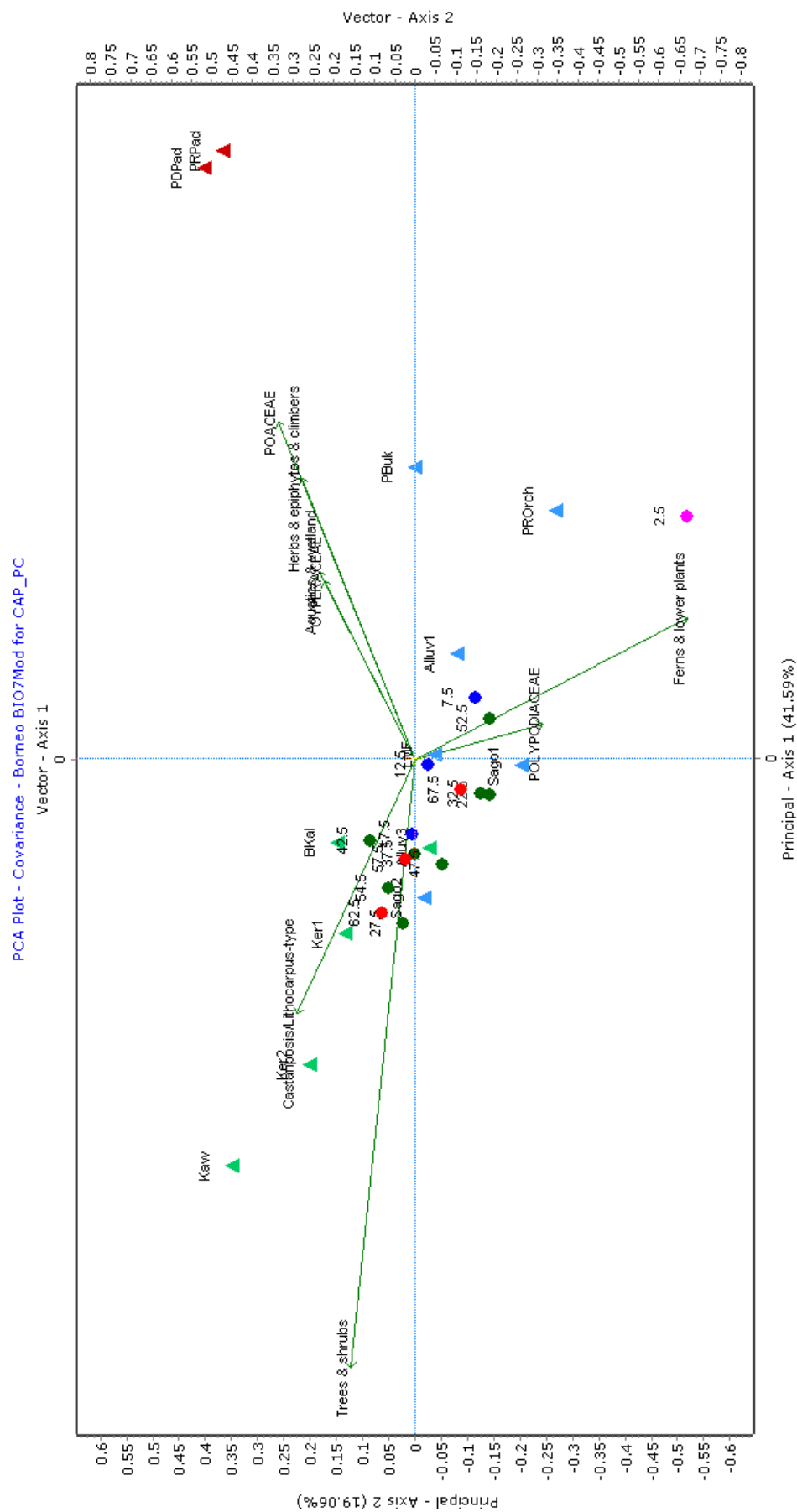
According to these newly defined dimensions, the three axes displayed across the two PCA plots presented in Figures 6.8 and 6.9 seem to parallel structural and compositional elements of vegetation communities implied by the constituent assemblages. Axis 1 (both Figures 6.8 and 6.9) is interpreted to represent a forest cover gradient, with assemblages rich in tree and shrub pollen plotting to the left of centre whilst those that suggest a more open vegetation plot to the right. Axis 2, plotted against Axis 1 in Figure 6.8, appears to describe a compositional gradient across assemblages which imply a structurally open parent vegetation, with paddy-type assemblages dominated by grasses and sedges plotting in the upper right, whilst fern-dominated assemblages appear below centre. In Figure 6.9, Axis 3 seems to represent an edaphic gradient with assemblages rich in *kerangas* heath elements of podzols situated above centre, and those rich in LMF elements typical of loams appearing below centre.

Inferences regarding human signatures can be drawn from both plots. In Figure 6.8, all fossil assemblages, save for that from the distinctive uppermost subsample (2.5cm depth), cluster slightly left of the centre of the plot, along with a number of the modern assemblages from vegetation communities that are both

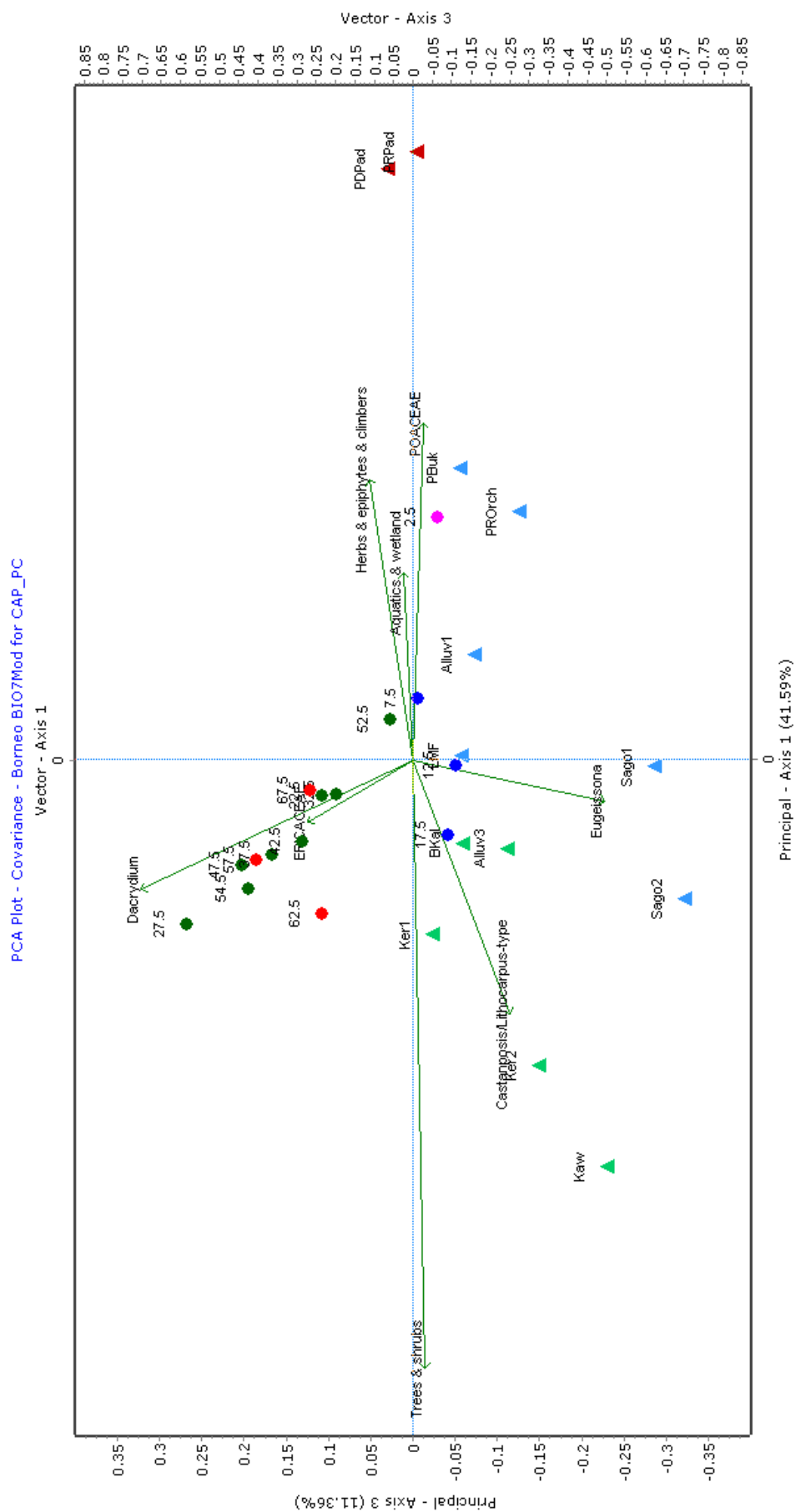


minimally and moderately influenced by land use. Within this cluster, two smaller groupings can be discerned, both containing scattered assemblages from the three lower zones of the BIO-7 fossil sequence as well as assemblages from the modern dataset: a group positioned just inside the upper left quadrant, comprising fossil assemblages from depths 62.5, 57.5, 54.5, 47.5, 42.5, 37.5, 27.5, and 17.5cm, and closely surrounded by modern assemblages from the minimally human-modified vegetation communities at sites Kerangas 1, Bukit Kelit, Alluvial Forest 3, and Sago Stand 2; and a second group positioned just inside the lower right quadrant, comprising fossil assemblages from depths 67.5, 52.5, 32.5, 22.5, 12.5, and 7.5cm, and surrounded by modern assemblages from the moderately human modified sites of Sago Stand 1, Alluvial Forest 1, and Lower Montane Forest. The fossil assemblage from the uppermost subsample at 2.5cm depth appears in the extreme bottom right of the plot, in a similar position with respect to Axis 1 as that of the assemblages from the heavily human modified sites of Pa' Ramapuh Orchard and Padi Bukit.

The distribution of assemblages displayed in the PCA plot defined by Axes 1 and 3 of the ordination (Figure 6.9) serves to reinforce the interpretation that the majority of the BIO-7 fossil sequence represents *kerangas* heath forest at various developmental stages, and also to identify the assemblages from the uppermost four subsamples as more analogous to modern assemblages. Of note in the plot in Figure 6.9, though, is the position of the assemblage from 52.5cm depth, which is loosely clustered with those from the upper subsamples just mentioned. The 52.5cm depth assemblage plots near to the assemblages from the moderately human-modified modern sites of Alluvial Forest 1 and Lower Montane Forest with respect to all three of the ordination axes presented (Figures 6.8 and 6.9). Both of these modern sites, whilst displaying signs of moderate intensity human use, are located adjacent to rivers or streams and undoubtedly are prone to natural as well as anthropogenic disturbance. It could



**Figure 6.8** Axes 1 and 2 of PCA plot including BIO-7 fossil assemblages and modern dataset. Fossil assemblages are displayed as filled circles; modern assemblages are represented as filled triangles.



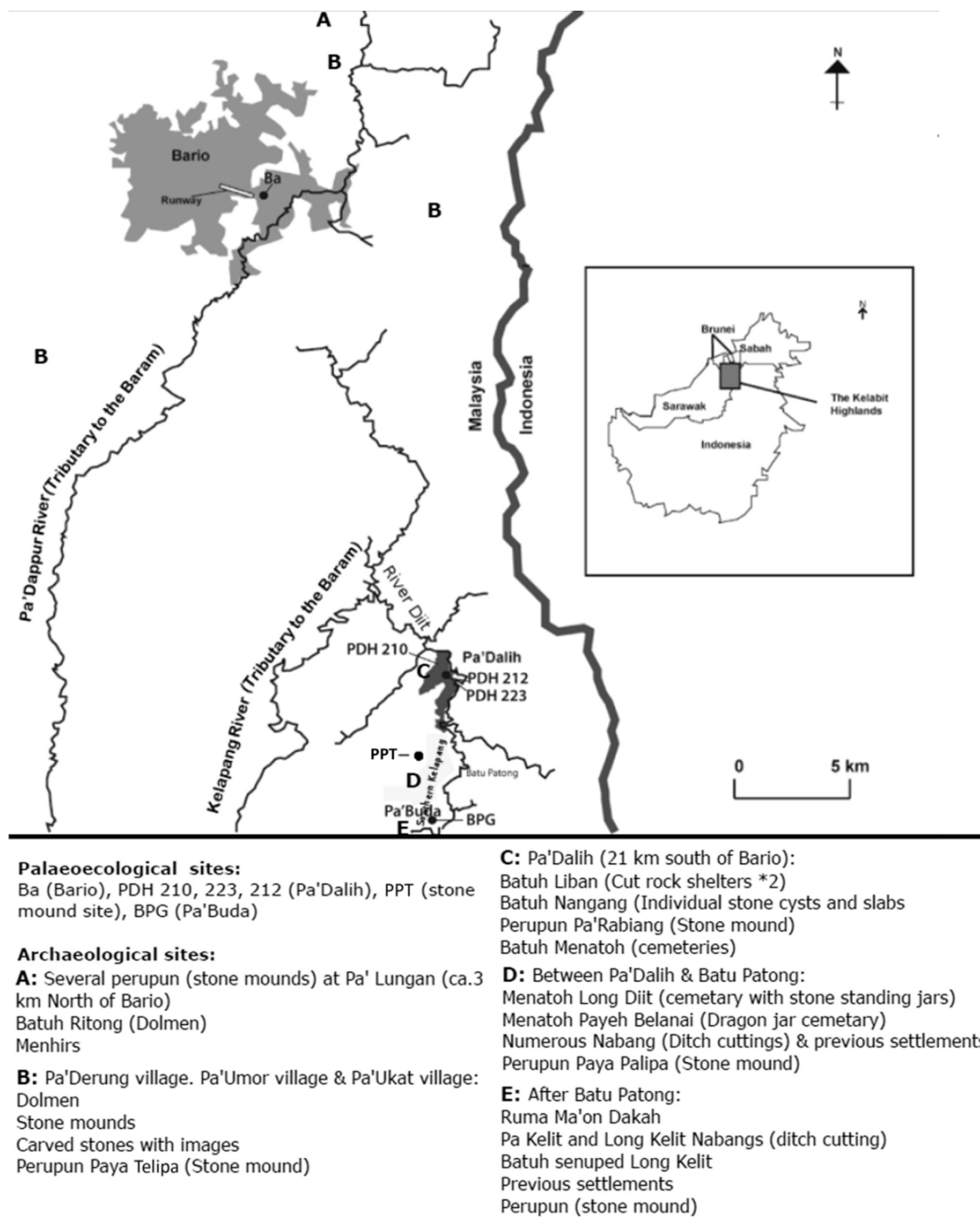
**Figure 6.9** Axes 1 and 3 PCA plot including BIO-7 fossil assemblages and modern dataset. Fossil assemblages are displayed as filled circles; modern assemblages are represented as filled triangles.

be that the assemblage at 52.5cm depth, with its short-lived reduction in *Dacrydium* and increase in fern spores (refer back to pollen diagram; Figure 6.5) represents a hydrologically driven disturbance, whilst the assemblages from the upper four subsamples show increasing intensity of human modification of the vegetation.

In light of the modern analogue analysis described above, the following narrative interpretation is offered. Silicate sands, derived from the surrounding slopes of the Tama Abu range, were fluvially deposited by the Dappur River at the BIO-7 coring site prior to 4000 cal BP. This well-drained, oligotrophic substrate was then colonised by and subsequently supported montane *kerangas* heath until its disappearance, presumably around 1200 cal BP. During that span, acidic raw humus accumulated atop an actively podzolising profile, supporting a developing *kerangas* forest prone to intermittent soil water stress as well as low-intensity disturbance probably related to climatically driven fluvial activity. After 1200 cal BP, a more open vegetation, somewhat analogous to that at some of the moderately human-modified modern sites sampled, such as the Sago Stands and Alluvial Forest sites, replaced the *kerangas* heath. Due to the statistical similarity of these upper, post-1200 cal BP assemblages with those from the moderately human-modified sites, this change is interpreted to reflect reduction of the *kerangas* forest by humans, perhaps as a means for promoting sago growth or taro cultivation (*Eugeissona* and *Colocasia* pollen appeared in these upper assemblages). From the microcharcoal counts, burning on both a local and regional scale does not appear to be an initial factor in this vegetation change, though may have later been promoted by it. In any event, the vegetation local to the BIO-7 coring site does not appear to reflect a decidedly anthropogenic landscape until the very recent past.

### **6.3 New analyses of summary data from Jones (2012)**

In the subsections to follow, modern analogue analyses of four cores from across the Kelabit Highlands that were previously examined by Samantha Jones as part of the CRF project are presented. Figure 6.10 is a map of CRF coring and archaeological sites from Jones *et al.* (in press), which includes the sites of



**Figure 6.10** Map of Kelabit Highlands showing locations of CRF palaeoecological coring sites, archaeological sites, plateau drainages, and modern settlements. Source: Jones *et al.* (in press).

these four cores. Each of the palynological sequences presented here in summary have been described in detail in Samantha Jones' PhD thesis (2012), as well as in associated later publications which will be referenced in the respective subsections below. Jones (2012) offered a number of alternative interpretations for Holocene portions of the sequences she analysed which contain signs of episodic mineral deposition, variable pollen preservation, fluctuations in

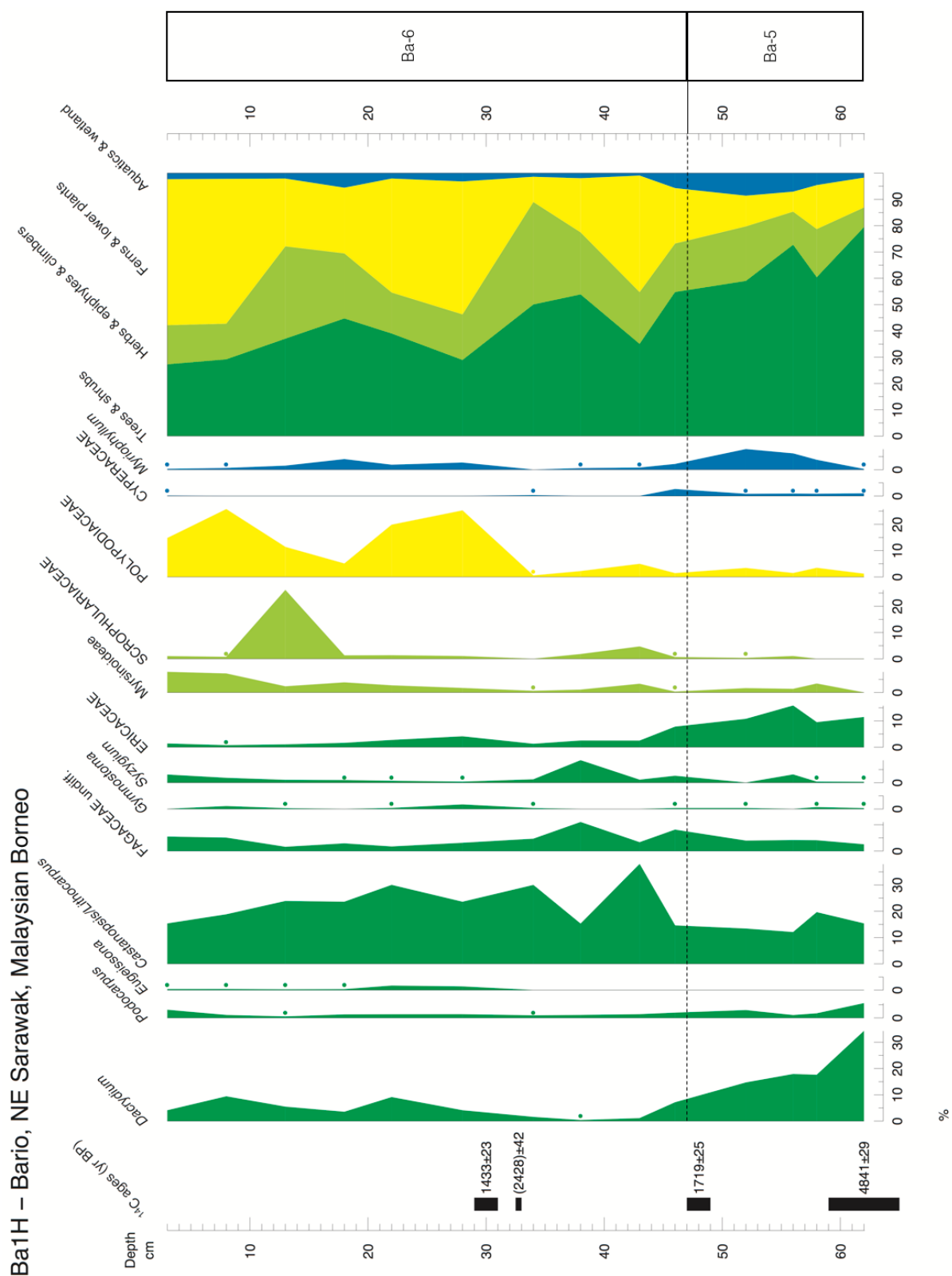
sedimentary charcoal abundances, pollen of successional taxa, presence of pollen types which she ascribed to plant taxa that provide many resources valuable to humans, as well as changing phytolith assemblages. The specifics of these interpretations are discussed below within subsections relating to the respective cores to which they refer. The alternative interpretations offered by Jones (2012) and expanded upon in Jones *et al.* (2013a & b; 2014; and in press) are statistically examined below via the modern analogue analytic approach described in Chapters 3 and 4, presented in Chapter 5, and demonstrated above by application to the BIO-7 fossil sequence. The aim throughout the following analyses is the same: to compare pollen assemblages from the Holocene portions of four fossil sequences with pollen assemblages from the suite of sites sampled across a gradient in modern land use intensity using the multivariate ordination technique of Principal Component Analysis (PCA) in order to detect potential assemblage-scale palynological signatures of past human modification of vegetation.

### **6.3.1 Bario (Ba)**

Core 'Ba' represents the sole record from the Bario area in the northern Kelabit Highlands analysed by Jones (2012) (Figure 6.10). This record, along with that from the PDH 212 core from the southern portion of the Kelabit Highlands near Pa' Dalih (described below in subsection 6.3.3), extend into Marine Isotope Stage (MIS) 3 and to the limit of meaningful radiocarbon age determination, >50 ka BP. The Ba record, as well as that of PDH 212 and other sequences from montane regions of the Austral-Asian tropics (eg Anshari *et al.*, 2001; Hope *et al.*, 2004), have major discontinuities spanning the last glacial maximum (LGM), terminal Pleistocene, and early Holocene. In the case of the Ba chronology, this is manifest in two AMS ages from within the upper 80cm of the ~3m long core, both on single wood fragments within matrices of organic sediments: a date of 30,756–30,219 cal BP at 80-78cm depth; and a date of 5645–5483 cal BP just 15cm above at a depth of 65-59cm. Detailed palynological and sedimentological interpretation of the Pleistocene portions of both the Ba and PDH 212 records within the context of regional climatic and vegetational changes can be found in Jones *et al.* (2014).

The following modern analogue analysis focuses on the Holocene portion of the Ba record, comprising the upper 14 subsamples from depths 62-3cm (zones Ba-5 and Ba-6 of Jones, 2012; curves for select taxa and summary diagram are presented below in Figure 6.11), which appear to represent the last ~5600 years of depositional history and vegetational change. The original results were presented in Jones (2012) and expanded upon in Jones *et al.* (2013a; 2014; & in press). The predominant palynological changes across this portion of the record parallel changes observed in the BIO-7 sequence presented above in section 6.2.3. *Kerangas* elements *Dacrydium* and Ericaceae in zone Ba-5 were replaced in zone Ba-6 by the wind-pollinated tropical lower montane oaks in genera *Castanopsis* and *Lithocarpus*, accompanied by increases in the disturbance indicators Myrsinoideae (likely *Ardisia*) and Scrophulariaceae. According to the Ba chronology, this change occurred just after 1699-1558 cal BP ( $1719 \pm 25$   $^{14}\text{C}$  yr BP). Jones (2012) interprets this change to represent a climatic shift from cooler and drier conditions to a modern tropical montane perhumid climate. Pollen from hill sago (*Eugeissona*) was first tallied in the 28cm depth subsample and maintained presence throughout the remainder of the sequence, whilst spores from the fern family Polypodiaceae became abundant in these same upper assemblages in which sago pollen was counted. Jones (2012) also noted an abundance of rounded-echinate phytoliths of the type produced by palms on the same microscope slides that yielded the assemblages just mentioned containing *Eugeissona* pollen and Polypodiaceae spores. She interprets the late Holocene portion of this Ba record, from about 1298 cal BP (Jones, 2012), to potentially represent human management of sago palms in a plateau setting surrounded by lower montane forest with riparian and wetland communities growing along watercourses.

The modern analogue analysis to follow aims to test whether the modern dataset from the present study provides empirical support for this interpretation via multivariate statistical comparison of the Ba fossil assemblages with those from the suite of modern sites presented in Chapter 5, in the same manner as has been done above for the BIO-7 sequence.



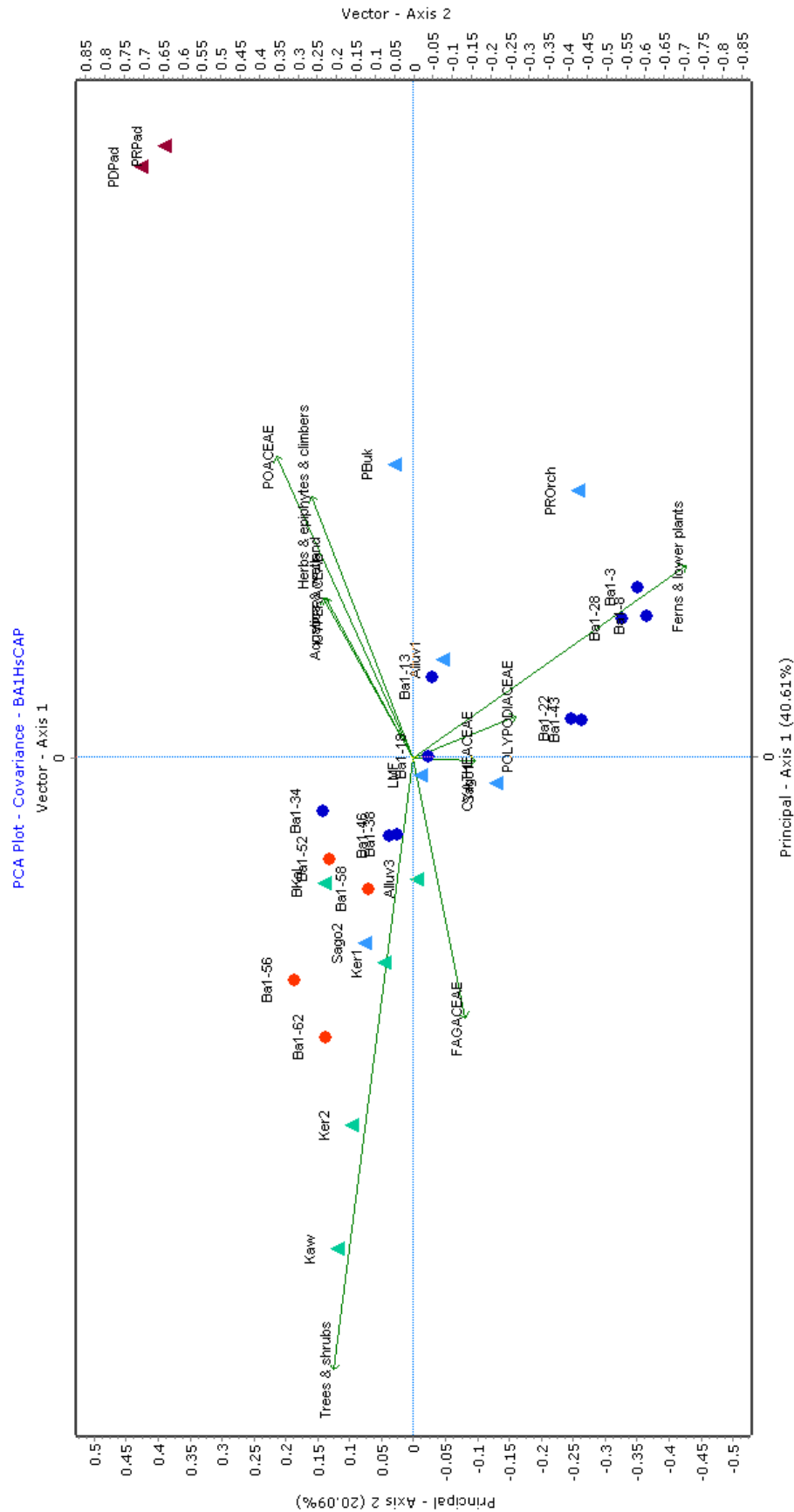
**Figure 6.11** Pollen diagram using Holocene data from Jones' (2012) Ba core, showing uncalibrated  $^{14}\text{C}$  chronology, curves for select taxa and summary groupings. Trees and shrubs in dark green; Herbs, epiphytes, and climbers in light green; Ferns and lower plants in yellow; Aquatics and wetland taxa in blue. Jones' original zonation notation appears at right.



### ***Modern analogue analysis***

A PCA plot comparing the Ba fossil assemblages with those from the modern training set is presented below in Figure 6.12. This plot displays the first two axes of this ordination, which combine to describe 60.70 per cent of the variance in the dataset. The distribution of assemblages from modern sites (filled triangles), as well as the orientation of vectors that represent influential pollen taxa, is similar to that produced for the ordination of the BIO-7 fossil sequence alongside the modern training set. This undoubtedly reflects the nearby locations in the landscape of the two coring sites (refer to map in Figure 6.1; p. 202) and hence their similar palynological representation of nearby vegetation changes. As explained in the description of site selection in Chapter 4, the Ba site is located within a boggy deposit that sits atop the flat valley bottom of the plateau immediately east from the Bario airstrip, and just over one kilometre west from the Dappur river, whilst the BIO-7 core comes from the infill of a palaeochannel of the Dappur which was cut into a Holocene terrace within the post-glacial cut-and-fill sequences closer to the modern active channel. The upper ~55-65cm of deposit at both sites consists of highly organic mid-late Holocene sediments that contain the fossil assemblages analysed in this study.

Constituent assemblages of zone Ba-5 (red circles), which constitute the palynological representation of vegetation between 5645–1558 cal BP (bracketed by the two radiocarbon ages of  $4841 \pm 29$  and  $1719 \pm 25$   $^{14}\text{C}$  yr BP shown in the pollen diagram in Figure 6.11), cluster within the upper left quadrant of the PCA plot amongst the minimally human-modified modern sites of Kerangas 1 & 2, Sago Stand 2, Bukit Kelit, and Alluvial Forest 3. Whilst still just inside the upper left quadrant of the plot in Figure 6.12, three of the four oldest assemblages from zone Ba-6 (blue circles for 46, 38, and 34cm depths) begin the general trend with decreasing depth of the younger assemblages plotting further towards a loose cluster of assemblages from the moderately human modified sites (light blue triangles) towards the lower right of the plot. A date of 1699–1558 cal BP on a wood fragment at 49–47cm depth provides chronological control for the boundary between zones Ba-5 and Ba-6. This boundary marks the



**Figure 6.12** PCA plot of ordination of Ba fossil assemblages (filled circles) and modern training set (filled triangles). Axis 1 accounts for 40.61 per cent of the variance across the combined datasets, whilst Axis represents 20.09 per cent. Note the constituent assemblages of zone Ba-5 (red circles) plot amongst those of the modern sites of minimal human modification (green triangles) whilst assemblages from zone Ba-6 (blue circles) cluster loosely with those from moderately human modified sites (light blue triangles).

beginning of a trend of increasing statistical similarity of younger fossil assemblages with those of increasing intensity of human land use.

The modern analogue analysis of the Ba fossil assemblages, embodied in the PCA plot in Figure 6.12, provides empirical support for Jones' interpretation that anthropogenic signatures are discernible in the Ba sequence from ~1700 cal BP (Jones, 2012; Jones *et al.*, in press). This analysis therefore also lends support to Jones' interpretation that the increases in *Eugeissona* pollen, rounded-echinate phytoliths, and fern spores within the Ba fossil assemblages of the last 1700 years represent human modification of the local vegetation, likely for sago exploitation. Additionally, nearly identical trends are visible within the upper portion of the nearby BIO-7 sequence, whilst that record also shows a pronounced increase in pollen from *Colocasia* in the uppermost three assemblages (Figure 6.5c; p. 214). This may be attributable to taro as a vegicultural component of the land uses of the past 1700 years in the Bario area that appear to also have incorporated sago-based arboriculture. The earliest secure archaeological date from the northern portion of the Kelabit Highlands of 2026-1826 cal BP comes from cremated bone within a stone mound (Perupun Raya Pa' Lungan) a few kilometres north from Bario (area A in Figure 6.10; p. 229). Whilst no plant remains or residues have been found in association with archaeological artefacts of this age in the northern Kelabit Highlands, the signatures of human land use within the portions of the Ba and BIO-7 fossil sequences from the last ~1700 years suggest that the subsistence practises of the people living in the area at the time included forms of arboriculture and vegiculture.

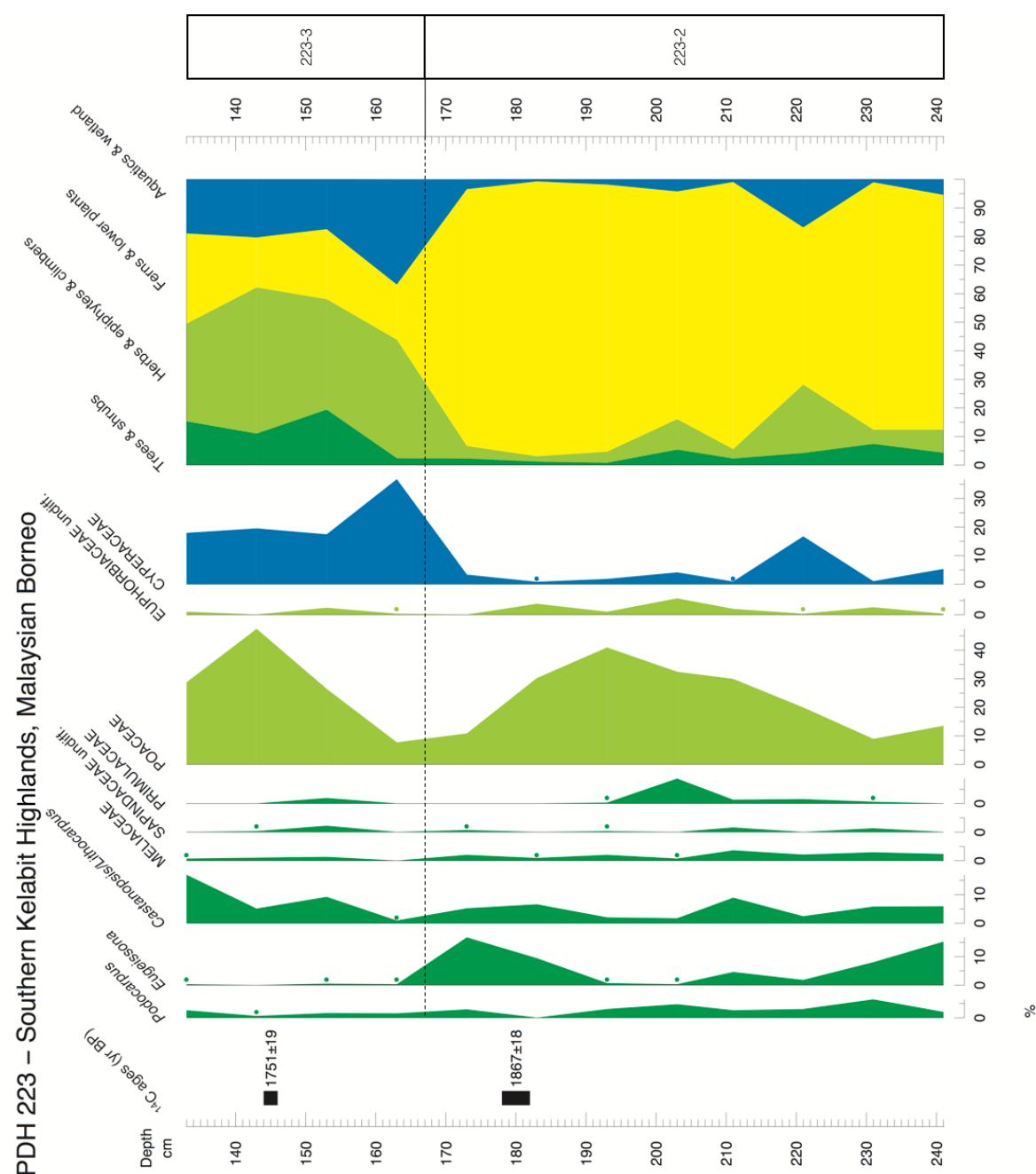
### **6.3.2 Pa' Dalih 223 (PDH 223)**

The PDH 223 record comes from a 2.7m core from an infill of a palaeochannel of the Kelapang river on the south-eastern margin of the southern Kelabit longhouse settlement at Pa' Dalih (Figure 6.10; p. 229). The site is used today as an orchard, and is surrounded by wet rice paddy fields and gardens associated with the longhouse community, as well as secondary lower montane forest on nearby slopes. This is the same locale as the site of "Pa' Dalih Orchard"

within the suite of modern sites sampled in compilation of the modern training set (see Chapter 5, section 5.2.1; p. 184). The sediments did not yield pollen in sufficient concentration to include in the final modern dataset. Similarly, the upper ~130cm of the PDH 223 sediment core consists of iron-mottled clays with low organic content and very low pollen concentrations (Jones, 2012; Jones *et al.*, 2013b); fossil pollen counts in the basal 30cm are comparably low. As such, the summary diagram below (Figure 6.13) includes only the assemblages from 241–133cm depths (zones 223-2 and 223-3 of Jones' original pollen diagrams), which attained main pollen sums near 300 grains.

Jones (2012) reports three AMS ages from the PDH 223 sequence, the upper two of which are displayed in uncalibrated  $^{14}\text{C}$  years alongside the sediment column at the left of the summary pollen diagram presented below (Figure 6.13). The basal age of 2352-2322 cal BP was obtained on charcoal from the charcoal-rich sandy clays with low pollen concentration at the base of the sequence (Jones, 2012). In concert with this basal date, ages of 1868-1734 cal BP at 182-178cm depth (charcoal) and 1715-1604 cal BP at 146-144cm depth (also on charcoal) provide for interpolation of a near-linear sedimentation rate throughout the sequence as represented in the age-depth model in Jones (2012). The intermittent layers of charcoal-rich sediments throughout, combined with significant percentages of *Eugeissona* pollen, presence of pollen from disturbance-indicating taxa, and dominance of fern spores in the assemblages of zone 223-2 led Jones to the interpretation that humans were managing sago at or near the site between ~2300-1800 cal BP.

Jones also points to the appearances of pollen from taxa indicative of standing or slow-moving water (ie *Myriophyllum* and *Utricularia*), diatoms, as well as phytoliths that are morphologically comparable to rice (identified as *Oryza cf sativa* by Jones *et al.*, in press) at stratigraphic levels corresponding to 2000-1800 cal BP to suggest the possibility of wet rice cultivation at this early date. This interpretation is qualified by Jones and colleagues' comment that rice phytoliths, whilst present in these earlier subsamples, do not become abundant until the uppermost 15cm of the PDH 223 sequence.



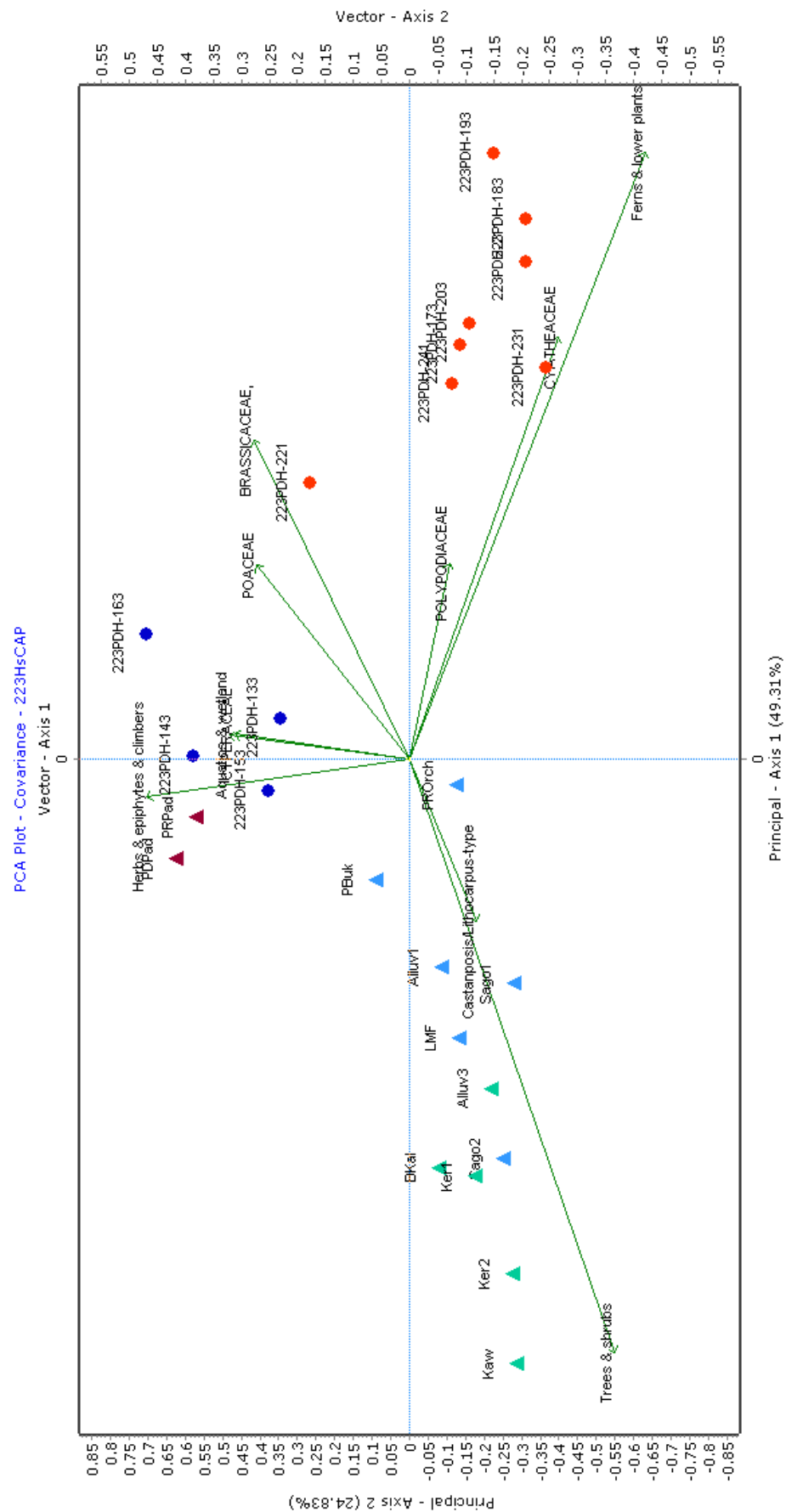
**Figure 6.13** Pollen diagram using data from Jones' (2012) PDH 223 core, showing uncalibrated  $^{14}\text{C}$  chronology, curves for select taxa, and summary groupings. Trees and shrubs in dark green; Herbs, epiphytes, and climbers in light green; Ferns and lower plants in yellow; Aquatics and wetland taxa in blue. Jones' original zonation notation appears at right.

These interpretations of sago management from 2300-1800 cal BP and potential wet rice cultivation from as early as 2000 cal BP are empirically examined below by multivariate statistical comparison with the modern assemblages from sites of modern land uses presented in Chapter 5.

### ***Modern analogue analysis***

Ordination of the 12 fossil assemblages from the portion of the PDH 223 core spanning depths of 241-133cm alongside the 13 assemblages of the modern training set is presented below in the PCA plot in Figure 6.14. The primary axis of this plot (Axis 1, forming the horizontal dimension) accounts for 49.31 per cent of the variance across this dataset, whilst Axis 2 provides the vertical dimension and describes 24.83 per cent of the variance. Significant components of the two long vectors, representing relative abundances of the summary groupings for Trees and shrubs, and Ferns and lower plants, parallel Axis 1 in nearly opposite directions. This reflects the negative correlation of palynological representation of these two groupings, and has been shown throughout this study to be a consistent feature across modern and fossil assemblages. Axis 1 is thus interpreted to represent an apparent gradient in degrees of structural openness and of disturbance of the parent vegetation.

Most of the fossil assemblages from zone 223-2 of the PDH 223 sequence (red circles) cluster in the bottom right quadrant of the PCA plot due to the dominance of fern spores at those levels. In contrast, the majority of the modern assemblages plot in the lower left quadrant reflecting the markedly higher representations of arboreal pollen tallied in those assemblages. The separation between these two clusters in the PCA plot indicates statistical dissimilarity between the two groups. Despite displaying significant quantities of *Eugeissona* pollen, high fern spore abundances within the zone 223-2 assemblages, which date to 2300-1800 cal BP, suggest either a vegetation quite different to that at the two modern sites containing managed stands of hill sago, or differential post-depositional preservation in favour of fern spores which tend to be more robust than most pollen grains (Havinga, 1964).



**Figure 6.14** PCA plot of ordination of the PDH 223 fossil assemblages (filled circles) alongside the modern assemblages (filled triangles). Fern spore abundance of zone 223-2 assemblages (red circles in lower right) separate them from the modern assemblages (green and blue triangles in lower left); zone 223-3 assemblages (blue circles) cluster with modern wet rice paddy assemblages (red triangles) near top of Axis 2.

The most interesting aspect of the PCA plot in Figure 6.14 is the cluster of assemblages toward the top of Axis 2. This cluster consists of the four assemblages from zone 223-3, along with the two assemblages from the modern wet rice paddy sites that have been so statistically distinct within all other ordinations. The vertical axis (Axis 2) along which this cluster is situated is paralleled by vectors representing abundances of pollen from herbaceous and wetland taxa, namely sedges (Cyperaceae) and grasses (Poaceae).

Three possible interpretations of these data are offered here. Firstly, the statistical similarity of the zone 223-3 assemblages with those from the modern wet rice paddy sites might be employed as empirical support for Jones' (2012) interpretation that the rice-like phytoliths found at these levels represent wet paddy cultivation from as early as 2000 cal BP. It should be noted, however, that no macrobotanical rice remains have been recovered from archaeological contexts of this age, and rice cultivation in the interior highlands of Borneo is thought to have played a minor role – if any at all – in subsistence until significant trade with Chinese and Malay populations in the lowlands in recent centuries (Barton and Denham, 2011; Ewart, 2009). This is discussed further in section 6.4 below. Alternatively, in light of the fact that the wet rice paddy sites were the only modern swamp and grassland fallows sampled in the present study, two additional possibilities must be considered. No modern analogues exist in the Kelabit Highlands for the prehistoric form of taro, yam, and banana-based vegiculture that has been inferred for comparable regions such as the Upper Waghi Valley of highland Papua New Guinea (eg Golson, 1977; Denham *et al.*, 2003; Fullagar *et al.*, 2006; Haberle *et al.*, 2012).

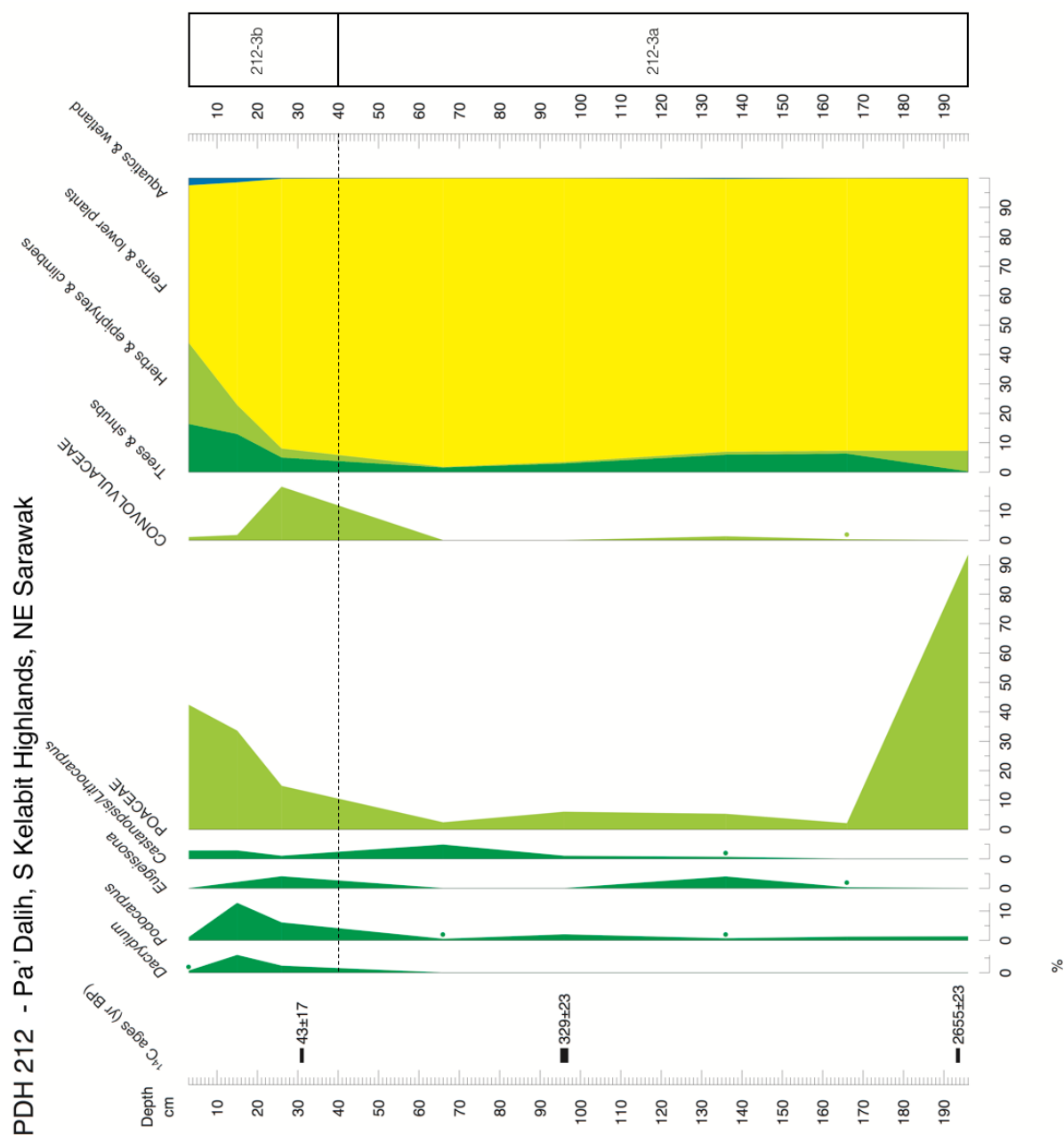
### **6.3.3 Pa' Dalih 212 (PDH 212)**

Core PDH 212 comes from another of the CRF palaeoecological sites that occupies an infilled palaeochannel cut into a river terrace. The palaeochannel and terrace from which this core was extracted are located about five hundred metres south from the present longhouse community at Pa' Dalih and from the site of the PDH 223 core analysed in the previous subsection (map in Figure 6.10, p. 229; refer to Jones (2012) for a more detailed map). Like the Ba record from



the Barrio area in the northern portion of the highlands, the PDH 212 sequence extends into MIS 3, but with a major discontinuity spanning the LGM, terminal Pleistocene, and early-mid Holocene (Jones *et al.*, 2014). The upper ~2m of the sequence, above an AMS age on charcoal of 2838-2744 cal BP at 194-193cm (Figure 6.15), provide the focus of the modern analogue analysis to follow. However, unlike at the Ba site, the late Holocene portion of the PDH 212 deposit is composed of clays, silts, sands, and charcoal bands with only a minimal organic component. As such, pollen counts and palynological richness are comparatively lower, suggesting poorer pollen preservation which probably owes to dynamic fluvial activity during the late Holocene and higher oxidation rates associated with greater magnitude fluctuations in the moisture content of these less-organic sediments. Assemblages displayed in the diagram above and used in the modern analogue analysis below constitute a subset of the data presented originally in Jones (2012), comprising only those assemblages with a main pollen sum (excluding fern spores) that exceeds 100 grains. This limits the analysis presented here to assemblages from eight subsample depths: those from 196, 166, 136, 96, 66, 26, 15, and 3cm. Assemblages from 136 and 96cm consist of pollen counts between 100-150 grains, whereas the remaining six assemblages have higher counts in the range of 250 grains.

Jones (2012) also notes this issue with preservation in the late Holocene portion of the PDH 212 sequence. However, on the basis of minor representation of *Eugeissona* pollen (see diagram above in Figure 6.15, which summarises Jones' pollen data), rounded-echinate phytoliths typical of palms, dominance of pollen from taxa indicative of open environments, Poaceae bulliform phytoliths which she attributes to *Oryza* (also in Jones *et al.*, in press), and lack of late Holocene signals from the other nearby cores for climatic cooling and drying, Jones argues that anthropogenic manipulation of vegetation is evident in this sequence from ~2800 cal BP. Specific interpretations to examine via ordination with the modern training set relate to: Jones' (2012) suggestion of possible sago management from 2000 cal BP; and much later notional signs of rice cultivation from 450 cal BP.

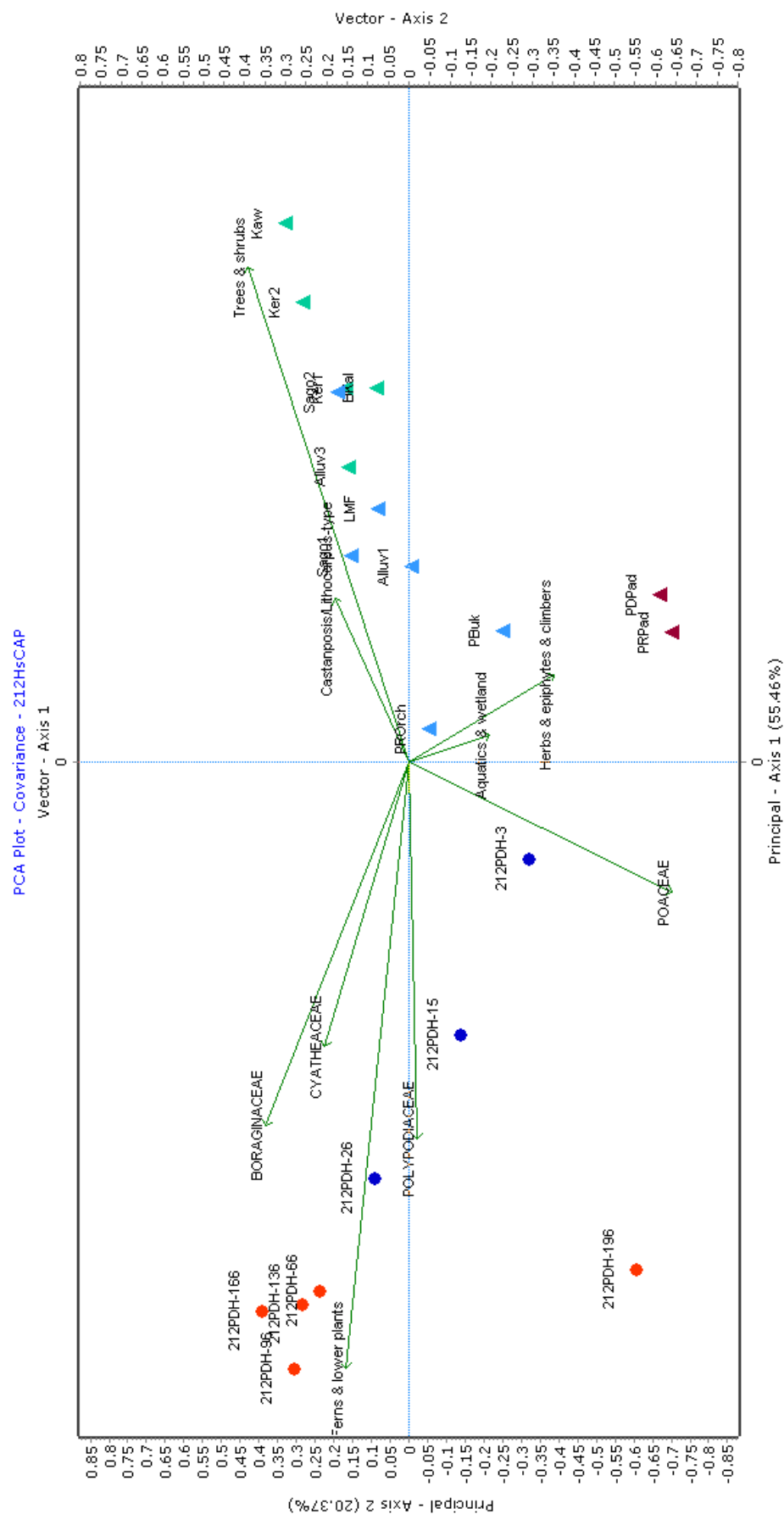


**Figure 6.15** Pollen diagram using data from Jones' (2012) PDH 212 core, showing uncalibrated <sup>14</sup>C chronology, curves for select taxa and summary groupings. Trees and shrubs in dark green; Herbs, epiphytes, and climbers in light green; Ferns and lower plants in yellow; Aquatics and wetland taxa in blue. Jones' original zonation notation appears at right.

### ***Modern analogue analysis***

Ordination of the late Holocene fossil assemblages from the PDH 212 sequence alongside those from the modern training set yielded a PCA plot (Figure 6.16) with similar relative structure to that of the nearby PDH 223 assemblages described in the previous subsection. The stratigraphically lower assemblages, which comprise zone 212-3a (red circles) and cover the majority of the late Holocene portion of the PDH 212 sequence (subsample depths 196-66cm), plot at the extreme left along Axis 1 (which accounts for 55.46 per cent of the variance across the dataset) at the ends of vectors representing various fern, open ground, and disturbance-indicating taxa. In contrast, all of the modern assemblages plot to the right of centre and are spread along the vector representing abundance of pollen from the Trees and shrubs summary grouping. The two modern wet rice paddy sites appear statistically distinct from all other samples, displaying very negative values with respect to Axis 2 (20.37 per cent of the variance). Vectors representing grasses, herbs, and wetland taxa roughly parallel this axis, implying a gradient in similarity to human-maintained open landscapes of a paddy nature. A trend is displayed across the fossil assemblages from the uppermost three subsamples, comprising zone 212-3b (blue circles), which plot progressively further from the cluster of fern-dominated assemblages of zone 212-3a and toward the modern paddy assemblages with decreasing depth.

Modern analogue analysis of Jones' (2012) original data from the PDH 212 sequence presented here does not suggest support for her interpretation that signatures of sago management might be present from 2000 cal BP (ie from subsample depths 166cm and above). Despite the exclusion from this analysis of assemblages with lowest pollen counts that likely represent preferential post-depositional survival of more robust microfossils, the preponderance of fern spores throughout the late Holocene portion of this sequence (refer to summary diagram in Figure 6.15) still distinguishes the constituent assemblages of zone 212-3a from those of the modern sites which include Sago Stands 1 & 2. Marginal pollen preservation throughout the key portion of this sequence prevents



**Figure 6.16** PCA plot of PDH 212 assemblages alongside the modern training set. Note the separation along Axis 1 (55.46% of variance) between clusters of fossil (coloured circles) and modern (coloured triangles) assemblages, the those from zone 212-3b (blue circles) trending toward the modern paddy assemblages.

meaningful statistical comparison of assemblages from these levels with the modern dataset. This is similar to, yet more pronounced than, the ambiguous results for modern analogue analysis of the oldest portion of the PDH 223 core. However, although statistically not as striking as the relationship between the post-2000 cal BP portion of the PDH 223 record with the modern paddy sites, the trend shown in the PCA plot across the uppermost three subsamples from the PDH 212 record (Figure 6.16) suggest a landscape of the past 250 years that looks increasingly with time like the modern wet rice paddy sites. The contrasts in timing between apparent onset of intensive human land use at these two sites which are so nearby to one another suggests the localised spatial scale across which human land use patterns were likely distributed during the late Holocene. This potentially provides a fossil signature of the ethnographically-documented Kelabit practise of periodically shifting the locales of their longhouses and spatial foci of land use (Ewart, 2009).

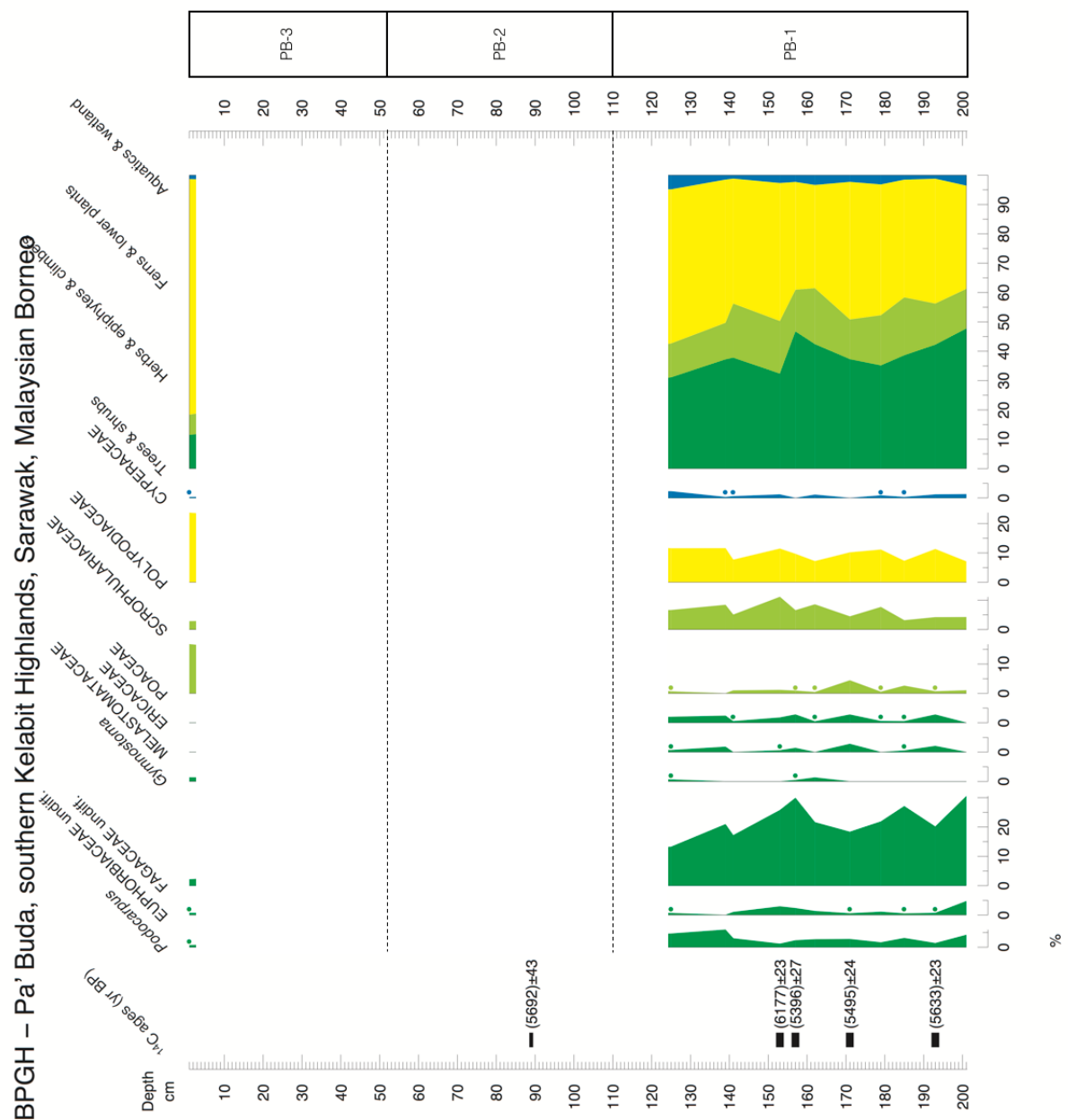
#### **6.3.4 Pa' Buda (BPG)**

The last of the four cores from Jones (2012) to be re-visited via application of the modern training set presented in Chapter 5 is the core from the site of Pa' Buda (site code "BPG" in reference to the nearby cluster of recently-abandoned Kelabit dwellings and paddy fields called Batu Patong). This site is both intriguing in that has been interpreted to represent the earliest signs of potential manipulation of forest by humans on the Kelabit Plateau, and also challenging owing to its apparent dynamic depositional setting and to its problematic chronology (Jones *et al.*, 2013a; in press). As with the majority of the CRF project fossil pollen sequences from the Highlands, save for that from site Ba, the BPG core comes from an infilled palaeochannel. The site is different from the other palaeochannels cored as part of the CRF project, though, as it was extracted from the fill of a paddy field in fallow that had been constructed within this palaeochannel. Jones (2012) states to have based selection of this particular site upon its physiographic similarity to other coring sites, combined with its perceived potential to yield direct insights regarding the history of rice cultivation in the highlands.

The basal ~70cm of the sequence (203-130cm depths) consists of alternating layers of sands, organic clays, organic silts, and charcoal (Jones *et al.*, 2013a). Ten of the twelve pollen assemblages re-examined here come from this basal 70cm of the core where pollen preservation was decent (average pollen sums of 186 grains per assemblage, with none below 167 grains). The lithology of the upper 130cm consists of

comparatively inorganic iron-mottled clays probably representing the intermittently oxidised clayey substrate of the recent wet paddy field. Within this upper portion, only the assemblage from 125cm depth at the base of these clays, and that from the very top at one cm depth show decent preservation that yielded pollen counts of greater than 150 grains. These two subsamples constitute the remaining assemblages analysed here. The stratigraphic gap in acceptable pollen preservation is reflected in the omitted levels within the pollen diagram reproduced from Jones' (2012) data below (Figure 6.17).

A series of five AMS ages were obtained from the BPG sequence, all on charcoal (Jones, 2012; Jones *et al.*, 2013a & in press). The lower four ages come from charcoal-rich layers within the basal, more organic sediments between depths 194 and 152cm. All of these ages fall between 7163-6218 cal BP, though they are stratigraphically mixed (uncalibrated  $^{14}\text{C}$  ages are shown next to the depth column along left margin of Figure 6.17). The remaining AMS age of 6573-6399 cal BP comes from a single charcoal fragment embedded in grey clayey sands at 89cm depth. Jones *et al.* (2013a & in press) interpret the lithology and radiocarbon ages to represent a deposit that accumulated rapidly within a palaeochannel following an episode of burning within the catchment centred around ~6500 cal BP. Pollen and phytolith assemblages indicative of a mosaic of forest, open environments, and back-levee swamp or oxbows were noted, with indications of disturbance throughout. Jones *et al.* (2013a) make particular mention that seral vegetation is not represented following disturbance, but rather assemblages with pollen of diverse families that contain fruit trees were tallied in the levels above distinct charcoal-rich layers. This evidence, combined with inferences from phytolith assemblages, led Jones *et al.* to suggest that the BPG record might represent arboricultural practises within the catchment from ~6500 cal BP. Assemblages from within the uppermost 30cm of the BPG core, including that from the one cm depth subsample included in the present analyses, are attributed to recent deposition reflecting the modern landscape dominated by rice paddy as well as secondary *kerangas* and lower montane forest.



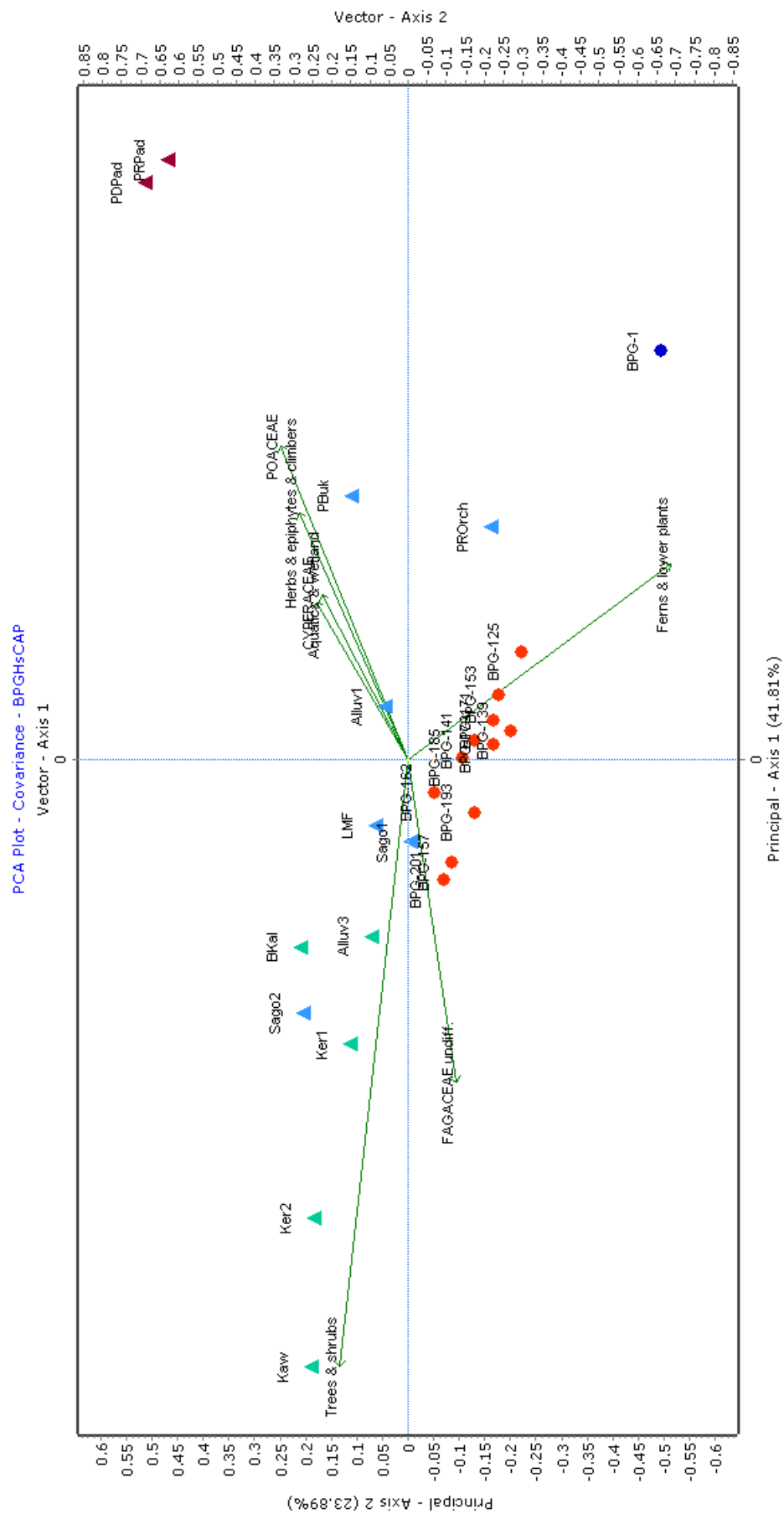
**Figure 6.17** Pollen diagram adapting data from Jones' (2012) BPG core, showing <sup>14</sup>C chronology, curves for select taxa, and summary groupings. Trees and shrubs in dark green; Herbs, epiphytes, and climbers in light green; Ferns and lower plants in yellow; Aquatics and wetland taxa in blue. Jones' original zonation notation appears at right. Gap represents levels of poor preservation.

### ***Modern analogue analysis***

Ordination of the twelve fossil assemblages from the BPG sequence with pollen sums in excess of 150 grains alongside the assemblages from the modern dataset is described here. Within the PCA covariance plot of this ordination (Figure 6.18), the distribution of assemblages aligns horizontally along Axis 1 (41.81 per cent of the variance across this combined dataset), roughly paralleled by a long vector representing relative abundance of pollen from the Trees and shrubs summary grouping. All of the BPG fossil assemblages (coloured circles) except for that from one cm depth (blue circle in lower right quadrant) cluster just below the intersection of the two principal axes, and are loosely surrounded by four of the modern assemblages from sites characterised by moderate levels of human modification of the vegetation (light blue triangles): Sago Stand 1; Lower Montane Forest; Alluvial Forest 1; and Pa' Ramapuh Orchard. The BPG fossil assemblages are distinguished from those of the minimally human-modified modern sites (light green triangles) by lower abundances of arboreal pollen and slightly greater fern components in the fossil assemblages, as evidenced by the relative positions with respect to the two vectors that represent those summary groupings. This ordination also seems to imply a closer similarity between the uppermost BPG assemblage with modern orchard and hill paddy sites than with the wet rice paddy sites.

This modern analogue analysis supports the interpretation put forth by Jones (2012) and expanded upon by Jones *et al.* (2013a & in press) that the BPG record contains signs of anthropogenic manipulation of the surrounding vegetation. The modern assemblages with which all of the BPG fossil assemblages display statistical similarity come from sites that are influenced by a moderate intensity of land use, whether this be management of sago or fruit trees (Sago Stand 1; Pa' Ramapuh Orchard), or disturbance via livestock trample or foot traffic (Alluvial Forest 1; Lower Montane Forest). However, ascribing these signs of human land use in the fossil record from the BPG core to a rough date of 6500 cal BP seems tenuous. All of the AMS ages come from





**Figure 6.18** PCA plot of BPG and modern assemblages. Fossil assemblages (red circles) cluster just below origin, surrounded by four modern assemblages from sites of moderate human impact.

charcoal, are stratigraphically out of sequence, and are embedded amongst layers deposited fluvially that contain indications of catchment-scale disturbance. An alternative interpretation to that offered by Jones (2012) and Jones *et al.* (2013a & in press), and the interpretation that is favoured here, is that deposition of the entirety of this sequence post-dates the five AMS ages spanning 7163-6218 cal BP, owing to fluvial redeposition of old charcoal that was liberated from its original contexts upstream when vegetation was removed via disturbance. *How much* younger the signs of past land use in the BPG record are than those mixed mid-Holocene dates is a matter of speculation that may go unresolved.

#### **6.4 Landscape-scale interpretations and Holocene narrative**

Application of the modern training set to the five fossil sequences examined above suggests a better fit for the data with a modification of some of the original interpretations put forth by Jones and CRF colleagues regarding palaeoecological signatures of Holocene land use. Simultaneously, these new analyses have strengthened some of the other original readings of the data. Of the five records analysed in the present study, four (BIO-7, PDH 223, PDH 212, and BPG) come from infills of palaeochannels which appear from their lithological sequences to have received periodic overbank flows during the late Holocene from the modern rivers to which they owe their ultimate origins. Whilst this is not ideal for interpretation of pollen taphonomy and radiocarbon chronology, nor for microfossil preservation, the similarity in physiographic settings do provide for cross-correlation.

The mid-late Holocene sedimentary sequences from these Kelabit Highlands records all begin with basal sands, overlain at the southern sites by alternating layers of organic silts, clays, sands, and charcoal. The alluvial valleys, floodplains, and slopes surrounding the highland plateau defined what was clearly a dynamic landscape at this time. Mid-late Holocene forests in and around the northern portion of the plateau consisted of a much larger *kerangas* heath component, as evidenced by the Ba and BIO-7 records, than did those of the southern highlands near Pa' Dalih which were dominated by the oak-laurel

associations of tropical lower montane forest (Ashton, 2014). This pattern mirrors the distribution of the highland vegetation types today (Lim, 2006) and undoubtedly reflects an interplay between topography and the distribution and Holocene development of underlying soils. As described in Chapters 2 and 3 in the introduction to the regional setting and earlier in this chapter, the bedrock geology of the northern and western margins of the Highlands is comprised of the late Miocene Meligan Formation of silicate sandstones. This unit provides the predominant sediment source carried by minor tributaries of the Dappur river flowing off the slopes of the Tama Abu range, and thus forms a large component of the Quaternary alluvium encased in valley bottoms as broad plains, river terraces and bases of palaeochannel fills across the northern portion of the plateau. This silicate sand-dominated alluvium, patchily distributed according to dynamic fluvial processes, formed the parent material for development of the podzols which support drought- and low nutrient-tolerant *kerangas* heath. In contrast, the southern and eastern portions of the highlands, which comprise the drainages of tributaries to the Di'it and Kelapang rivers flowing past Pa' Dalih, are underlain by an eroded anticline of the Oligocene-lower Miocene Kelabit Formation of turbiditic mudstones, sandstone and impure limestone (Singh, 1999). This formed the parent material for richer loams supporting lower montane forest, whilst also providing a source of varied sediments for the rivers of these southern drainages to sort and deposit episodically with fluctuations in flow regimes.

Signs of human modification of vegetation in the palaeoecological records appear earlier in the southern highlands from sites near Pa' Dalih than in the records from the Bario area. If the alternative interpretation of the chronology of the record from Pa' Buda (BPG) is correct, then the episodes of burning and signs of potential management of forest resources by humans seen in that record may date to a similar time as those of the PDH 223 and PDH 212 records. Both of these sites near Pa' Dalih display marginal pollen preservation with a diagenetic exaggeration of the pteridophyte component of their assemblages. It is thus difficult to compare in a meaningful way the sago-bearing assemblages from 2800-2000 cal BP from these records to those of the modern Sago Stand sites.

However, the assemblages from core PDH 223 from ~2000 cal BP onwards, that Jones (2012) tentatively interpreted to represent rice cultivation based upon pollen and phytolith evidence, are revealed by the modern analogue analysis presented in this chapter to be very similar to those from the modern wet rice paddy sites. This may mean that rice cultivation was practised in the southern Kelabit Highlands from ~2000 cal BP, possibly supplemented with some form of arboricultural management of sago and fruit trees, as Jones (2012) had initially postulated. And as Jones *et al.* (in press) note, this fits reasonably well with the earliest secure archaeological date in the southern highlands of 2050-1880 cal BP, from charcoal in the fill of a posthole at a site of a former settlement near Pa' Buda called Ruma Ma'on Dakah. However, since no modern analogues exist for fallows of forms of pre-rice non-sago cultivation that may have been practised during the mid-late Holocene, as in highland New Guinea (ie Golson, 1977; Denham *et al.*, 2003; Haberle *et al.*, 2012), the possibility cannot be ruled out that these assemblages represent swamp and grassland fallows following some form of land use other than rice paddy cultivation.

Signs of human modification of the vegetation from the records in the northern highlands appear slightly later, at ~1700 cal BP with evidence in both the Ba and BIO-7 records of an opening of the vegetation, presence of sago pollen, and assemblage-scale palynological signatures similar to those of the modern sites under human management of moderate intensities. The BIO-7 record also shows signs of what might be taro-based vegiculture. The earliest archaeological date from the northern highlands of 2026-1826 cal BP slightly predates these ecological imprints, coming from cremated bone within a stone mound called Perupun Raya Pa' Lungan north of Bario.

A final interpretation offered here is that the spatial distribution of soils of varying fertilities may have contributed to what appears to be an earlier adoption of paddy cultivation, perhaps based upon local wild *Oryza* species, in the southern highlands. In contrast, early subsistence in the northern highlands appears to have been based upon sago and fruit tree arboriculture, and possibly taro-based vegiculture. Support for this interpretation comes from ethnographic documentation of the Kelabit knowledge that rice cannot be grown on ground

from which *kerangas* forest was cleared (Janowski, 1991; Christensen, 2002; Pearce, *pers. comm.*, 2013), a knowledge undoubtedly gained through trial and error, perhaps with considerable time-depth.

## **6.5 Conclusion**

A new fossil record and four existing records from the Kelabit Highlands have been presented in this chapter and analysed in the context of the modern training set described in Chapter 5. Insights gained from these analyses provide support for some original interpretations of mid-late Holocene human modification of vegetation across the plateau, whilst also providing impetus for development of some alternative interpretations. In Chapter 7 to follow, the initial stages of application of this same approach within the different environmental and archaeological setting of seasonal, coastal northern Palawan is presented in order to demonstrate the potentially broad applicability of the approach.



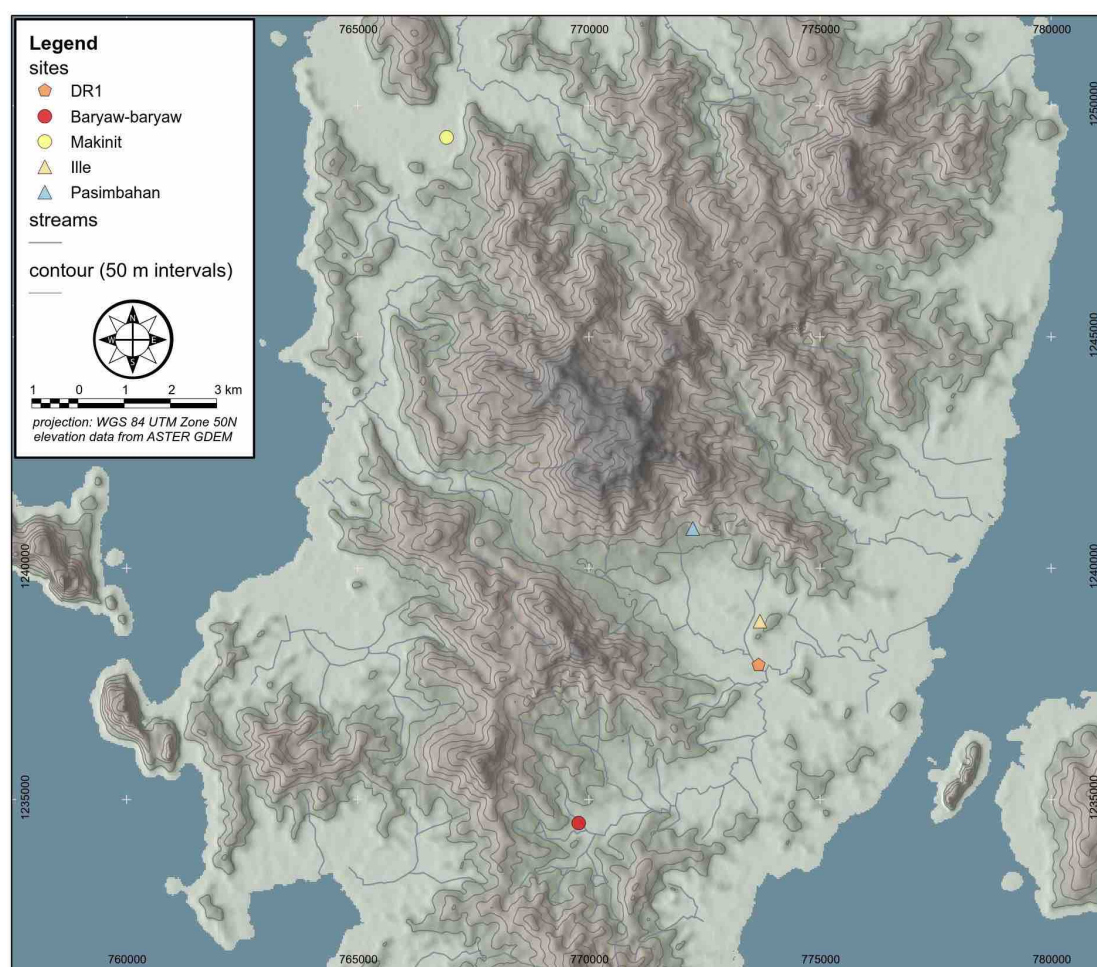
## **7 Palynological investigations into northern Palawan Island, Philippines**

### **7.1 Introduction**

The modern analogue approach described in Chapters 3 and 4, presented in Chapter 5, and demonstrated in Chapter 6 has enabled the development of holistic interpretations of potential human signatures in fossil pollen records from the Kelabit Highlands, Sarawak. Presentation of results for the initial stages of application of this same approach to the Dewil Valley and surrounding landscapes of lowland, seasonal northern Palawan Island in the western Philippines provides the focus of Chapter 7. The aims of this chapter are twofold: firstly, to highlight the potential utility of the modern analogue approach to detection of past land use within the context of ongoing archaeological research that has yielded a long terminal Pleistocene-Holocene record of cultural change (Lewis *et al.*, 2008; Paz *et al.*, 2010) in an environmental context different to that of the Kelabit Highlands; and secondly, to present original palaeoecological data that form the first fossil pollen record from the region and thus supplement existing archaeobotanical (Carlos, 2010), zooarchaeological (Piper *et al.*, 2008 & 2011; Ochoa *et al.*, 2014), and isotopic (Bird *et al.*, 2007) palaeoenvironmental records from the Dewil Valley.

Summary data from the programme of modern botanical surveys are presented first. As in the Kelabit Highlands, these data come from a suite of sites spanning various human-modified and natural vegetation types. However, as mentioned in Chapter 4, attempts at recovery of modern pollen from surface sediments in parallel with these surveys were unsuccessful, owing to low initial pollen concentrations in the dynamic and highly oxidised surface sediments at these sites, and further degradation of pollen residues between laboratory-based sample processing in Manila and microscopy in Cambridge. This issue and possible solutions for future work are discussed further in the concluding sections to Chapter 7. Absent corresponding pollen assemblages, the modern botanical data are presented in summary and provide for a description of the

vegetation types and land uses encountered within the Dewil Valley landscapes of today. This is followed by presentation of palaeoenvironmental data from a sediment core extracted from the Makinit Site within an adjacent catchment to that of the Dewil Valley, and in a similar physiographic setting to that from which existing archaeological records derive (Figure 7.1). In so doing, groundwork and a clear path are laid for future modern analogue investigation into potential signatures of past human land uses in pollen records from northern Palawan Island.



**Figure 7.1** Map of northern Palawan showing locations of palaeoenvironmental and archaeological sites. Two sites, DR1 and Baryaw-Baryaw, did not yield fossil data used in the present study, though the modern vegetation at Baryaw-Baryaw was surveyed. Map produced by Emil Robles.

## 7.2 Modern botanical data

The following data were collected during the week of 6-13 April 2013 as part of the present study, and in parallel with ongoing archaeological excavations at cave sites within the Ille, Pasimbahan, and Makangit karsts associated with the



annual field season of the Palawan Island Palaeohistoric Research Project (PIPRP). Sixteen sites spanning various vegetation types and land uses within and around the Dewil Valley were surveyed botanically for the present study (Figure 7.2). These surveys were led by Ramon Bandong, a University of the Philippines botanist who had previously conducted a similar botanical programme within the Dewil Valley in 2005, also as part of the PIPRP. All 16 sites sampled in 2013 occur below 100m elevation, though they collectively span various physiographic contexts. Lists of taxa were compiled for each of the 16 sites surveyed. Presentation of the botanical data here provides a descriptive picture of the heterogeneity of modern landscapes and vegetation communities encountered within the Dewil Valley, which together form a qualitative basis upon which the fossil pollen assemblages are interpreted.

Summary data are presented in Table 7.1; a complete species list appears in Appendix 1, which includes all taxa identified within the present study, supplemented by additional records from the similar programme of surveys conducted by Ramon Bandong in 2005. Chapter 4 of Jun Cayron's (2012) PhD thesis also provides for a few extra species records not noted during either of the surveying programmes led by Ramon Bandong. Across all of these surveys, at least 322 taxa were recorded. This is a minimum number, as individual sites which supported multiple congeneric species were often recorded simply as [*Genus*] spp. These 322 taxa represent 100 plant families and 261 genera. Of these 322 taxa, 222 were assigned species-level determinations, whilst 98 were identified to genus-level, and the remaining two taxa (Orchidaceae spp. and Menispermaceae sp.) were recorded at family-level. Ramon Bandong (in Stevenson *et al.*, 2006) notes the occurrence of five Philippine endemics: *Amorphophallus palawanensis* Bogner & Hett. (Araceae); *Dinochloa palawanensis* (Gamble) S.Dransf. (Poaceae); *Garcinia binucao* (Blanco) Choisy (Clusiaceae); *Gardenia longiflora* Vidal (Rubiaceae); and *Hoya el-nidicus* Kloppenb. (Apocynaceae). It should be noted that under the APG III classificatory system (APG III, 2009; Stevens *et al.*, 2001 onwards) *Gardenia longiflora* is now considered a synonym of the more widespread *Gardenia elata* Ridl., and the



**Figure 7.2** Dewil Valley aerial photograph from GoogleEarth. Flag-shaped pins show locations of most of the sites visited during the 2013 programme of botanical surveys; light blue balloon markers show locations of the Pasimbahan and Ille archaeological sites. Mangroves at the mouth of the Dewil River appear dark green in southeast corner of image; road from El Nido coming in from the northwest follows the axis of the Dewil Valley and parallels the river. The alluvial landscape of the valley plains appears on either side of the road as a patchwork consisting of rice paddies, gardens, and swidden regrowth. Hills fringing the valley can be discerned by their differently textured secondary lowland rainforest cover. Scattered karst towers cast distinct shadows. The Makinit site is eight km northwest from the area covered in this image, whilst site Baryaw-Baryaw is five km to the southwest.

taxonomic and nomenclatural status of *Hoya el-nidicus* remains unresolved.

Cayron's (2012) observations contribute valuable ethnobotanical insights and a descriptive physiographic framework for spatially grouping the various subsistence activities and tying them to landscape features. He divides the Dewil Valley landscape into four physiographic zones which support distinct vegetation communities and, thus, different suites of resources that people today exploit: a hill zone; a karstic tower zone; a plains zone; and a beach zone. The programme of modern botanical surveys for the present study included sites within the first three of these zones (Figure 7.3), with greatest representation of sites that fall within the plains zone. However, sampling also included sites that represent heterogeneity within this zone. For example, within this plains physiographic unit, four sites of paddy and swidden regrowth at various stages were classed as open grassland (sites Open Grassland 1-3, and site Paddy), three sites represent wetlands (sites Wetland, Miano Marsh, and Baryaw-Baryaw), two sites support riparian vegetation communities (Makangit Stream and Riparian), and the patch of forest at the base of the Ille karst tower was cleared in the early 1960s but has been allowed to regenerate ever since (site Secondary LRF2, 'LRF' being an abbreviated site name for Lowland Rain Forest).

There are, however, some commonalities running through this heterogeneity. Due mainly to intensive modern rice paddy farming and swiddening within the alluvial plains of the Dewil Valley and on the lower slopes of fringing hills, many early- to mid-seral stage elements of seasonal lowland evergreen forest are widespread. Within the sites classed as open grassland and secondary forest, the mid-successional species *Macaranga tanarius* (L.) Müll.Arg. and *Melanolepis multiglandulosa* (Reinw. ex Blume) Rchb. & Zoll. (both in family Euphorbiaceae) are conspicuous. Much of the swidden regrowth on the valley floor is dominated by dense stands of two bamboo species, *Schizostachyum lumampao* (Blanco) Merr. and *Dinochloa palawanensis* (Gamble) S.Dransf. (family Poaceae). Many small shrubby and herbaceous plants within the daisy (Asteraceae), nettle (Urticaceae), mint (Lamiaceae), and legume (Fabaceae) families form thick groundcover in disturbed areas. *Ludwigia* spp. (Onagraceae),

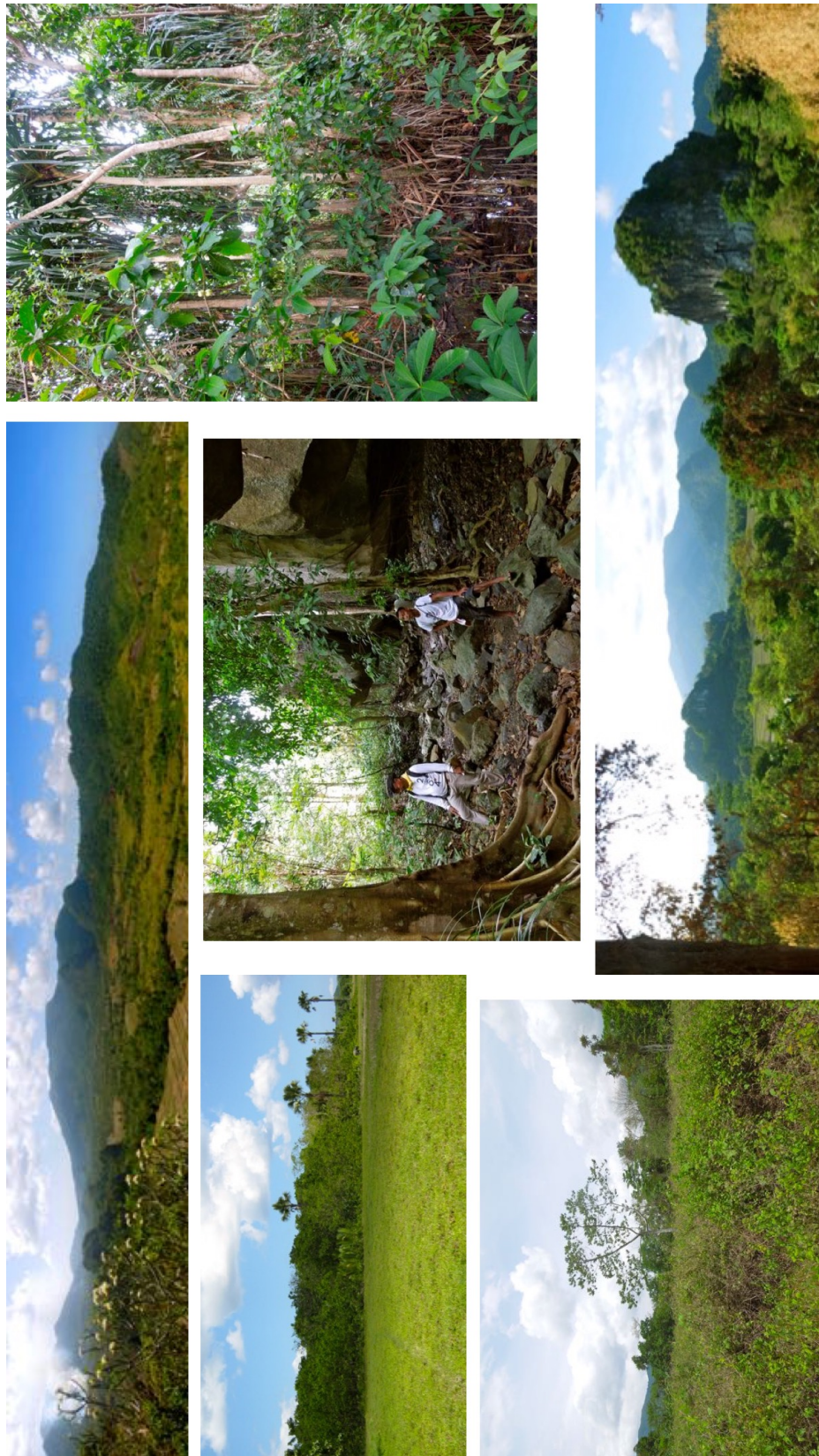
**Table 7.1** Summary data from botanical surveys in the Dewil Valley and surrounds from 6-13 April 2013.

Site Name	Elevation	Physiography	Land use	Important taxa
Back mangrove	9m	Mangrove	Foraging; perennial harvesting	<i>Bruguiera</i> spp., <i>Nypa fruticans</i> , <i>Acrostichum</i> spp., <i>Xylocarpus granatum</i>
Makinit	9m	Plain	Uncultivated; surrounded by paddy	<i>Hibiscus tiliaceus</i> , <i>Cerbera manghas</i> , <i>Palaquium</i> sp., <i>Glochidion</i> sp., <i>Flagellaria indica</i> , <i>Ficus</i> sp., <i>Sonneratia alba</i> , <i>Bruguiera</i> sp., <i>Acrostichum aureum</i>
Miano Marsh	15m	Wetland	Uncultivated; surrounded by paddy	<i>Pandanus tectorius</i> , <i>Senna alata</i> , <i>Cyperaceae</i> spp., <i>Alocasia macrorrhizos</i> , <i>Antidesma ghaesembilla</i> , <i>Nauclea orientalis</i> , <i>Ludwigia</i> sp., <i>Acrostichum</i> sp., <i>Asplenium</i> sp.
Wetland	16m	Wetland	Uncultivated; surrounded by paddy	<i>Ludwigia</i> spp., <i>Cyperaceae</i> spp., <i>Ipomoea aquatica</i> , <i>Monochoria hastata</i> , <i>Desmodium</i> sp.
Open Grassland 1	17m	Plain	Swidden	<i>Schizostachyum lumampao</i> , <i>Dinochloa palawanensis</i> , <i>Pachyrhizus</i> sp., <i>Chromolaena odorata</i> , <i>Lanata camara</i> , <i>Macaranga tanarius</i> , <i>Melanolepis multiglandulosa</i> , <i>Melastoma malabathricum</i> , <i>Phyllanthus niruri</i>
Open Grassland 3	20m	Plain	Swidden	Refer to Open Grassland1
Makangit Stream	21m	Riparian	Uncultivated; surrounded by paddy, veg gardens, artificial ponds with taro	<i>Cyperaceae</i> spp., <i>Barringtonia racemosa</i> , <i>Nauclea orientalis</i> , <i>Neonauclea</i> sp., <i>Elaeocarpus</i> sp., <i>Stenochlaena palustris</i> , <i>Nephrolepis</i> sp., <i>Azolla pinnata</i> , <i>Alocasia macrorrhizos</i> , <i>Colocasia esculenta</i> , <i>Nypa fruticans</i> , <i>Acrostichum aureum</i>
Paddy	23m	Plain	Permanent rice paddy in dry season fallow	<i>Oryza sativa</i> , <i>Mimosa pudica</i> , <i>Ageratum conyzoides</i> , <i>Colocasia esculenta</i> , <i>Lagerstroemia speciosa</i> , <i>Hyptis</i> sp.
Secondary LRF 2	25m	Plain	Swidden, last cleared in early 1960s	<i>Streblus asper</i> , <i>Artocarpus blancoi</i> , <i>Kleinhovia hospita</i> , <i>Canarium</i> sp., <i>Celtis</i> sp., <i>Garcinia</i> sp.

Riparian	26m	Riparian	Cultivated fruit trees	<i>Nauclea orientalis</i> , <i>Barringtonia racemosa</i> , <i>Pandanus tectorius</i> , <i>Pistia stratiotes</i> , <i>Coffea</i> sp., <i>Ficus</i> spp., <i>Mangifera indica</i> , <i>Anacardium occidentale</i> , <i>Chrysophyllum cainito</i> , <i>Cocos nucifera</i>
Limestone Forest	29m	Karst tower	Uncultivated; birds' nest & honey harvesting	<i>Begonia</i> sp., <i>Dracaena multiflora</i> , <i>Euphorbia trigona</i> , <i>Piperomia</i> sp., <i>Amorphophallus</i> sp., <i>Sterculia foetida</i> , <i>Plumeria</i> sp., <i>Drynaria quercifolia</i>
Baryaw-baryaw	31m	Wetland	Uncultivated surrounded by permanent paddy	<i>Typha angustifolia</i> , <i>Cyperaceae</i> spp., <i>Azolla pinnata</i> , <i>Radermachera</i> sp., <i>Nauclea orientalis</i>
Open Grassland 2	37m	Plain	Swidden	Refer to Open Grassland1
3-yr Regrowth	55m	Hill	Swidden, last cleared 3 years ago	<i>Melanolepis multiglandulosa</i> , <i>Macaranga tanarius</i> , <i>Ficus</i> spp., <i>Ipomoea</i> spp., <i>Hyptis</i> sp., <i>Tabernaemontana pandacqui</i> , <i>Trema</i> sp.
Pasimbahan	87m	Hill	Uncultivated; surrounded by limestone forest & swidden	<i>Streblus</i> spp., <i>Ficus</i> spp., <i>Koordersiodendron pinnatum</i> , <i>Pterocymbium tinctorium</i> , <i>Parameria laevigata</i> , <i>Balakata luzonica</i> , <i>Goniothalamus</i> sp., <i>Piper</i> sp., <i>Leea</i> sp.
Secondary LRF 1	99m	Hill	Selective logging	<i>Dipterocarpus grandiflorus</i> , <i>Vitex parviflora</i> , <i>Intsia bijuga</i> , <i>Azelia rhomboidea</i> , <i>Pterocarpus indicus</i> , <i>Shorea contorta</i> , <i>Canarium asperum</i> , <i>Koordersiodendron pinnatum</i>

*Monochoria hastata* (L.) Solms (Pontederiaceae), and multiple sedge taxa (Cyperaceae spp.), often in association with planted rice (*Oryza sativa* L.) and taro (*Colocasia esculenta* (L.) Schott), signify wetlands. Early successional species such as *Melastoma malabathricum* L. (Melastomataceae), *Mimosa pudica* L. (Fabaceae), *Urena lobata* L. (Malvaceae), and many grasses, daises, sedges, and legumes are common in paddy left fallow over the dry season during the northeast monsoon months of the northern hemisphere winter (November –





**Figure 7.3** Clockwise from top left (viewed in landscape layout): Dewil Valley landscape looking NW from atop the Ille karst tower, with the Makangit karst complex visible above the *Plumeria* at the left of the image, and Istar and Diribungan karsts the pyramidal hills just below the ridge in the centre distance; riparian vegetation at Makangit Stream, showing *Pandanus tectorius* and pneumatophores of *Elaeocarpus* sp.; looking NW from the fresh swidden at Open Grassland 2, with Ille at the right of the image, the Istar and Diribungan karsts in centre distance and the Makangit karst complex at left; site 3yr Regrowth with open ground taxa of Lamiaceae, Asteraceae, and Urticaceae with a fast-growing *Trema* sp. behind; patch of back mangrove and beach taxa at Makinit, with *Nypa fruticans* visible in centre along forest edge and scattered *Corypha utan* palms, amongst paddy and pasture; in centre, site Secondary LRF1 showing buttress roots of scattered mature canopy trees within an open forest on the hills fringing the Dewil Valley to the north.

April). Common riparian taxa growing along the valley drainages and streams that often flow around and through the bases of limestone towers include *Barringtonia racemosa* (L.) Spreng. (Lecythidaceae), *Nauclea orientalis* (L.) L. (Rubiaceae), *Pandanus tectorius* Parkinson ex Du Roi (Pandanaceae), an *Elaeocarpus* sp. (Elaeocarpaceae) with pneumatophores (see site Makangit Stream in Figure 7.3), and multiple *Ficus* spp. (Moraceae). Whilst no orchard sites were surveyed, many fruit trees are tended within the valley, dominated by cashew (*Anacardium occidentale* L., Anacardiaceae), mango (*Mangifera indica* L., Anacardiaceae), banana (*Musa* spp., Musaceae), jackfruit (*Artocarpus odoratissimus* Blanco, Moraceae), breadfruit (*Artocarpus altilis* (Parkinson ex F.A.Zorn) Fosberg, Moraceae), coconut (*Cocos nucifera* L., Arecaceae), and star apple (*Chrysophyllum cainito* L., Sapotaceae), with many others less abundant as well as fruits used as vegetables such as gourds and aubergines.

Whilst there are eight limestone karst towers scattered throughout the Dewil Valley landscape, only a single limestone forest site was surveyed. This was due mainly to accessibility. The site called Limestone Forest is a patch of distinctive vegetation growing in thin soil on one of the flatter portions of the route up to the top of the Ille karst tower. The vegetation is characterised by *Dracaena multiflora* Warb. ex Sarasin (Asparagaceae), *Begonia* spp. (Begoniaceae), *Euphorbia trigona* Mill. (Euphorbiaceae), *Piper* sp. (Piperaceae) creeping along limestone walls, *Amorphophallus* sp. (Araceae), *Ficus* spp. (Moraceae), and *Sterculia foetida* L. (Malvaceae). Apart from the introduced *Plumeria* sp. (Apocynaceae) growing on the exposed portions of the karst tower, this vegetation has been little manipulated by people as the most common modern land uses of these karst towers are harvesting of swiftlets' nests and honey (Cayron, 2012).

On hill slopes surrounding the intensively cultivated valley floor are remnants of secondary lowland evergreen forest. The forests occupying this physiographic unit have been selectively logged continuously since the 1960s (*pers. comm.* Ramon Bandong, recorded in field notes from 2013). A single site was sampled from this landscape unit, called Secondary LRF 1 (Secondary LRF 2 is the patch of forest regeneration at the base of the Ille karst tower which

supports a more highly disturbed vegetation with no dipterocarps). Indicative of its previous mature forest cover, the species composition of the open canopy at this site consists of *Dipterocarpus grandiflorus* (Blanco) Blanco (Dipterocarpaceae), *Vitex parvifolia* A.Juss. (Lamiaceae), and the leguminous species *Intsia bijuga* (Colebr.) Kuntze, *Afzelia rhomboidea* S.Vidal, and *Pterocarpus indicus* Willd. Other dipterocarps that occur within this zone are *Dipterocarpus gracilis* Blume, *D. hasseltii* Blume, and *Shorea contorta* S.Vidal.

One site at the landward edge of the expanse of mangroves at the mouth of the Dewil River, site Back mangrove (Figure 7.2), was surveyed as part of this study. Whilst the rest of the PIPRP team visited archaeological cave sites on islands immediately offshore from the mangroves at the mouth of the Dewil River, Ramon Bandong also informally recorded a few species within a patch of true mangrove near the river mouth. Recorded at this true mangrove site were *Rhizophora mucronata* Lam., *R. apiculata* Blume, *Bruguiera cylindrica* (L.) Blume, *Ceriops tagal* (Perr.) C.B.Rob. (all in family Rhizophoraceae), *Sonneratia alba* Sm. (Lythraceae), *Avicennia* sp. (Acanthaceae), and *Lumnitzera* sp. (Combretaceae). At site Back mangrove, on the landward edge of the mangrove complex where brackish water and tidal influence are present, *Bruguiera* sp. (Rhizophoraceae) is dominant, whilst *Nypa fruticans* Wurmb (Arecaceae), the mangrove fern *Acrostichum aureum* L. and a congeneric not identified to species (both in family Pteridaceae), as well as the mangrove mahogany *Xylocarpus granatum* J.Koenig (Meliaceae) co-occur. Finally, in a neighbouring catchment eight kilometres to the northwest from the Dewil Valley, but occurring at the same elevation as site Back mangrove (9m) despite being twice the distance from the present coast (3.5km versus 1.8km), the hot spring and coring site of Makinit supports a unique mix of beach forest, back mangrove, riparian, and open landscape taxa as an isolated island within a sea of permanently cultivated dryland rice fields, *Corypha utan* Lam. (Arecaceae) palms, and pasture. Species recorded in the modern Makinit vegetation include *Hibiscus tilliaceous* L. (Malvaceae), *Cerbera manghas* L. (Apocynaceae), *Palaquium* sp. (Sapotaceae), *Glochidion* sp. (Phyllanthaceae), *Flagellaria indica* L. (Flagellariaceae), *Ficus* spp. (Moraceae), *Sonneratia alba*, *Bruguiera* sp., and *Acrostichum aureum*. The substrate that



supports this vegetation is a fibrous peat capped by a thin, light-coloured mineral crust, both of which presumably owe their existences within this seasonal climatic setting and intensively managed surrounding landscape to the hot spring which issues from beneath and leaves via a small outlet stream. This provides a nice segue into the following presentation of the results from the programme of coring of the peats and underlying sediments at the Makinit site.

### **7.3 Makinit core sequence**

Palaeoenvironmental proxies from the Makinit sediment core are presented across the following subsections. Data from physical analyses are presented first, which include descriptions of the constituent lithological units, radiocarbon chronology, loss-on-ignition (LOI) measurements, magnetic susceptibility readings, and microcharcoal counts. Descriptions of the palynological results follow, comprised of a stratigraphic pollen diagram supplemented with multivariate statistical analyses which aid in revealing underlying structure across the pollen dataset as well as guiding interpretation.

#### **7.3.1 Lithology**

As mentioned in the section describing the modern vegetation, sediments at and immediately below the ground surface at the Makinit coring site today are dominated by peats capped by a thin mineral crust. A 480cm core was extracted from these deposits which had accumulated at the edge of what is now a hot spring and small outlet stream (Figure 7.4). The following is a brief description of the lithological sequence encapsulated within the Makinit core; these descriptions are summarised in Table 7.2.

The lithological sequence evokes that from Stevenson *et al.*'s (2010) core from coastal Paoay Lake in northwest Luzon. The entire sequence can initially be split between a lower portion of sands, silts, and clays of variable colour and organic content, and which often appear as thin bands and lamina, and an upper portion of fibrous peats which grade between dark brown and red-brown in colour. The change between these broad units occurs at 214cm depth (Figure



**Figure 7.4** Makinit coring, showing core site, peaty deposit, light-coloured surface mineral crust, standing pool of the hot spring, small outlet stream, and surrounding remnant riparian and back mangrove vegetation.

7.5). Within both of these portions of the sequence, subtler changes are noted. The basal 24cm of sediments (480-456cm depths) are composed predominantly of coarse sands. These are overlain by nearly 2.5m (456-214cm depths) of finer sands and silts which are variably grey, brown, and black in colour, and often occur as thin bands and lamina. Additionally, significant sections of these sands and silts exhibit a predominant underlying colour which suggest changes in depositional environment and hydrology. For example, from 456-384cm and again from 329-214cm shades of brown predominate, whereas light greys lend a gleyed and reduced look to the sediments from 350-329cm. Loss-on-ignition and pollen data will shed additional light on the palaeoenvironmental contexts in which these sediments were deposited. Within the upper peats, a thin layer of light brown sands or grit that resemble the mineral crust at the surface occurs at 52-50cm depth.



**Figure 7.5** Section of Makinit core spanning 200-250cm depths. Note the change at 214cm from upper fibrous peats at left to banded clays and silts of variable colour below and to the right.

**Table 7.2** Lithological descriptions of constituent units that together comprise the Makinit sequence. Grey background denotes peats of upper 214cm.

Depth (cm)	Description
0-7	Light brown sand / mineral crust
7-38	Dark brown sandy fibrous peat; less sandy with depth
38-50	Dark brown fibrous peat
50-52	Light brown sand (resembles mineral crust at surface)
52-100	Dark brown fibrous peat; more red with depth
100-119	Red-brown fibrous peat
119-122	Dark brown fibrous peat
122-131	Red-brown fibrous peat
131-133	Grey-brown organic detritus & peat
133-170	Red-brown fibrous peat
170-171	Red-brown fibrous peat with coarse sand
171-214	Red-brown fibrous peat
214-220	Dark brown organic, clayey silt
220-221	Light grey clayey silt
221-224	Dark brown & black bands of organic, clayey silt with charcoal
224-234	Grey-brown clayey silt with charcoal; large wood fragment
234-238	Light grey clayey silt with charcoal
238-239	Black organic, clayey silt
239-244	Grey-brown & light grey lamina of clayey silt with charcoal
244-245	Black organic, clayey silt
245-255	Grey-brown & light grey lamina of clayey silt
255-272	Dark brown organic, clayey silt with brown & black lamina; charcoal
272-275	Light brown clayey silt with dark brown & black lamina
275-277	Dark brown clayey silt with black lamina
277-287	Light grey clayey silt with charcoal
287-299	Grey-brown clayey silt

299-300	Light grey fine sandy silt
300-315	Light grey-brown clayey silt with charcoal
315-320	Grey-brown clayey silt with charcoal
320-329	Dark grey-brown clayey silt with black lamina
329-338	Light grey sandy, clayey silt
338-342	Light grey clayey, sandy silt
342-350	Light grey sandy, clayey silt
350-361	Light grey-brown sandy, clayey silt with brown lamina & charcoal
361-370	Dark grey-brown sandy, organic silt with charcoal; burnt wood
370-375	Grey-brown silty sand
375-382	Dark grey-brown sandy organic silt with charcoal
382-384	Grey silty light grey, coarse sand
384-389	Dark grey-brown sandy, organic silt
389-409	Dark grey-brown organic silt with minor sand component
409-418	Dark grey-brown organic, clayey silt with charcoal
418-419	Dark grey-brown silty sand
419-426	Dark grey-brown sandy, organic silt with charcoal
426-438	Dark grey-brown silty sand
438-456	Dark grey-brown sandy, organic silt with charcoal
456-461	Light grey coarse sand
461-465	Grey silty light grey, coarse sand
465-466	Grey coarse sand with charcoal
466-469	Grey silty light grey, coarse sand
469-472	Pale grey coarse sand
472-475	Light grey coarse sand
475-480	Dark grey silty light grey coarse sand

### ***Chronology***

Three AMS radiocarbon age determinations provide for chronological control of the Makinit sequence. Bulk sediment samples were submitted for all three due to lack of availability of individual large organic fragments at the stratigraphic positions of most interest. A coarse and a fine fraction of decayed plant fragments were separated from the sample at 20-19cm depth within the upper peats; the coarse fraction was selected for AMS age determination because it was perceived to be most likely to be stratigraphically intact and derived from plants growing on-site at the time of deposition of the sediments. Table 7.3 shows the depths and ages returned from all three samples. A linear regression on the three ages plotted against depth yields an  $r^2=0.99028$ , so linear

sedimentation is the assumed depositional model within the following descriptions of the palynological results. The chronology thus established for the Makinit sequence places the beginning of the record immediately following the conspicuous mid-Holocene (5000-7000 cal BP) shell midden deposits in the Ille and Pasimbahan archaeological records (Lewis *et al.*, 2008; Ochoa *et al.*, 2014; Piper *et al.*, 2011; Szabó *et al.*, 2004).

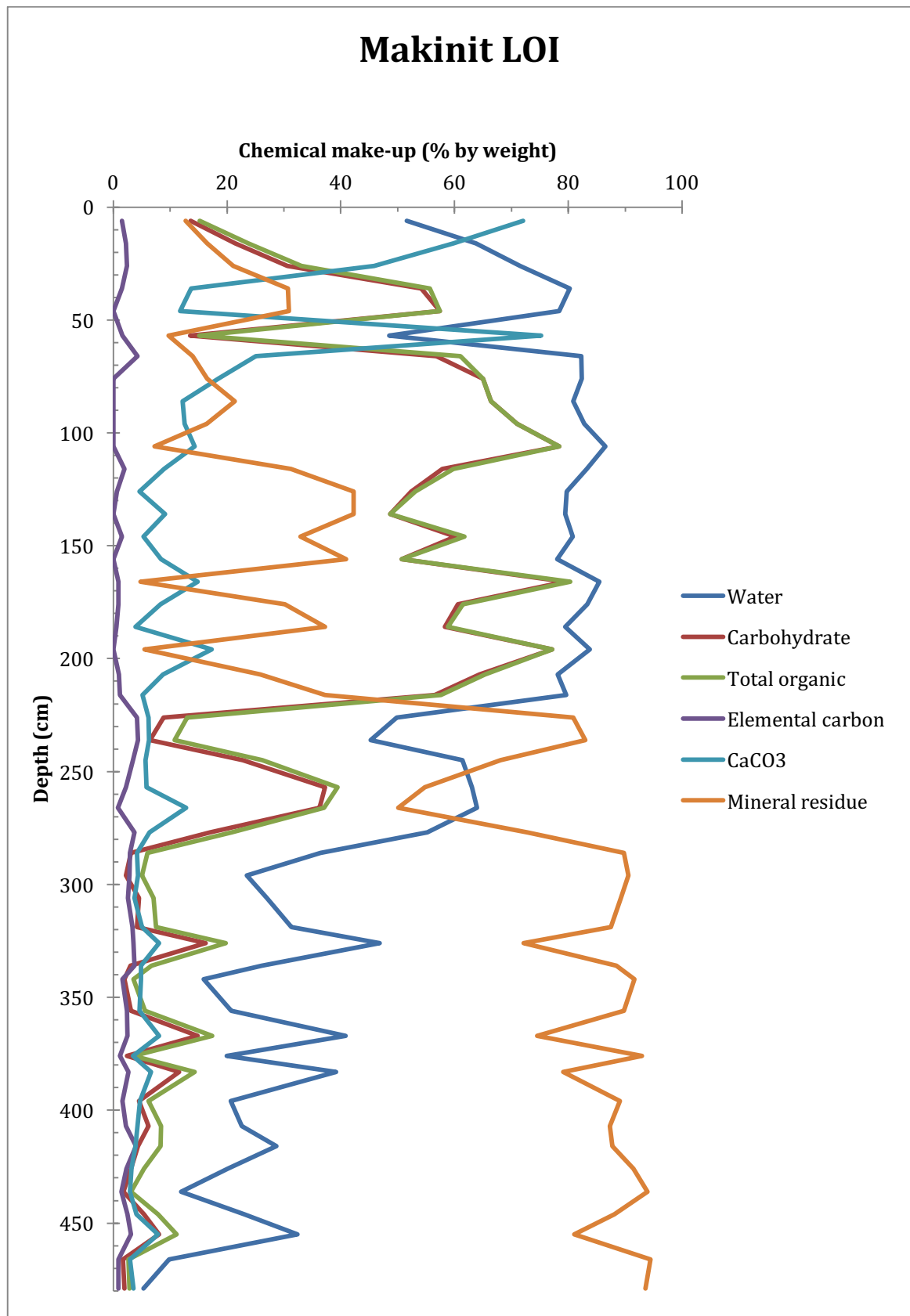
**Table 7.3** Makinit chronology provided by three AMS age determinations, yielding linear age-depth model.

Depth (cm)	<sup>14</sup> C yr BP	2-σ Calibrated	Material	Reference
19-20	140±30	285-0 cal BP	Plant fragments	Beta-399191
213-214	2682±26	2844-2752 cal BP	Bulk sediment	UBA-27250
453-454	4462±29	5285-4972 cal BP	Bulk sediment	UBA-27251

### ***Loss On Ignition (LOI)***

The Makinit sequence was subsampled for loss-on-ignition (LOI) analyses at roughly 10cm increments throughout the depth of the 480cm core. Sampling and processing methods followed those outlined in Chapter 4. Results are displayed as a line graph in Figure 7.6. Constituent chemical components are represented by coloured curves, with respective percentages by weight plotted on the horizontal axis against core depth in centimetres along the vertical.

An inflexion point at ~220cm depth is clearly visible, marking the lithological change highlighted in the previous subsection. Subsamples from 480-220cm depths are primarily mineral (average of 81.45 per cent by weight), but with many fluctuations which probably represent the same fluctuations in depositional environment inferred from the visual and tactile inspection of the core lithology. These lower, mineral-rich sediments are mostly fine-grained and of variable though minor organic content, suggesting a low energy subaqueous depositional environment subject to hydrological fluctuations. Changes in fluvial activity, rainfall, and/or water level of any standing water body at the site might produce such a sequence.



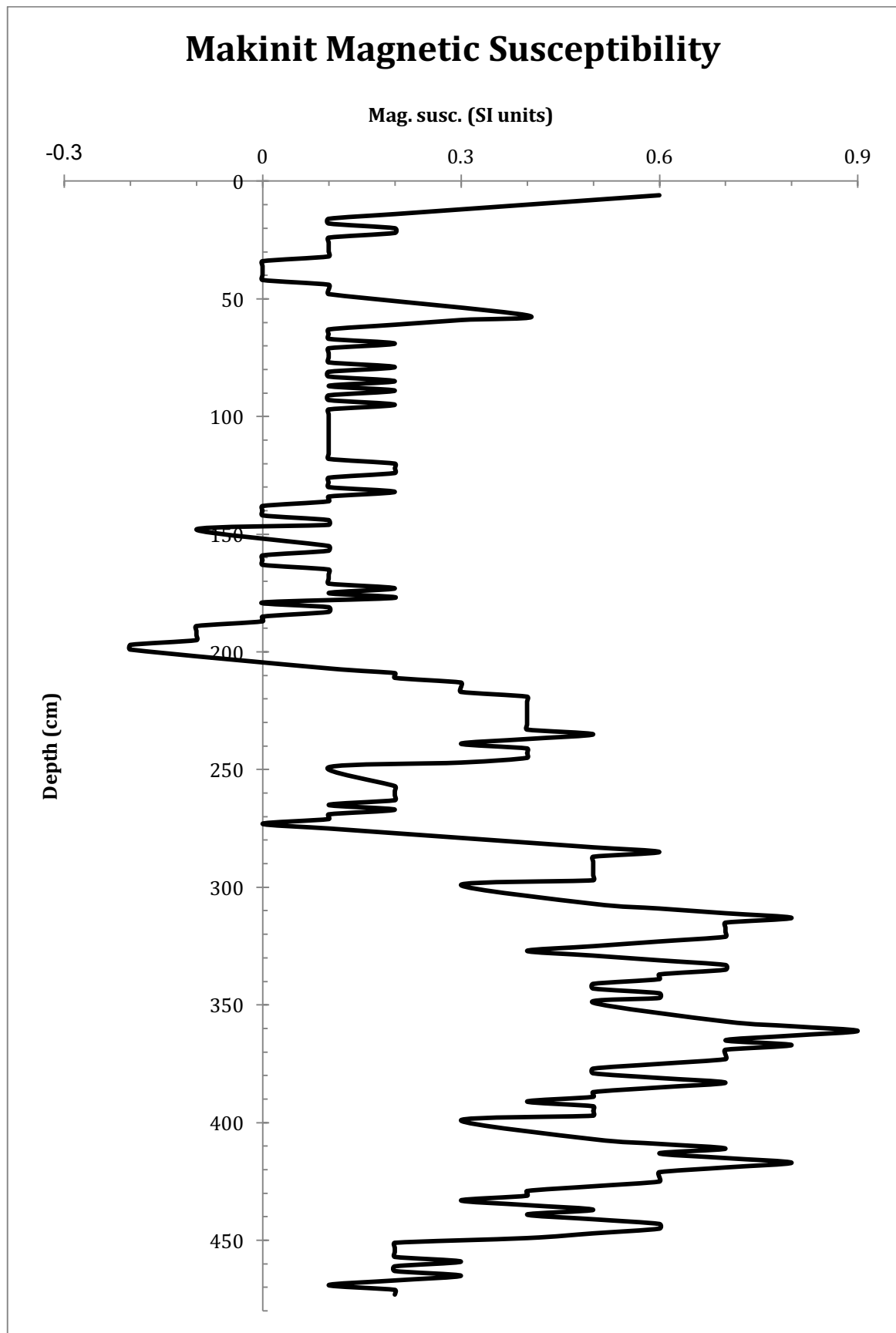
**Figure 7.6** LOI data for the Makinit sequence; the six coloured curves represent percentage by weight of respective chemical components of the sediments at a given depth. Note the change from basal mineral- to upper organic-rich sediments at ~ 220 cm, as well as discrete bands of carbonates at 57 cm and surface carbonate crust.



Whilst appearing visually more homogeneous than the underlying clays, silts, and sands, the upper 214cm of peats are revealed by the LOI data to fluctuate significantly in organic and mineral content. Above the marked change at 214cm, total organics constitute on average 55.31 per cent of the sediments by weight but range from a maximum of 80.37 per cent at 166cm to a minimum of 15.08 per cent at the discrete layer of grit or sand identified in the lithology at 52-50cm depth. Inspection of the carbonates curve in Figure 7.6 ( $\text{CaCO}_3$  in light blue), however, reveals a contrast between the chemical make-up of the basal sands (480-456cm depths) with this sandy layer and surficial mineral crust: these upper sands appear to be largely carbonates (>70 per cent by weight), whereas the coarse basal sands are of a different chemical composition.

### ***Magnetic susceptibility***

Magnetic susceptibility was measured at one cm increments across the depth of the Makinit sequence. These results, quantified in SI units, are presented in Figure 7.7. The basal mineral-rich clays, silts, and sands from 480-214cm are significantly and unsurprisingly more magnetic than the upper organic peats that overlie them. Oscillations within this lower portion of the sequence appear to exhibit cyclicities on multiple scales. In concert with the lithological descriptions and results from the LOI analyses presented above, these magnetic data suggest fluctuations in oxidation state of the ferromagnetic component of the sediments (Thompson & Oldfield, 1986), which implies dynamic hydrology at the site and an ultimate climatic driver. Based upon their magnetic signatures and visual appearance, the alternating bands of light brown, dark brown, gleyed and black clays, silts, and sands that comprise these lower units likely consist of various species of iron and manganese minerals in alternating reduced and oxidised states. Such minerals are common, mobile components of soils, especially those of the seasonal tropics that are slightly acidic and subject to frequent wetting and drying (Cornell & Schwertmann, 2003; Post, 1999). The discrete carbonate layer at 52-50cm, as well as the mineral crust which appears from the LOI data to be of the same composition, also display magnetic susceptibility values above those of the organic peats

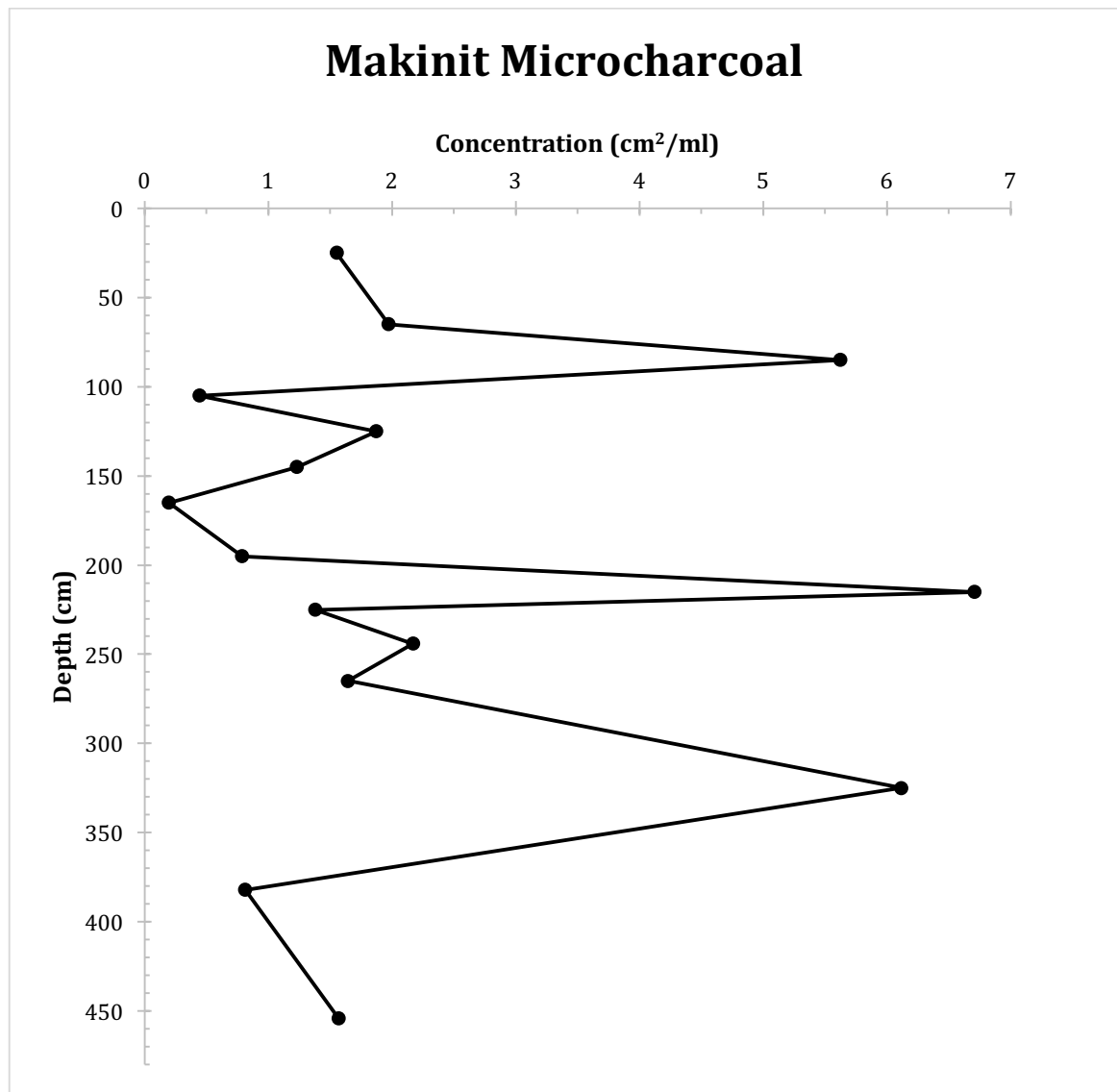


**Figure 7.7** Makinit magnetic susceptibility, showing the variably magnetic lower ~ 220cm and the near neutral upper peats. Note the magnetic peaks at 52-50cm and surface, associated with carbonates.



within which they are embedded. This indicates that these carbonate minerals are not pure calcite sands, but possibly derive from ferromagnetic impurities within nearby limestones (Schmidt, 2007). A petrographic study of the Upper Jurassic Imorigue Limestone that constitutes the distinctive karst formations within the Dewil Valley was conducted by Joseph Foronda, a University of the Philippines geologist, as part of the 2010 PIPRP field season (Paz *et al.*, 2010). His study classifies these limestones as commonly recrystallised and/or dolomitised mudstones with significant silicate and chert components, but with no mention of ferromagnetics. The likely scenario, then, is that the thin layer of carbonates at 52-50cm depth and those of the surficial mineral crust, both of which display elevated magnetic susceptibilities, are precipitates from dissolved minerals which include both carbonates and ferromagnetics within the groundwater that issues from the hot spring. These two levels within the sequence seem to represent periods of extended exposure to evaporative dry air resulting in mineral precipitation, suggesting temporary drops in water table or reduction in vegetative cover.

Microscopic charcoal counts from the same slides that contain the pollen assemblages are variable throughout the sequence (Figure 7.8). Whilst visual inspection of the core lithology revealed layers with increased abundances of macroscopic sand-sized charcoal particles (63µm–2mm) throughout much of the lower clays, silts, and sands, the curve for microcharcoal counts displays three distinct peaks at 325cm, 215cm, and 85cm depths. These peaks roughly coincide with higher magnetic susceptibilities, and likely represent periods of increased extra-local burning and mobilisation of sediment from slopes within the catchment.



**Figure 7.8** Microscopic charcoal abundance throughout the Makinit sequence, displaying three distinct peaks which roughly coincide with peaks in magnetic susceptibility seen in Figure 7.7.

### 7.3.2 Palynology

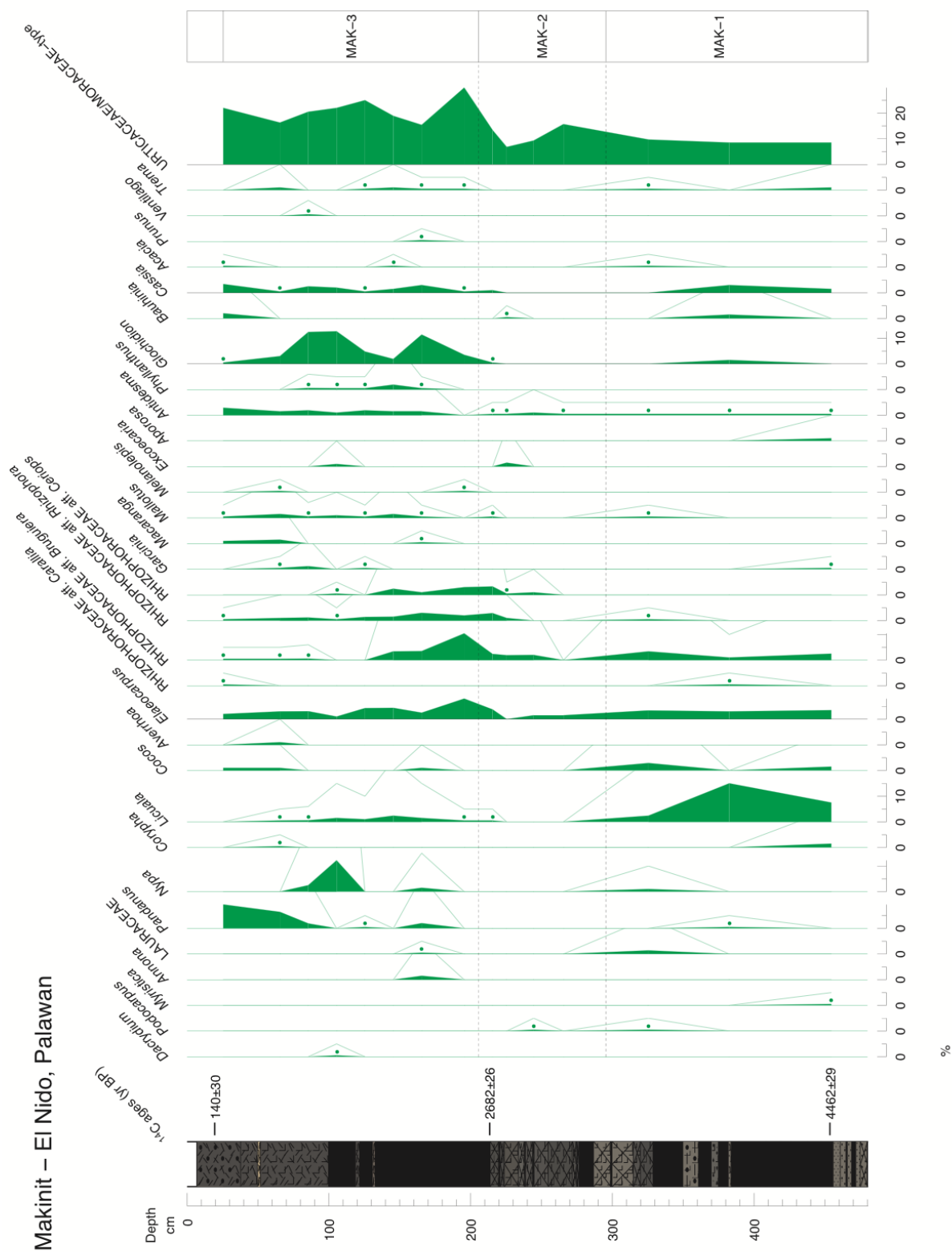
Pollen data from the Makinit core sequence are presented here in full. Fifteen subsamples yielded usable pollen assemblages with total counts exceeding 200 grains. These samples span the entirety of the depth of the sequence, thus producing the first record of vegetation history for northern Palawan Island which spans the past >5000 cal yr, albeit with coarse temporal resolution at this stage. Across the following subsections, these pollen data are presented in the same manner as were those from the BIO-7 fossil sequence from the northern Kelabit Highlands in the previous chapter. A stratigraphic pollen diagram is presented first, followed by multivariate statistical analyses

which justify diagram zonation and aid in interpretation of diachronic vegetation changes.

### ***Pollen diagram***

The complete stratigraphic pollen diagram from the Makinit core is split across the following four pages, appearing as Figure 7.9a, b, c, and d, respectively. Depth from the modern ground surface, expressed in centimetres, forms the vertical axis and is displayed along the left margin of all four pages. Similarly, in adjacent columns successively to the right of the depth scale are a sediment column representing core lithology, and the three radiocarbon ages expressed in uncalibrated radiocarbon years before present (yr BP). To the right of the radiocarbon age column are the relative abundances with depth curves for each pollen and spore type identified during microscopy, expressed as percentages of the relevant pollen sum. The order from left to right in which these pollen types are displayed is organised on two levels: firstly, by life form of the parent plant likely to have produced them, colour-coded accordingly (trees and shrubs in dark green; herbs, epiphytes, and climbers in light green; ferns and lower plants in yellow; aquatics and wetland taxa in blue); and secondly, within each of these life form groupings, taxa from lineages that are most ancestral according to the APG III classificatory system (APG III, 2009; Stevens, 2001 onwards) are plotted first, followed by those from increasingly derived lineages in columns proceeding to the right. Following the curves for individual taxa is a summary diagram (Figure 7.9d) in which aggregated curves for each of the four life form groupings are plotted. The final columns comprise zonation notation and a CONISS dendrogram which forms the statistical justification for definition of the pollen zones.

The following subsections contain descriptions of trends in the pollen data throughout the depth of the Makinit sequence and, therefore, across time spanning the local depositional history at the site. Descriptions are presented by zone, moving from the base of the core and, hence, the earliest assemblages deposited at the site up through to the top of the sequence and towards present day.

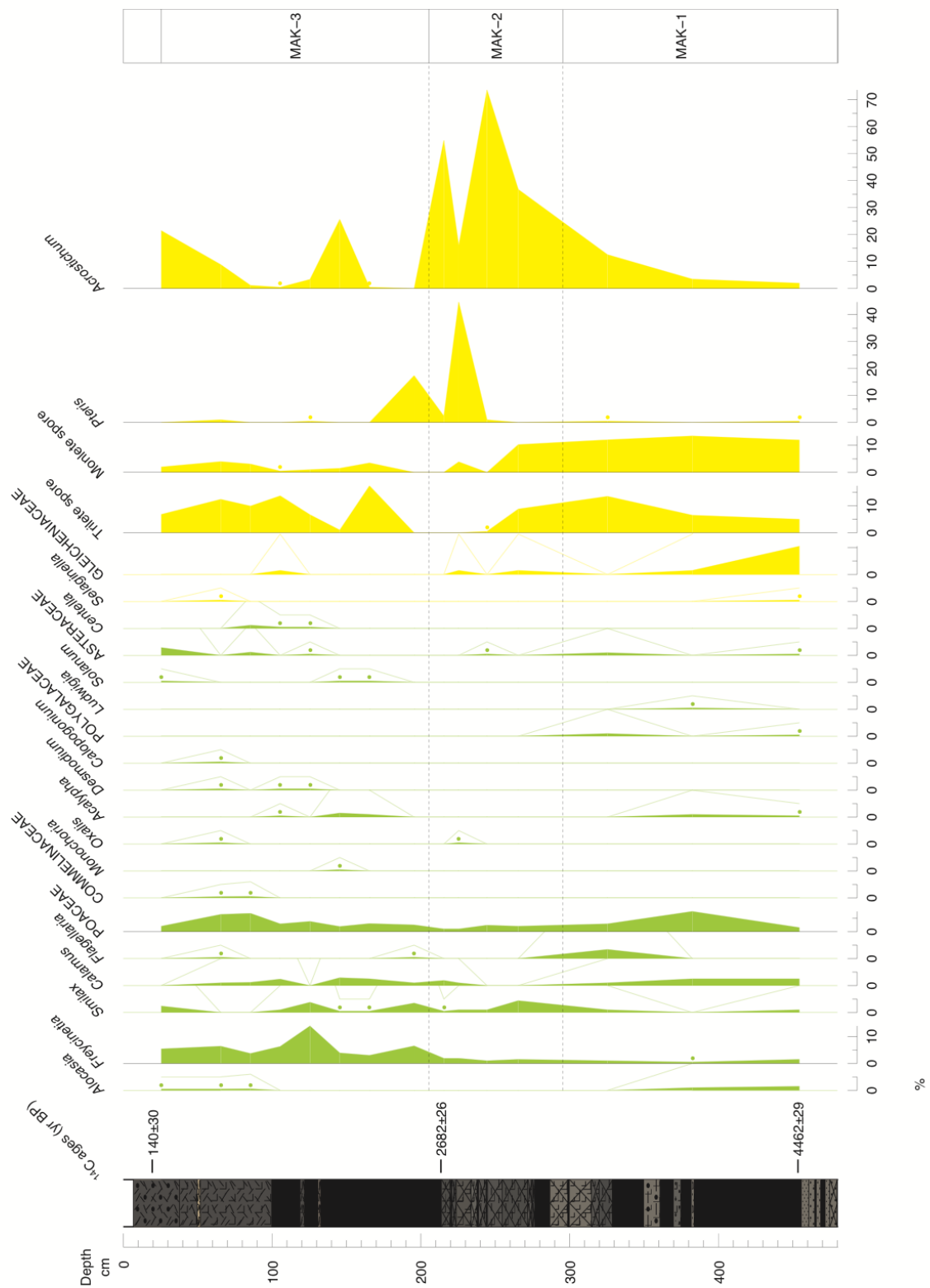


**Figure 7.9a** Makinut pollen diagram: tree and shrub taxa, with outline curves representing 10x exaggeration; dots signify non-zero values <1 per cent.

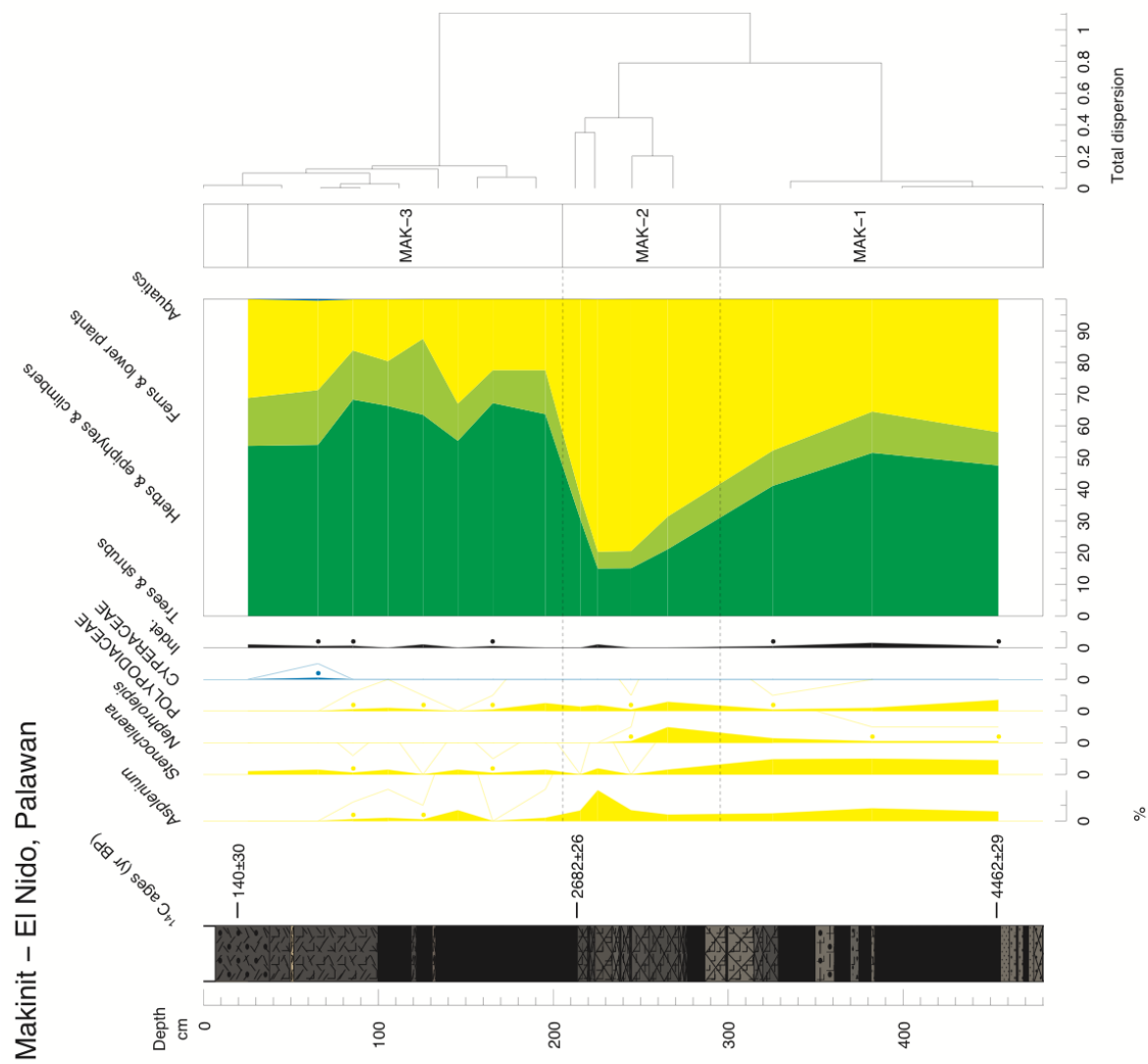


**Figure 7.9b** Makinit pollen diagram: tree and shrub taxa in dark green; herb, epiphyte, and climber taxa in light green. Outline curves are 10x exaggeration; dots show non-zero values <1 per cent.

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**Figure 7.9c** Makinit pollen diagram: herbs, epiphytes, and climbers in light green; ferns and lower plants in yellow. Outline curves are 10x exaggeration; dots show non-zero values <1 per cent.



**Figure 7.9d** Makinit pollen diagram: ferns and lower plants in yellow; aquatics and wetland taxa in blue. Outline curves are 10x exaggeration; dots show non-zero values <1 per cent.

**Pollen Zone MAK-1: 5285-3450 cal BP (454-296cm)**

Pollen zone MAK-1 spans the ~1800 years immediately following the period of 5000-7000 cal BP encompassed in the archaeological sequences at the Ille Cave & Rockshelter and Pasimbahan-Magsanib Sites by deposits interpreted as shell middens consisting of estuarine, brackish water, and mangrove species. The pollen assemblages within this zone are dominated by elements of beach forest, back mangrove, and freshwater riparian communities, with minor representation of seasonal tropical lowland forest of an open aspect. Individual pollen taxa indicative of beach forest within this zone are the fan palms (*Licuala*), coconut palm (*Cocos*), she-oak (Casuarinaceae, undoubtedly representing the beach she-oak or agoho, *Casuarina equisetifolia* L.), *Pisonia*, *Terminalia*, *Canarium* cf *littorale*, *Cerbera*, *Alocasia*, and *Flagellaria*. Back mangrove and true mangrove elements include *Nypa*, Rhizophoraceae aff *Bruguiera*, and *Avicennia*, whilst the presence of pollen from *Elaeocarpus*, *Syzygium*, and *Neonauclea* suggest freshwater streams nearby. Open, seasonal tropical forest is also suggested by minor occurrence of pollen from *Mallotus*, *Aporosa*, *Antidesma*, *Glochidion*, *Bauhinia*, *Cassia*, *Acacia*, *Trema*, *Ardisia*, *Tabernaemontana*, and grasses (Poaceae). The assemblages are composed predominantly of an even split between trees and shrubs, and ferns and lower plants, with minor representation of herbaceous plants.

**Pollen Zone MAK-2: 3450-2750 cal BP (296-206cm)**

MAK-2 encompasses assemblages that are dramatically different to those of both of the other two pollen zones, as will be further supported in the multivariate statistical analyses presented below. Nearly all elements of the Trees and shrubs summary grouping temporarily drop out of the record (in absolute counts as well as relative abundances) within the pollen assemblages of zone MAK-2, save for sparse occurrence of riparian and mangrove taxa *Syzygium*, *Barringtonia*, and *Avicennia* along with the hyper-speciose and ecologically diverse rubiaceae shrub genus *Psychotria*. Distinctiveness of zone MAK-2 is driven, however, by overwhelming fern spore representation within the constituent assemblages, largely composed of huge peaks in the back mangrove



fern genus *Acrostichum*. Whilst a diagenetic bias toward preferential preservation of robust fern spores is a possible explanation for assemblages within this zone, the gleyed, fine-grained clayey silts with frequent thin lamina along with minor persistence of riparian, and back and true mangrove taxa suggest that open, slow-flowing or standing water of a brackish estuarine environment is most likely. Also of note within this zone is marked representation of *Colocasia* pollen which may add support to the suggestion of open, standing water, as taro is frequently encountered in the Dewil Valley landscape of today on bunds of flooded paddy fields and along margins of ponds used to farm *Tilapia*. It is unclear whether the taro observed in such locations today are planted, feral, or wild forms, but the ecological setting alongside standing water bodies is consistent.

***Pollen Zone MAK-3: 2750-0 cal BP (206-25cm)***

Zone MAK-3 consists of the assemblages from the upper eight subsamples of the Makinit sequence, and thus spans the past 2750 cal yr. All eight subsamples that comprise this zone come from the peats that constitute the upper 214cm of the sequence. Despite the dramatic contrast in lithologies between the sediment from which this zone derives and those of the lower two zones, the pollen assemblages are very similar to those of the basal zone MAK-1. However, assemblages of zone MAK-3 are distinguishable from those of MAK-1 in their: lesser representation of the beach forest elements *Licuala*, *Cocos*, *Casuarinaceae*, *Terminalia*, *Canarium cf littorale*, and *Alocasia*; greater representation of back mangrove and true mangrove elements, as exemplified most markedly by taxa of *Rhizophoraceae*, as well as *Avicennia*, *Nypa*, *Xylocarpus*, *Pandanus*, and *Freycinetia*; greater prevalence of open landscape taxa and disturbance indicators such as *Macaranga*, *Mallotus*, *Antidesma*, *Phyllanthus*, *Glochidion*, *Cassia*, *Trema*, *Urticaceae/Moraceae-type*, *Melastomataceae*, *Sapindus*, *Nauclea*, *Desmodium*, and grasses (*Poaceae*); and minor representation of *Chisocheton*, *Thymelaeaceae*, *Dipterocarpus*, *Kleinhovia*, and *Ixora*, hinting at the presence nearby of patches of a more closed forest, perhaps on slopes, as gallery forests, or sheltered at the base of karst towers.

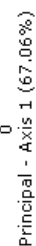
### ***Zonation***

The CONISS dendrogram that appears along the right margin of the final page of the Makinit pollen diagram (Figure 7.9d) provides statistical justification for delimitation of the stratigraphic sequence of assemblages into discrete pollen zones as described above. Horizontal lengths of branches represent dissimilarity or ‘dispersion’ scores between stratigraphically adjacent samples or groups of samples on either side of a given node. As can be seen in the structure of the Makinit dendrogram, zone MAK-1, which consists of assemblages from the basal three subsamples, as well as zone MAK-3, comprising the upper eight subsamples, have very high degrees of internal similarity. The horizontal lengths of the branches internal to both of these zones are an order of magnitude shorter than are the lengths of branches between each of the three zones. Additionally, there is greater internal dispersion between the four assemblages that constitute zone MAK-2 than there are within either of the other two zones. Thus, the CONISS dendrogram provides support for dividing the stratigraphic pollen record from the Makinit sequence into three zones, though MAK-1 and MAK-3 exhibit more internal cohesion than does MAK-2. This structure suggests significant environmental changes through time, particularly from the youngest of the MAK-1 assemblages at 3,450 cal BP through the MAK-2 assemblages to the oldest of the MAK-3 assemblages at 2,750 cal BP. This will be discussed further in the final section of this chapter within the context of relevant local and regional literature.

### ***Ordination***

The PCA plot presented in Figure 7.10 provides an alternative graphical representation of multivariate statistical comparison of the pollen assemblages that together comprise the Makinit record. The same underlying structure across the dataset can be seen in this plot as was revealed in the CONISS dendrogram just described. The assemblages which constitute zones MAK-1 (red circles) and MAK-3 (blue circles) cluster together around the origin of the ordination Axes 1 and 2. Axis 1 accounts for 67.06 per cent of the variability within the data, whilst Axis 2 encompasses 13.39 per cent. Assemblages from zone MAK-2 (green

circles) are diffusely spread across the half of the plot corresponding to negative values with respect to the primary ordination axis. This primary axis seems to represent a structural gradient, as suggested by the long anti-phase vectors for trees and shrubs, and ferns and lower plants, which are orientated askew to Axis 1 but with significant components parallel to it. Assemblages with higher relative abundances of tree and shrub pollen (all but one of the assemblages from zones MAK-1 and MAK-3) display positive values with respect to Axis 1 (right of centre), whilst the four MAK-2 assemblages that are dominated by various types of fern spores, exhibit negative values along Axis 1. Axis 2 seems to represent a compositional gradient that is most marked within the fern-dominated assemblages of zone MAK-2. Assemblages from 265.5, 244.5, and 215.5cm depths have higher abundances of the back mangrove fern genus *Acrostichum*, whereas the assemblage from subsample depth 225.5cm contains mostly *Pteris* spores. The ecological meaning of this difference is uncertain, but could potentially be related to a short-lived change from brackish estuarine water to a less saline environment. Within the more tightly clustered assemblages of zones MAK-1 and MAK-3, there appears to be a much weaker gradient driven by the higher abundances of back mangrove taxa in the MAK-1 assemblages and greater herbaceous as well as Urticaceae/Moraceae-type representation within the MAK-3 assemblages.



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#### 7.4 Interpretation and Holocene narrative

The suggestion from all lines of palaeoenvironmental evidence presented here from the Makinit sediment sequence is that of shifting, open coastal and sub-coastal environments against a backdrop of marine regression following the mid-Holocene high sea stand (Bird *et al.*, 2010). The composition and structure of vegetation implied by the constituent pollen assemblages are predominantly that of back mangrove, freshwater riparian, and seasonal tropical lowland forest of an open structure, with signs of both true mangrove and, within the last 2750 cal yr, patches of a more closed lowland forest nearby. Lamina within the mineral-rich basal portion of the sequence, combined with the open structure of the vegetation suggested by many elements of the pollen assemblages, are testament to marked seasonality and perhaps climatic variability across a range of supra-annual scales. Much evidence exists from both sides of the tropical Pacific from multiple palaeoenvironmental proxies for increasing intensity of the ENSO beginning between ~5000-3000 BP (Donders *et al.*, 2007; Gagan *et al.*, 2004; Goldammer and Seibert, 1989; Haberle and Chepstow-Lusty, 2000; Haberle and Ledru, 2001; Haberle *et al.*, 2001; Markgraf *et al.*, 1992; Mooney *et al.*, 2011; Partin *et al.*, 2007; Power *et al.*, 2008). This complicates attempts at disentangling climatic from anthropic signals within any mid-late Holocene record of vegetation and fire from the seasonal portions of the tropical circum-Pacific. Had acceptable concentrations of pollen been recovered from the suite of modern human-modified vegetation types, complete modern analogue analyses of the Makinit record might have informed interpretation of potential human signatures within the fossil pollen assemblages. This will have to be undertaken in the future, perhaps by placing some form of pollen traps or sampling polsters above the dynamic surface sediments in vegetation types of interest, followed by storage of pollen residues in cool, mildly acidic media so as to inhibit micro-organismal activity. As it stands, the causal mechanism(s) for the open structure of mid-late Holocene environments observed in the Makinit pollen assemblages is not speculated upon here.

Interesting palaeoenvironmental inferences can still be made, though, when the Makinit pollen record is considered within the context of existing data

and interpretations from various lines of evidence derived from PIPRP work on cave sediments from Ille, Pasimbahan, and Makangit. That the Makinit pollen record indicates open forest across the mid-late Holocene is significant, even if the mechanism(s) driving this vegetation structure is not obvious. In her master's research on archaeobotanical remains from Holocene contexts of the Ille Rockshelter deposits, Jane Carlos interpreted the frequent prevalence of *Canarium hirsutum* Willd. (Burseraceae) nuts to represent both the presence and human use of closed forest environments within the Dewil Valley (Carlos, 2010). Similarly, Michael Bird's isotopic analyses of a long guano sequence spanning the pre-LGM through late Holocene from a cave in the nearby Makangit karst complex (~500m west of Ille) suggests a transition from more open, C4-dominated vegetation during MIS 2 to a more closed forest during the Holocene composed mainly of plants using the C3 photosynthetic pathway (Bird *et al.*, 2007). Perhaps most interestingly, Piper *et al.* (2011) and Ochoa *et al.* (2014) note the early Holocene disappearance of large deer (*Cervus/Rusa* sp.) and the late Holocene (after 3500 cal BP) extirpation of the Calamian hog deer (*Axis*), as well as parallel increases in pig bones within the zooarchaeological assemblages at both Ille and Pasimbahan from the mid-Holocene around 5000 cal BP. Amongst the effects of human hunting pressure, they attribute the decline of deer bones and increase in those of pigs from the mid-Holocene to environmental changes associated with Holocene climatic amelioration and mid-late Holocene forest expansion at the expense of the previously widespread open landscapes.. In somewhat contrast to all of the aforementioned studies, the pollen sequence from the Makinit Site presented here does show minor evidence for the presence of lowland tropical forest of a closed structure after 2750 cal BP (cf curves for *Chisocheton*, Thymelaeaceae, *Dipterocarpus*, *Kleinhovia*, and *Ixora* in Figure 7.9b), but the most striking aspect of the dryland components of the sequence is the prevalence and persistence of open landscape taxa and possible disturbance indicators.

## 7.5 Conclusion

Initial stages of the modern analogue approach described and demonstrated in previous chapters have here been presented in the context of

the seasonal lowland tropics to show the potential widespread utility of the approach. Modern botanical data and the first fossil pollen sequence from Palawan together suggest the continuity throughout the late Holocene of open landscapes and resource-rich coastal environments amongst a mosaic punctuated, dissected, and bordered by patches of a more closed forest, riparian communities, and mangroves. This contrasts in some ways with inferences from other palaeoenvironmental proxies that suggest a predominantly forested sub-coastal landscape. Speculation as to the mechanisms driving maintenance of open landscapes has here been avoided. Future completion of full modern analogue palynological analyses can potentially reveal whether any signatures of past human management of vegetation can be detected.

In the following chapter, the results of the current study that have been presented across the previous three chapters are discussed within the context of the ongoing subdisciplinary dialogues relating to the nature of past human use of and impact upon rainforest environments. In so doing, implications of this study's results will be situated in relation to existing literature, future research directions, and modern conservation.





## 8 Discussion and conclusions

### 8.1 Introduction

In this final chapter, the present study is discussed within the contexts of current palaeoecological and archaeological dialogues surrounding past human-rainforest interactions. A brief recapitulation of the preceding chapters is offered first. This begins with a description of the framework upon which this research hangs. Major structural elements of this framework are provided by our evolving understandings of tropical forest histories and our roles in them, as well as the implications of these understandings for global conservation. The multidisciplinary nature of vegetation history is then highlighted in a summary of existing knowledge relevant to Island Southeast Asia (ISEA). Gaps in this knowledge are then recounted. This is followed by the general questions that this research addresses, and the modern analogue approach employed to address them. A brief statement is given of the palynological methodology used. Results are then discussed in relation to the specific questions posed at the outset of this research.

A critical assessment of the research follows this brief recapitulation. Discussion of the explicit assumptions of the modern analogue approach emphasises the potential pitfalls associated with a simple projection of the present upon the past. Weaknesses in the data are then acknowledged, and suggestions are made for how these might be redressed in future research. Particular attention is called to the degree of quantification in the present study, as well as the ever-present problems of temporal resolution and chronological control that represent challenges within most studies of fossil records.

The crux of this final chapter comprises a discussion of the contributions that this research makes to the relevant bodies of knowledge. A primarily regional scope is taken in situating the results of the present study within the contexts of current palaeoecological and archaeological interpretations and narratives. However, comments pertaining to tropical forest history globally are also offered. Discussion of the contributions that this work makes to the method

and theory of examination of human roles in rainforest histories then follows. Suggestions for future work that builds upon the present study are then offered. This thesis closes with some concluding reflections on where this research stands, and where related enquiry might go, with particular comparisons drawn between parallel dialogues in Amazonia and Madagascar regarding human-vegetation interactions in the past, and how these types of studies relate to conservation.

## **8.2 Recapitulation**

### **8.2.1 *Framework and approach***

Tropical forests are the most diverse and ecologically complex of all terrestrial biological communities (Myers, 1984). They are also of economic, intellectual, and spiritual value to people. This value is manifest in the sources of food, shelter, raw materials, knowledge, and well-being that tropical forests provide. Yet the ecosystem services that we receive from them are undervalued in the current economic paradigm (TEEB, 2010). The mounting pressure that this puts on tropical forest resources, and the peoples who depend directly upon them, has sparked global conservation initiatives, many stemming from the 1992 Rio Earth Summit. Responses to the threats to tropical forests represent both growing local initiatives and a gradual broadening of awareness within societies that derive value from the tropics, yet are spatially removed from them. Recognition of these threats have also stimulated continued research.

The temporal dimensions of ecological and cultural change are focal aspects of this research. Palaeoecology provides a temporally expanded perspective which enables the extension of long-term ecological monitoring. It thus provides for the establishment of new baseline information for conservation and restoration projects. As disciplines in the study of vegetation and human histories, respectively, palaeoecology and archaeology have key roles to play in unravelling the ways in which the cultural and natural pasts are entwined (Stahl, 1996; Troufflard, 2013). As well as encouraging multidisciplinary interpretations of human and vegetational histories, this perspective can be particularly informative in taking management and policy

decisions that aspire to social and environmental justice in the present and future. Such aspirations are embodied in the recently adopted UN Sustainable Development Goals (General Assembly resolution 69/315, 2015).

Palaeoecology and archaeology have ultimate roots within the uniformitarian geology that emerged from the Scottish Enlightenment, and have proved a successful tandem since the 1940s in uncovering nuances in the inter-relationships between cultural and ecological histories (eg Iversen, 1941; Simmons, 1969). Recent data from ISEA challenge existing archaeological and palaeoecological narratives and interpretations related to histories of subsistence and disturbance to vegetation. As a result, new questions are being asked, and new data called for. The impetus for the present study also derives from the need in the present to better understand patterns and processes of change in the past that operate on timescales greater than those encompassed within long-term ecological monitoring.

In parallel with the growing influence of ecological thought since at least the 1960s, an appreciation of the multidisciplinary nature of a holistic understanding of vegetational histories has also increased. The geological evolution of ISEA has driven changes in past distributions of land and sea; ocean and atmospheric circulation patterns; climates and soils, and thus the distributions of habitats; opportunities for biotic dispersals; and the distributions of environments and resources available for later human immigrants into the region to exploit. The continued northward drift of the Australian Plate since the mid Eocene, and the increasing constriction of the Indonesian Throughflow that has resulted as Australia has made contact with eastern Indonesia since the early Miocene, are linked with the initiation of the East Asian monsoonal system as well as the formation of the Indo-Pacific Warm Pool. Repeated drowning and flooding of the shallow continental shelves across ISEA during the Quaternary have driven geographic and climatic changes on timescales an order of magnitude shorter than those of the earlier Cenozoic.

These elements of the physical geography of ISEA provide for natural mechanisms of ecological disturbance, variability, and heterogeneity in space

and in time. The >50,000-year modern human prehistory of the region is embedded within ecological systems that have evolved over geologic time to coexist with regular disturbance. Drought, fire, and people all have long histories in ISEA. The problem of equifinality remains in interpretation of changes observed in proxy palaeoenvironmental records from the region.

Increases in the ecological importance of fire, evidence for vegetation of an open structure, and cultural changes across ISEA seem to co-occur in times and in places during the Holocene. Previous lack of success in identification of causal mechanism(s) driving these changes represented a primary gap in knowledge at the outset of the present study. Details regarding practices of landscape management around this time are also unclear, as the archaeological record across ISEA is heavily biased in favour of cave sites during this critical period. Details about what people were doing in the broader landscape outside of caves during the mid-late Holocene across ISEA are wanting.

The present study has addressed these knowledge gaps through a modern analogue approach, applied to detection of land use within the tropics. Through comparison of vegetation and pollen from a variety of modern land uses with fossil pollen records of vegetation history, the aim of this research has been to detect signs of land use in the past. In so doing, climatic and anthropogenic drivers of past vegetation changes begin to be disentangled, and a higher degree of objectivity is applied to resolving a picture of past vegetation management.

### **8.2.2 Methodology**

Botanical taxon lists were compiled at a suite of sites that span a gradient in land use intensity, as well as various 'natural' vegetation types. This was replicated within both of the case study areas: the Kelabit Highlands on Borneo, and in the Dewil Valley on Palawan. Modern pollen was extracted from surface sediments collected at each of these sites, though the modern pollen from the sites on Palawan were rendered unusable due to decay that occurred during delays in transit of this material. The resultant combined modern dataset from Borneo was then compared with fossil pollen assemblages for new and existing sediment cores using multivariate statistical techniques. A gentler method of

pollen extraction was used for all samples analysed in the present study. This was in light of the marginal preservation within the sediments studied, as well as to facilitate comparison with existing pollen assemblages from the region that were produced via the same technique. These pollen data were supplemented by microscopic charcoal counts, as well as collection of physical sedimentological data. Chronological control for the BIO-7 sequence from the Kelabit Highlands, and for the Makinit sequence from northern Palawan, was provided by a limited number of AMS radiocarbon age determinations.

### **8.2.3 Results**

This section provides a recapitulation of the results of the present study in relation to the specific questions posed in Chapter 3, which followed definition of the modern analogue approach (subsection 3.3.3; p. 73).

#### ***Are pollen assemblages from modern land uses statistically distinct?***

The results from the programme of botanical surveys and analysis of associated modern pollen assemblages from across the Kelabit Highlands of Sarawak were presented in Chapter 5 (pp 127-202). These results have shown that the pollen assemblages from modern land uses are indeed statistically distinct. This conclusion is supported, in part, by patterns observed in the summary diagram in which the pollen assemblages from all modern sites are displayed along the qualitatively assessed gradient in land use intensity (Figure 5.32; p. 195). Relative abundance of the summary grouping of pollen from trees and shrubs within a given modern pollen assemblage appears to be negatively correlated with the qualitative placement of that site along the land use intensity gradient.

Multivariate statistical analyses provide empirical support for these qualitative and semi-quantitative assessments of the modern data. The resultant dendrogram from the clustering analysis (Figure 5.33; p. 197) splits the 13 modern pollen assemblages into three primary groups defined by all adjacent samples connected by a node with Bray-Curtis similarity scores  $<0.796$  (50 per cent of the range of similarity scores across the modern dataset). These three groups correspond with high, moderate, and low land use intensities or 'natural'

vegetation as inferred independently via qualitative assessment. The wet rice paddy sites comprise the group of assemblages from the highest intensity of land use; the group representing moderate land use intensities encompasses assemblages from orchards, swidden regrowth, forest disturbed by foot traffic or livestock, and the sago stands; assemblages from the 'natural' vegetation or sites under a low intensity land use derive from patches of edaphically controlled vegetation such as *kerangas* or alluvial forest, as well as ridgetop vegetation. The PCA plot of these data (Figure 5.34; p. 200) further emphasises the distinctiveness of the wet paddy sites. Assemblages from the groups of sites representing moderate and low intensity land use form less pronounced though still distinct clusters.

***Are fossil assemblages statistically similar to those from modern land uses?***

Five 'modern analogue ordinations' were performed on subsets of the total pollen dataset from the Kelabit Highlands analysed in the present study, which includes both modern and fossil assemblages. These ordinations are presented in Chapter 6 (subsections 6.2.4-6.3.4; pp. 225-252). Each of these five ordinations included the 13 modern assemblages as part of their respective subsets; the remaining assemblages within each of these five ordinations encompass the Holocene portions of the five fossil core sequences. Only the subsamples that contained acceptable microfossil counts (ie total pollen sums > 150 grains) were included. In total across these five ordinations, 61 fossil assemblages were compared against the 13 modern assemblages. Statistical similarity was assessed based upon proximity of assemblages within PCA plots. This is semi-quantitative. This point is revisited in subsection 8.3.2 below.

Forty-five of the 61 fossil assemblages plotted within close proximity to at least one of the modern assemblages. In many cases, fossil assemblages are surrounded by multiple modern assemblages within the PCA plots. A parallel observation is that 12 of the 13 modern assemblages plot closely to at least one fossil assemblage. The only modern assemblage that did not appear to be an analogue of any fossil assemblage was that from Kawang. Of the 16 fossil assemblages that did not plot within close proximity to any of the modern

assemblages, all contain a greater than 55 per cent proportional representation of spores from ferns and lower plants. Ten of these 16 assemblages contain a fern spore proportion greater than 90 per cent of the total assemblage, whilst four of the remaining six have fern spore components between 80-89 per cent. The dissimilarity displayed between these fern-dominated assemblages and those from the modern sites is almost certainly due to a preferential preservation of robust fern spores within assemblages that are otherwise poorly preserved (ie Havinga, 1964). Excluding fern spores from the pollen sum of these subsamples would have effectively reduced the pollen sum to a few grains.

The modern analogue ordinations appear to show that the majority of fossil assemblages analysed are statistically similar to those from one or more modern land uses (45 out of 61, or 77.8 per cent). The utility in comparing fossil and modern assemblages appears to be dependent upon the state of fossil preservation, as the modern assemblages are all well-preserved. It may also be that some of these fossil assemblages come from environments that are not analogous to any of the modern sites sampled, though this is not possible to assess without larger non-pteridophyte counts.

***What patterns through time can we see in the relationships between fossil and modern assemblages?***

Different chronologies and diachronic patterns are displayed within core sequences from the southern Kelabit Highlands (PDH 223; PDH 212; and Pa' Buda) and those from the northern sites (Ba and BIO-7). Assemblages from 2000 cal BP and younger in core PDH 223 cluster with the two assemblages from modern wet rice paddy sites. The upper three assemblages at site PDH 212 that date to the last 250 years display increasing similarity through time with the modern orchard, swidden regrowth, and two wet rice paddy assemblages. The antiquity and chronology of the Pa' Buda sequence are uncertain, as the five radiocarbon ages from the 2m core all come from charcoal, all fall between 7163-6218 cal BP, and are stratigraphically mixed. Combined with the nature of the sediments, it is likely that these ages represent reworked charcoal liberated from slopes within the catchment of the coring site. The palaeochannel infill from

which this core derives sits ~7m above the modern river channel, suggesting significant antiquity (C. Hunt, *pers. comm.*, 2016), though the true age of the sequence may remain a matter for speculation. However, 11 of the 12 fossil assemblages from the Pa' Buda core analysed in the present study form a cluster within the PCA plot that is bounded by four modern assemblages, all from sites supporting vegetation under moderate intensity land uses: those from Sago Stand 1, Lower Montane Forest, Alluvial Forest 1, and Pa' Ramapuh Orchard. Therefore, these assemblages from the Pa' Buda core likely represent a parent vegetation under moderate intensity human management sometime more recently than ~6200 years ago.

Trends within the two cores from the northern portion of the Kelabit Highlands (Ba and BIO-7) reinforce one another. This is unsurprising as the coring sites are on adjacent terraces. Fossil assemblages older than ~1700 cal BP in both cores align closely with the modern assemblages from natural vegetation types. After 1700 cal BP, fossil assemblages display statistical similarity with modern assemblages from the sago stand sites and the disturbed forest sites of Lower Montane Forest and Alluvial Forest 1. Additionally, the upper three assemblages from the BIO-7 core display elevated values for *Colocasia* pollen (5-9 per cent of the assemblages). These assemblages overlie a radiocarbon age reversal (discussed below in subsection 8.3.2), so the antiquity of this suggested increase in the abundance of taro is not certain.

Two conclusions can be drawn from these trends. Anthropogenic signatures in fossil pollen sequences are suggested slightly earlier in the southern Kelabit Highlands (~2000 cal BP) than in the north (~1700 cal BP). It should be noted, however, that this 300-year difference is small relative to the precision of the radiocarbon ages, so this temporal difference is tentative. The forms that these signatures take differ. The possible presence of wet rice paddies is suggested from 2000 cal BP near Pa' Dalih, whilst the land use signatures in cores from the north near Bario are more akin to those from moderate intensity forest use and from the modern sago stands. This spatial heterogeneity may potentially be due to the distribution of soil fertility. The nutrient-poor siliceous sandy substrates and *kerangas* forest are more prevalent in the northern portion



of the Highlands. *Eugeissona* species (particularly *E. tristis*) in the lowlands are known to occur within *kerangas* forest (Dransfield *et al.*, 2008), and the term *kerangas* refers to land that, if cleared, is unsuitable for rice farming (Ashton, 2014). The palynological trends may reflect local-scale spatial patterning in past land use in response to soil fertility, with early wet rice paddies focused in the southern Highlands where the bedrock mudstone geology of the Kelabit Formation provides parent material for relatively fertile soils, whereas the geology in the northern Highlands that is dominated by second-cycle orthoquartzose sandstones of the Meligan Formation yields open-draining siliceous sandy soils that support *kerangas* forests and that might only be usable for sago harvest.

#### ***Do these patterns support previous interpretations?***

Patterns within the cores from the northern Kelabit Highlands (Ba and BIO-7), as well as the post-2000 cal BP portion of the PDH 223 core from Pa' Dalih, support the interpretations suggested originally in Jones (2012) and expanded upon in subsequent publications (eg Jones *et al.*, 2013a&b; 2014; in press). Particularly, these results support the spatial heterogeneity noted in Jones *et al.* (in press) with early signs of rice in the south and possibly sago in the north, as well as the slightly earlier sign of human-rainforest interactions in the south of the region.

In contrast, these results suggest that the statistical dissimilarity between the modern assemblages and those of most of the Holocene portion of the PDH 212 sequence, as well as the pre-2000 cal BP assemblages from the PDH 223 core, is likely due to post-depositional diagenetic processes. These assemblages are overwhelmingly composed of fern spores, which are thick-walled and are more robust than most pollen grains (Havinga, 1964). Additionally, pollen of *Eugeissona* are large and highly ornamented (Dransfield *et al.*, 2008), and so are also likely to preserve preferentially in sedimentary contexts. All of the subsamples from the two cores from near Pa' Dalih that contain hill sago pollen in relative abundances higher than two per cent, also contain fern components greater than 75 per cent. The highest values for *Eugeissona* pollen in any of the

fossil assemblages from the Kelabit Highlands come from the PDH 223 core, specifically from subsample depths 241cm (15.2 per cent), 183cm (9.4 per cent), and 173cm (16.7 per cent). The fern spore components of all of these assemblages are greater than 82 per cent, and contain very little else other than fern spores and sago pollen.

Compare these fossil assemblages with the modern assemblages from the two sago stand sites. The assemblage from Sago Stand 2 (Figure 5.7; p. 145) in the southern Kelabit Highlands is diverse, and contains 55.2 per cent *Eugeissona* pollen and 19.3 per cent fern spores; the assemblage from Sago Stand 1 (Figure 5.21; p. 173) in the northern Highlands is also diverse, and contains 38.5 per cent *Eugeissona* pollen with a fern spore component of 41 per cent. Relative abundances of sago pollen and other flowering plants are much higher in these modern sago stand assemblages than in the fossil assemblages from PDH 223, and fern abundances are much lower. It is possible that the fossil assemblages from the PDH 223 core that contain elevated proportions of hill sago pollen alongside overwhelming percentages of fern spores could represent diagenetically augmented assemblages that were similar to those from the modern sago stand sites shortly after the fossil assemblages were deposited. Alternatively, these fossil assemblages from the Pa' Dalih cores might represent some form of sago management that has no modern analogue. The conclusion, however, is that the results of the present study neither preclude the possibility, nor support the interpretation, that the PDH 223 and PDH 212 cores contain signs of ancient sago use. Preservation is too marginal for a convincing case to be made on the current evidence.

#### ***How do these patterns relate to existing archaeological narratives?***

On a local scale within the Kelabit Highlands of Sarawak, the palaeoecological signs of past land use inferred from the modern analogue analyses of the present study chime well with the oldest ages from secure archaeological contexts, as described in Chapter 3 and detailed in Lloyd-Smith *et al.* (2010; 2013). The oldest archaeological radiocarbon age from the southern Kelabit Highlands of 2050-1880 cal BP comes from charcoal from the fill of a

posthole at the old longhouse site of Ruma Ma'on Dakah. This site is situated on a terrace of the Kelapang river, ~5km south from Pa' Dalih and the coring sites of PDH 223 and PDH 212. Directly across the Kelapang river from Ruma Ma'on Dakah is another old settlement site, Ruma Ma'on Taa Payo. Two stone pounders with palm starch granules on their surfaces (Figure 3.16; p. 91) were recovered from a trench at this site in association with a posthole that produced charcoal dated to 1540-1360 cal BP from its fill (Lloyd-Smith *et al.*, 2010). In the north, at a megalithic site called Perupun Raya Pa' Lungan, cremated bone from within a stone mound produced an age of 2026-1826 cal BP, which slightly predates the suggestion of local sago management in the pollen records from ~1700 cal BP. The only archaeobotanical rice remains recovered from CRF sites are sparse and come from the last 250 years (Lloyd-Smith *et al.*, 2013). On all of this evidence, it seems that people were in the Kelabit Highlands by at least 2000 cal BP likely exploiting sago and possibly taro in the north near Bario, and perhaps a mixture of rice, possibly sago, and other tree and root crops in the south around Pa' Dalih.

On a regional scale, these interpretations of the results of the present study, and those of the CRF as a whole, are consistent with occupation of this part of the Borneo highlands by the early Metal Period (~2500 cal BP; Lloyd-Smith *et al.*, 2010). Whilst the literature review in Chapter 2 summarised the mounting evidence for pre-Austronesian exchange networks and sophisticated forms of plant processing and hunting techniques at sites across ISEA since the terminal Pleistocene, the results of the present study cannot add to this dialogue. This will be discussed further in the following section.

### ***Data and insights from Palawan***

The Makinit sequence forms the first fossil pollen record from Palawan Island. The pollen assemblages, charcoal counts, and lithological sequence of the Makinit core all display evidence of cyclic disturbance and hydrological fluctuations throughout the >5000-year record. The pollen assemblages suggest the persistence throughout the mid-late Holocene of semi-evergreen tropical forest of an open structure and which includes pollen of many pioneer taxa. This

contrasts with other proxy evidence from northern Palawan that indicate closed forest environments throughout the Holocene.

The archaeological records from Ille and Pasimbahan-Magsanib caves demonstrate that people have inhabited the Dewil Valley landscapes, exploiting the flora and hunting the fauna since the terminal Pleistocene. Palawan is also on the northern edge of the Indo-Pacific Warm Pool and, thus, the seasonal tropical climates that are subject to periodic fluctuations in the ENSO that have increased in frequency and intensity since the mid-Holocene. It is likely that periodic ENSO-induced droughts throughout the entire span of the Makinit record led to increased susceptibility of the local vegetation to fire. Additionally, given the archaeological evidence for the presence of people and their active management of local resources, anthropogenic manipulation of vegetation, perhaps through burning, is also likely to have contributed to the maintenance of open vegetation. These causal mechanisms are not mutually exclusive, nor is the simultaneous presence of patches of more closed forest that are evidenced in other proxy palaeoenvironmental records. Disentangling all of these signals might potentially be achieved via the modern analogue approach. The failed attempts at this approach in the present study owe to unfortunate, though surmountable, circumstances to do with decay of material during delays in transit. Much might still be gained by application of the modern analogue approach in these landscapes.

### **8.3 Assessment**

The following subsections contain a brief critical assessment of the weaknesses in aspects of the present study. Where possible, suggestions are offered for how these weaknesses might be redressed in future research.

#### **8.3.1 Assumptions**

The assumptions that the modern analogue approach necessitates were explicitly stated in Chapter 3 (subsection 3.3.2; pp. 72-3). Each of these assumptions is discussed below in turn, in relation to the limitations they impose upon the present study.

***Modern land uses exist that are analogous to some of those of the past.***

Whether the aims of a particular study relate to detection of past climatic change or changes in land use, the modern analogue approach to vegetation reconstruction assumes that analogues for past vegetation exist within the modern landscape. In the context of the present study, a limitation imposed by this assumption relates to the introduction histories of various crops or invasive species that can shift competitive balances in ecologies. Many of the species within the flora of modern human ecologies are now globally distributed crops or weeds that have been moved by people either intentionally or inadvertently (eg in Southeast Asia see Galinato *et al.*, 1999). Past land uses of interest, such as swiddening or irrigated rice farming, would not have included all of the species that are currently in modern crop and weed registers. However, it seems reasonable still to assume that the *structure* of the modern wet rice paddies, swidden patches, orchards, or stands of sago might be similar to those in the past, had those management practices been present, even if the species composition might differ. Structural differences between the assumed modern analogues and the vegetation under past management practices should be of degree, not type. Accounting for this limitation is achieved, in part, by emphasising the summary groupings by structural life form within pollen assemblages, ie trees and shrubs, or herbs, epiphytes, and climbers. An implication of this limitation, though, is that if the forms and processes involved in past land uses differed markedly from those of the present, then the modern analogue approach will likely fail to detect them. Clearly, a simple mapping of the present onto the past is insufficient in interpreting the results of this approach.

***Pollen extracted from surface sediments represents modern pollen rain.***

For the results of the modern analogue approach to be meaningful, it must be assumed that the pollen assemblages extracted relate to the vegetation surveyed. It is acknowledged that the surface sediment sampling strategy of the present study is less than ideal in this regard. In the perhumid portions of the tropics such as northwest Borneo, sediments are subjected to persistent wash by heavy rainfall, as well as high levels of biological activity, leading to turbation. Surface sediments at the site sampled in the present study may contain

temporally conflated pollen assemblages that incorporate some pollen from short-lived plants that were no longer growing on site when the vegetation was surveyed. Future studies might deploy pollen traps at sites of interest which catch pollen rain across a set period of time. This requires at least two site visits, as well as the intervening time, which would probably be one or more years.

***The taphonomic processes responsible for the creation of modern pollen assemblages are comparable to those that produced the fossil assemblages.***

This assumption relates to site selection for the surface sediment sampling. Pollen cores are drilled into deposits that, by definition, are distributed within depositional points in the landscape. Tropical vegetation grows in all physiographic contexts, and indeed the suite of sites sampled in the present study occurs on relatively flat floodplains, gentle and steep slopes, and sharp ridgelines. These encompass points in the landscape where both deposition and erosion of sediments are occurring. The pollen taphonomy of these physiographic settings may differ from each other, and also from the palaeochannel deposits that house the fossil assemblages to which these modern assemblages are compared. Here again, setting pollen traps, perhaps at different heights within the surveyed vegetation communities (ie ground-level; breast height; sub-canopy; above canopy; cf Flenley, 1973), might indicate how reasonable this assumption is.

### **8.3.2 Data**

The following weaknesses in the data themselves are also acknowledged.

#### ***Resolution***

Taxonomic resolution of the modern botanical data is primarily at genus-level, and that of the palynological data is mainly at family-level. The resolution of the botanical data was limited by the amount of time allotted for botanical surveys. Given the need to hire botanists with local field knowledge in both of the study areas, as well as the limited funds available for this purpose, a trade-off was encountered between number of sites surveyed and resolution of data collected. With the author's anticipated future development of improved field

botanical identification skills, or a better-resourced study, the taxonomic resolution of botanical data collected in association with such studies may improve. Additionally, exhaustive surveys of all plant taxa within a set sampling area might also be achieved, and a more comprehensive and statistically robust suite of sites might be sampled.

Taxonomic resolution of the palynological data was limited by available pollen reference material. The only local pollen flora published consists of the 253 pollen taxa enumerated by Jones and Pearce (2015) as part of the CRF. The remaining sources of reference images that were consulted during pollen identification for the present study drew upon pollen floras from adjacent regions, ie the online ANU-maintained Australasian Pollen and Spore Atlas and Huang's (1972) *Pollen Flora of Taiwan*. As is currently the case with palynology within speciose and under-collected tropical floras, taxonomic resolution of pollen data can be improved by future collection in the field and from herbarium specimens of anthers from which to extract pollen for reference material. The improvement of taxonomic resolution of both pollen and botanical data will benefit ecological interpretations, as genus- or family-level determinations encompass a vast diversity of ecologies, thus limiting the ecological value of such coarsely resolved data.

Sediment cores were subsampled at widely spaced intervals (5cm for the BIO-7 core, and 10cm for the longer Makinit core), and target pollen counts were set at 300 grains which is low for tropical contexts, due to limited time available to devote to microscopy. Once again, a trade-off between resolution and coverage was encountered. Due to coarse subsampling resolution, and relatively low pollen counts, patterns and processes may have been conflated and/or missed. The solution to this is fine-scale subsampling, higher pollen counts, and more time behind the microscope.

### ***Quantification***

A higher degree of quantitative data, particularly in relation to the botanical surveys, could improve the detail and objectivity of interpretations. By conducting exhaustive botanical surveys of set quadrats, and collecting

quantitative data relating to cover and/or abundance of each taxon, systematic mathematical assessment of pollen representation in relation to floristic composition could be determined, cf Davis (1963) or Wright (1967). These data could then be used to calibrate relative abundances observed within fossil assemblages, and thus reconstruct a more accurate and detailed picture of the likely floristic composition of past vegetation. This applies to 'natural' as well as human-modified vegetation types. Additionally, a metric might be developed to provide a quantitative or semi-quantitative measure of land use intensity. The present study used qualitative assessments based upon descriptions from local informants to place the sites in relative rank order along this gradient. A semi-quantitative metric applied here would increase objectivity of these assessments.

### ***Chronology***

As is the case with most studies of fossil records, a desire exists to improve chronological control. Chronology is a particular problem within the dynamic landscape of the Kelabit Highlands. All five of the pollen cores from Borneo analysed in the present study derive from palaeochannels or infilled depressions on river terraces. Three of these five cores contain Holocene age reversals (BIO-7, Ba, and Pa' Buda). These landforms are, by definition, dynamic. Whilst not ideal for recovery of continuous records with well-preserved fossil assemblages, the aims of the study and the lack of more suitable coring sites within the region of interest necessitated this approach. In addition to stratified portions with acceptable levels of microfossil preservation, the deposits at these sites also appear to include reworked material from surrounding slopes that have probably been transported fluvially and redeposited at the coring sites. This process is also likely responsible for the 4260-3980 cal BP age produced by charcoal from the fill of a posthole that also contained sherds of Qing Dynasty porcelain (Lloyd-Smith *et al.*, 2010) at the old settlement site of Ruma Ma'on Dakah. This site, like the palaeochannel fills, is also located on a river terrace.

## **8.4 Human-rainforest interactions in Island Southeast Asia**

Despite the weaknesses just detailed, this section comprises a discussion of the contributions that the results of this study make to our understanding of



past human impacts upon rainforests in ISEA. The following subsections are structured around the big-picture research questions defined within Chapter 3. These questions were designed to address current knowledge gaps as identified from the literature review in Chapter 2. The palaeoecological contributions of the present study relate to addressing the problem of equifinality in determination of the causal mechanisms of Holocene vegetation changes. Defining a path forward for the development of a more detailed picture of past land use practices through indirect detection within proxy palaeoenvironmental records comprises the archaeological contributions of this study. In both cases, the use here of the modern analogue approach as applied to detection of past land use is viewed as a test of its utility within tropical forest environments. Conceptualisation of this approach as one tool within a multidisciplinary toolkit to be employed in investigation of histories of tropical forests and subsistence represents the methodological and theoretical contribution of this research.

Interpretation of fossil pollen sequences relies upon comparison with modern assemblages from known vegetation. Few modern pollen-vegetation studies from ISEA exist. Those that do have sampled across altitudinal, climatic, or edaphic gradients, as the aims of these previous studies were to do with detection of changes in climate and ecology. For example, Kershaw and Hyland (1975) sampled at the rainforest-sclerophyll margin in Far North Queensland as a proxy for detection of changes in rainfall; Anderson and Müller (1975) sampled across the catenary sequence of a large ombrotrophic peat swamp in lowland Sarawak as a proxy for development through time of the phasic vegetation communities of lowland Malesian peats; Flenley (1973), Morley (1982), and Newsome (1988) all describe sampling along altitudinal gradients in order to define pollen representation within vegetation types that are controlled by changes in temperature. The present study has contributed a modern pollen-vegetation dataset from a gradient in land use, which has not previously existed for the tropics. This adds much needed contemporary data on tropical pollen representation, whilst also expanding the range of ecological contexts from which modern pollen rain in the region has been analysed. The more gradients across which we have modern pollen-vegetation data, the more we can

investigate past causal mechanisms evident in fossil pollen sequences. These data have provided for better understanding of pollen taphonomy within the tropical forest environments of the Kelabit Highlands, which was shown in previous chapters to contribute to refined interpretations of signs of past disturbance in fossil pollen records from the area.

The use of the modern pollen-vegetation dataset in the present study has demonstrated its utility in beginning to distinguish signs of manipulation of vegetation by people in the past by comparison with data from pollen cores. This comparison operates on the scale of entire assemblages rather than individual taxa, leading to more robust inferences. Some of the original interpretations of fossil pollen sequences from the Kelabit Highlands were bolstered by support from the present study, whilst statistical comparison of other fossil assemblages with the modern dataset suggests climatic drivers of change. Whilst the suite of sites sampled in the present study is small, and the problems with the data that were mentioned in the previous section exist, it does appear that it is possible to distinguish between past anthropogenic and climatically driven disturbance within sedimentary pollen and charcoal records from ISEA. As will be discussed within the section to follow, one of the ways in which the modern analogue technique can be improved is by increasing the sample size of sites that together span gradients in land use. Specifically, vegetation types from 'natural' ecologies that might parallel those of modern land uses (ie natural wetlands and wet rice paddies) should be targeted so as to further test the hypothesis that human-modified vegetation can be distinguished from 'natural' vegetation by their palynological signatures.

The results of the modern analogue approach presented in this thesis have implications for potential use at other sites within northern ISEA. As discussed within Chapter 2, review papers of pollen sequences from the region (ie Haberle *et al.*, 2004; Hunt & Rabett, 2014; Sémah & Sémah, 2012) have noted the subjective and somewhat arbitrary manner in which causal mechanisms for past vegetation disturbance and fire have been attributed. A modern pollen-vegetation dataset from a suite of land uses local to the Lake Sentarum area or the Kutai Peatlands in Kalimantan might shed additional light on Anshari *et al.*'s

(2001; 2004) and Hope *et al.*'s (2005) interpretations, respectively. From this, it might be possible to determine whether the late Pleistocene and Holocene burning observed within those records occurs alongside pollen assemblages that are more similar to those from natural or human-modified vegetation communities. A similar approach could enable tests of the hypotheses that Hunt and Premathilake (2012) pose for early Holocene swamp sago and possible rice exploitation in the Loagan Bunut record, and for the arguments for Holocene anthropogenic forest clearance through burning in the highland Sumatran and Javan records (ie Bulter & Flenley, 2001; Maloney, 1980; Morley, 1982; Stuijts *et al.*, 1988). A challenge, however, for the use of the modern analogue approach to analyse records from lowland Malaysian Borneo is represented by the prospects of locating and sampling vegetation that is managed under practices that are in any way analogous to those that are likely to have existed in the deep past. This is becoming increasingly unlikely with the pace and extent of conversion of lowland rainforest in northern Borneo to oil palm plantations, which might make testing hypotheses of signs of human impact in the Gan Kira and Kampong Irang (Hunt & Rushworth, 2005), as well as Niah (Hunt *et al.*, 2012), records difficult.

The Makinit sequence from northern Palawan contributes the first record of vegetation history from that island. As shown in Chapter 7, this record contains palynological and sedimentological evidence for environmental fluctuations from the mid-Holocene through to the present. The sediments and their magnetic signature, in particular, appear to exhibit cyclicities on multiple scales that corroborate studies from both sides of the tropical Pacific for increased ENSO frequency and intensity across this period. The pollen records from Paoay Lake in subcoastal northwest Luzon (Stevenson *et al.*, 2010) and Kara Lake in northeast Cambodia (Maxwell, 2001) provide two broadly comparable records from sites in the more seasonal climates surrounding the ever-wet Sundaland core from which the Bornean and Sumatran records derive. Both of these records also show increases in disturbance in the form of exaggerated seasonality associated with strengthening of monsoonal influence, as well as increases in the importance of fire. What sets the Makinit record apart from these other studies, though, is the rich archaeological sequence covering

the past >14,000 years that suggest human exploitation of forest resources (eg Lewis *et al.*, 2008; Ochoa *et al.*, 2014; Piper *et al.*, 2011). It is unfortunate that complete modern analogue analysis of the Makinit sequence was prevented by unsuccessful pollen extraction and preservation from surface sediments. This data might have enabled the testing of hypotheses regarding signature in human land use within the Makinit, and other, records. It is likely that signatures of both human and climatic drivers of open vegetation are convolved within the fossil assemblages of the Makinit sequence. Full modern analogue analysis in the future might test this hypothesis.

The Philippines and northern Borneo occupy geographical locations that are crucial to existing archaeological narratives regarding the histories of human subsistence and movements within the region during the mid-Holocene. As has been discussed within the literature review in Chapter 2, bioarchaeological data from open habitation sites across ISEA are thin on the ground (eg Spriggs, 2011), but those that do exist suggest subsistence practices and exchange networks that are difficult to reconcile with the dominant Austronesian hypothesis (eg Barker *et al.*, 2011a; Barton *et al.*, 2013; Bulbeck, 2008; Carlos, 2010; Hunt & Premathilake, 2012; Neri *et al.*, 2015). The results of the present study have broad implications for the archaeology of the region. From the modern analogue analyses of the core from the Kelabit Highlands, it appears that clear signs of manipulation of rainforests by humans in that portion of the interior highlands are evident only from about 2000 cal BP, roughly coincident with the onset of the Metal Period in the lowlands (Lloyd-Smith *et al.*, 2010). Combined with the evidence of population continuity within the mortuary sequence at Niah (Manser, 2005), this apparent delay seems discordant with a demic replacement or absorption by intrusive rice farmers ~4500-4000 cal BP, as is postulated by the Austronesian hypothesis (eg Bellwood, 2007). It might be expected that human signatures in vegetation histories would appear earlier within these highland records had such a dramatic displacement of populations occurred within the lowlands. Once again, a more detailed picture of management practices in the lowlands, and the attendant imprints upon local vegetation, could add much to our archaeological interpretations of the 'Neolithic' in ISEA.

Save for exceptional sites such as Niah in the Borneo lowlands, the dearth of direct archaeobotanical remains of past plant exploitation might be redressed by indirect detection of land use within proxy palaeoenvironmental records. The modern analogue approach employed with the present study shows potential for contribution to this end.

## 8.5 Wider implications

The development of thinking about rainforest history in Southeast Asia, and humans' role within it, is paralleled in Amazonia. Early naturalists from European colonial powers (eg Humboldt & Bonpland, 1822; Bates, 1865) likely encountered an Amazon Basin in which the effects of European disease preceded physical exploration of the upper stretches of river networks and surrounding forests, thus giving the impression of a sparsely inhabited, 'pristine', and primeval wilderness. The prehistoric archaeology that did exist was initially argued to represent a lack of cultural complexity and minimal environmental impacts (eg Meggars, 1971) due to perceived resource limitation. This debate echoes a similar dialogue in the late 1980s - early 1990s in SE Asia, with claims that human populations could survive within a rainforest environment only if embedded within exchange networks with agriculturalists (eg Bailey *et al.*, 1989; Bailey & Headland, 1991; cf Brosius, 1991). In the wake of industrial-scale deforestation in Amazonia beginning of the 1970s and 1980s, large rectilinear earthworks were uncovered beneath mature forest cover, as well as ubiquitous *terra preta* soils with enriched abundances of charcoal and containing earthenware sherds, implying long-term human habitation (eg Denevan, 1992; Heckenberger *et al.*, 2003; Neves *et al.*, 2004). Bush *et al.* (2015) review the history of the debate in South America, with the emergence of the extreme opposite view of the Amazon rainforest as an entirely cultural artefact owing to millennia of manipulation of resources by humans (Erickson, 2001).

A more ecological view of the histories of forests and subsistence in Amazonia suggests that the substantial prehistoric populations that did exist were concentrated along river courses and floodplains, as well as at lake margins, whilst the vast expanses of interfluvial forests were less impacted by

pre-Columbian human inhabitants (Bush *et al.*, 2015). McMichael *et al.* (2015) employ charcoal and phytolith analyses from shallow sediment cores at sites with known archaeological evidence of human habitation in much the same way as the present study has employed pollen data from modern land uses. These authors showed that a gradient in human impact upon rainforest was present from river networks to interfluvies, with palm enrichment and elevated charcoal abundance evident at sites in close proximity to rivers, and apparent manipulation of vegetation decreasing to a minimum within interfluvial forests.

The most convincing arguments for signs of past human-rainforest interactions come from areas where disturbance in palaeoecological records is corroborated by archaeological evidence for habitation and resource exploitation (Bayliss-Smith & Golson, 1992; Denham *et al.*, 2003; Fullagar *et al.*, 2006; Golson, 1977). This is an ideal situation, one that is realised in only a few fortunate locales. The implications of the present study relate to the strengthening of palynological analyses as an independent tool that can be brought to bear on these issues. Due to the sensitivity of ecologies within ISEA to ENSO cyclicities, the region seems an ideal testing ground for approaches to disentangling past signs of climatic versus anthropogenic signatures in sedimentary archives. Results and innovations can then be applied within other tropical regions.

## **8.6 Future work**

In order to drive tropical palynology forward, increasing the taxonomic coverage of securely identified modern reference material must be a priority. Botanical field collecting has always favoured collection of fertile material, as reproductive organs often comprise diagnostic characters. Pollen can be extracted from anthers collected alongside traditional field collecting, as well as from existing herbarium specimens (eg Rowley & Nilsson, 1972). Both of these approaches can sit alongside modern botanical collecting, as well as be incorporated within the recent push for digitisation of existing museum collections (eg Kew Science Strategy 2015-2020). Increasing the taxonomic coverage of reference material will improve the taxonomic resolution of fossil

identifications and, thus, the ecological interpretations of past vegetation changes and human impacts.

In parallel with expanding reference collections, more thoughtfully designed modern pollen-vegetation studies are needed across a variety of gradients. Targeting gradients in climatically controlled vegetation types, as well as those from a broader range of land uses than was sampled in the present study, might prove particularly fruitful both in filling knowledge gaps, but also in framing research within ongoing dialogues surrounding contemporary societal concerns where public money for research is being invested. The Philippines comprise a geographical locale that is particularly ripe for palaeoecological and modern analogue-based research. The archipelago sits on the edge of the IPWP and Sunda Shelf, harbours great topographic, geologic, climatic, and biotic diversities, and is situated in a key position for testing archaeological hypotheses related to Holocene human subsistence and movements. Prior to this study, only two published pollen records existed from the >7000 islands that constitute the country, despite the numerous volcanic and tectonic geomorphic features that likely house depositional basins conducive to studies of vegetation history. For example, with proper coring equipment, Manguao Lake ~40km south from the Dewil Valley in northern Palawan likely contains a long record of regional pollen deposition. Combined with a programme of modern pollen-vegetation relationships and reference material collection, a core from this lake might yield a record of interest to both the palaeoecological and archaeological histories of Palawan and ISEA. Similarly, a modern palynological dataset might be compiled for highland Sumatra, with which to revisit the numerous cores from that region that have been interpreted to represent signs of early Holocene human impact in the form of forest clearance (eg Flenley & Butler, 2001; Maloney, 1979; 1980; Maloney & McCormac, 1996; Newsome & Flenley, 1988).

In order to increase the potential utility of the modern analogue approach that has been tested and demonstrated in the present study, a number of lessons might be learned from its experience. Firstly, future work should aim at collecting as much quantitative data regarding the modern landscape as possible, with which to develop a detailed training set for use in calibration of fossil

records. The more detailed and quantitative the modern training set, the higher the resolution the potential inferences are that we can make about vegetation in the past that is represented by fossil pollen assemblages. Achieving this will rely upon studies that are better resourced in terms of time and money than was the present study. Standardised quadrats within which exhaustive vegetation surveys are conducted, and quantitative measures for cover / abundance are collected, can be combined with modern pollen assemblages collected from pollen traps with standardised surface areas and deployed for known periods of time. These types of data would facilitate the development of transfer functions that incorporate pollen representation that might be peculiar to local ecologies. A particularly interesting application of this approach might be to combine the resultant palynological data with the ethnoarchaeological work that has recently been done with the Pala'wan in the south of the island, aimed at deciphering past uses of lithic and plant-based technologies (eg Xhauflair, 2014; Xhauflair & Pawlik, 2010; Xhauflair *et al.*, in press). The combination of these approaches might produce a particularly nuanced picture of past resource management and human-rainforest interactions.

## **8.7 Conclusions**

This thesis has been about the relationships between pollen, vegetation, and land use within tropical Island Southeast Asia. The primary focus of the data and related discussion has been upon histories of tropical vegetation and our interactions with it in the past. However, this study was introduced within the context of the present value of tropical forests, of the increasing threats that they are under today, of the recent broadening of social awareness of ecological interconnections between human and 'natural' ecologies, and of the expanding network of conservation initiatives and global institutions that are driving increased research into long-term ecological monitoring. It is in this context of modern conservation that this thesis closes.

The perception of change drives a desire to conserve or restore. Baselines are established, from which change is measured. Palaeoecology, and particularly palynology, in concert with archaeology, have been used within the past quarter



of a century to extend back in time baselines related the roles that humans have played in natural histories (eg Willis *et al.*, 2007). This provides for a more informed and adaptable approach to defining habitats, ecosystems, and organisms that are under threat, that merit conserving, and that represent targets for restoration. The tropical grassland ecosystems that cover over 75 per cent of the island of Madagascar (Moat & Smith, 2007) represent an example of the role that palaeohistories can play in conservation. Traditional interpretations have been that these grasslands are anthropogenic (eg Green & Sussman, 1990; Kull, 2004), have relatively recent origins, and are therefore of little conservation value. In contrast, Bond *et al.* (2008) suggest that, on the basis of grassland-adapted faunas and of pollen records that indicate the presence of pre-settlement grasslands (Burney, 1987a; 1987b; Gasse & Van Campo, 1998; 2001), the current imbalance in conservation efforts in Madagascar in favour of forests represents a bias that is discordant with these biomes respective value to Malagasy biodiversity. Needham *et al.* (2015) describe, and continue to develop, high-resolution Scanning Electron Microscopy (SEM) approaches to identify various indigenous and introduced species of grasses in fossil pollen cores, and thus assess the conservation value of these tropical grasslands through detailed study of their palaeohistory.

The modern analogue approach that has been employed in the present study might be used in similar ways in order to assess whether habitats that are currently under threat are 'natural' or anthropogenic, the time-depth of related human influences, and suggestions as to the forms that those influences may have taken. Results of such enquiry might have utility in not only unravelling aspects of cultural and ecological histories, but also in guiding future management by defining how resilient a particular ecosystem is to various types of human activities. This type of approach constitutes an additional tool in the palaeoecological, archaeological, and conservation toolkits that can supplement data from traditional studies.



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## Appendix 1 – Dewil Valley botanical taxon list

### Ferns, lower vascular plants, gymnosperms, and basal angiosperms

	Taxon	Family
Ferns & lower plants	<i>Selaginella</i> sp.	Selaginellaceae
	<i>Sticherus laevigatus</i> (Willd.) C. Presl	Gleicheniaceae
	<i>Lygodium circinatum</i> (Burm. f.) Sw.	Lygodiaceae
	<i>Lygodium japonicum</i> (Thunb.) Sw.	Lygodiaceae
	<i>Azolla pinnata</i> R. Br.	Salviniaceae
	<i>Acrostichum aureum</i> L.	Pteridaceae
	<i>Pteris philippinensis</i> Fée	Pteridaceae
	<i>Taenitis blechnoides</i> (Willd.) Sw.	Pteridaceae
	<i>Asplenium nidus</i> L.	Aspleniaceae
	<i>Asplenium polydon</i> G. Forst.	Aspleniaceae
	<i>Pronephrium</i> sp.	Thelypteridaceae
	<i>Sphaerostephanos unitus</i> (L.) Holttum	Thelypteridaceae
	<i>Stenochlaena palustris</i> (Burm. f.) Bedd.	Blechnaceae
	<i>Nephrolepis</i> sp.	Nephrolepidaceae
	<i>Drynaria quercifolia</i> (L.) J. Sm.	Polypodiaceae
Gymnosperms	<i>Agathis philippinensis</i> Warb.	Araucariaceae
	<i>Gnetum gnemon</i> L.	Gnetaceae
	<i>Gnetum</i> sp.	Gnetaceae
ANITA grade	<i>Kadsura marmorata</i> (Hend. & A.A.Hend.) A.C.Sm.	Schisandraceae
Magnoliids	<i>Horsfieldia</i> sp.	Myristicaceae
	<i>Knema</i> sp.	Myristicaceae
	<i>Myristica</i> spp.	Myristicaceae
	<i>Magnolia liliifera</i> (L.) Baill.	Magnoliaceae
	<i>Magnolia</i> sp.	Magnoliaceae
	<i>Annona</i> sp.	Annonaceae
	<i>Friesodielsia</i> sp.	Annonaceae
	<i>Goniothalamus</i> sp.	Annonaceae
	<i>Polyalthia</i> sp.	Annonaceae
	<i>Uvaria</i> sp.	Annonaceae
	<i>Cinnamomum</i> sp.	Lauraceae
	<i>Litsea glutinosa</i> (Lour.) C.B.Rob	Lauraceae
	<i>Litsea luzonica</i> (Blume) Villar	Lauraceae
	<i>Persea americana</i> Mill.	Lauraceae
	<i>Peperomia</i> sp.	Piperaceae
	<i>Piper</i> spp.	Piperaceae

## Monocotyledons

Taxon	Family
<i>Alocasia macrorrhizos</i> (L.) G.Don	Araceae
<i>Alocasia</i> sp.	Araceae
<i>Amorphophallus palawanensis</i> Bogner & Hett.	Araceae
<i>Colocasia esculenta</i> (L.) Schott	Araceae
<i>Philodendron</i> sp.	Araceae
<i>Pistia stratiotes</i> L.	Araceae
<i>Pothos</i> sp.	Araceae
<i>Dioscorea hispida</i> Dennst.	Dioscoreaceae
<i>Dioscorea</i> sp.	Dioscoreaceae
<i>Tacca</i> sp.	Dioscoreaceae
<i>Freycinetia</i> sp.	Pandanaceae
<i>Pandanus odorifer</i> (Forssk.) Kuntze	Pandanaceae
<i>Pandanus</i> sp.	Pandanaceae
<i>Pandanus tectorius</i> Parkinson ex Du Roi	Pandanaceae
<i>Smilax</i> sp.	Smilacaceae
<i>Dracaea multiflora</i> Warb. ex Sarasin	Asparagaceae
Orchidaceae spp.	Orchidaceae
<i>Calamus</i> sp.	Arecaceae
<i>Caryota cumingii</i> Lodd. ex Mart.	Arecaceae
<i>Caryota maxima</i> Blume ex Mart.	Arecaceae
<i>Cocos nucifera</i> L.	Arecaceae
<i>Corypha utan</i> Lam.	Arecaceae
<i>Korthalsia</i> sp.	Arecaceae
<i>Licuala spinosa</i> Wurm	Arecaceae
<i>Oncosperma tigillarium</i> (Jack) Ridl.	Arecaceae
<i>Nypa fruticans</i> Wurm	Arecaceae
<i>Typha angustifolia</i> L.	Typhaceae
<i>Ananas comosus</i> (L.) Merr.	Bromeliaceae
<i>Cyperus</i> sp.	Cyperaceae
<i>Eleocharis dulcis</i> (Burm.f.) Trin. ex Hensch.	Cyperaceae
<i>Fimbristylis</i> sp.	Cyperaceae
<i>Fuirena</i> sp.	Cyperaceae
<i>Flagellaria indica</i> L.	Flagellariaceae
<i>Axonopus compressus</i> (Sw.) P.Beauv.	Poaceae
<i>Bambusa vulgaris</i> Schrad.	Poaceae
<i>Chrysopogon aciculatus</i> (Retz.) Trin.	Poaceae
<i>Coix lacryma-jobi</i> L.	Poaceae
<i>Cynodon dactylon</i> (L.) Pers.	Poaceae
<i>Dinochloa palawanensis</i> (Gamble) S.Dransf.	Poaceae
<i>Imperata cylindrica</i> (L.) Raeusch.	Poaceae
<i>Oryza sativa</i> L.	Poaceae
<i>Paspalum conjugatum</i> P.J.Bergius	Poaceae
<i>Schizostachyum lumampao</i> (Blanco) Merr.	Poaceae
<i>Zea mays</i> L.	Poaceae

<b>Taxon</b>	<b>Family</b>
<i>Aneilema</i> sp.	Commelinaceae
<i>Commelina benghalensis</i> L.	Commelinaceae
<i>Cyanotis axillaris</i> (L.) D.Don ex Sweet	Commelinaceae
<i>Monochoria hastata</i> (L.) Solms	Pontederiaceae
<i>Musa</i> sp.	Musaceae
<i>Donax canniformis</i> (G.Forst.) K.Schum	Marantaceae
<i>Alpinia galanga</i> (L.) Willd.	Zingiberaceae
<i>Alpinia haenkei</i> C.Presl	Zingiberaceae
<i>Amomum</i> sp.	Zingiberaceae
<i>Etlingera</i> sp.	Zingiberaceae
<i>Costus</i> sp.	Costaceae

## Eudicotyledons

Taxon	Family
<i>Arcangelisia flava</i> (L.) Merr.	Menispermaceae
Menispermaceae sp.	Menispermaceae
<i>Tinospora crispa</i> (L.) Hook. f. & Thomson	Menispermaceae
<i>Dillenia luzoniensis</i> (Vidal) Merr.	Dilleniaceae
<i>Dillenia philippinensis</i> Rolfe	Dilleniaceae
<i>Tetracera</i> sp.	Dilleniaceae
<i>Cissus</i> sp.	Vitaceae
<i>Leea guineensis</i> G. Don.	Vitaceae
<i>Connarus</i> sp.	Connaraceae
<i>Averrhoa carambola</i> L.	Oxalidaceae
<i>Oxalis corniculata</i> L.	Oxalidaceae
<i>Elaeocarpus</i> sp.	Elaeocarpaceae
<i>Bruguiera cylindrica</i> (L.) Blume	Rhizophoraceae
<i>Bruguiera sexangula</i> (Lour.) Poir.	Rhizophoraceae
<i>Ceriops tagal</i> (Perr.) C.B.Rob	Rhizophoraceae
<i>Rhizophora apiculata</i> Blume	Rhizophoraceae
<i>Rhizophora mucronata</i> Lam.	Rhizophoraceae
<i>Brackenridgea fascicularis</i> (Blanco) Fern.-Vill.	Ochnaceae
<i>Garcinia binucao</i> (Blanco) Choisy	Clusiaceae
<i>Garcinia</i> spp.	Clusiaceae
<i>Calophyllum</i> sp.	Calophyllaceae
<i>Kayea</i> sp.	Calophyllaceae
<i>Cratoxylum</i> sp.	Hypericaceae
<i>Drypetes littoralis</i> (C.B.Rob.) Merr.	Putranjivaceae
<i>Hydnocarpus</i> sp.	Achariaceae
<i>Passiflora foetida</i> L.	Passifloraceae
<i>Acalypha</i> sp.	Euphorbiaceae
<i>Acalypha spiciflora</i> Burm.f.	Euphorbiaceae
<i>Balakata luzonica</i> (Vidal) Esser	Euphorbiaceae
<i>Codiaeum palawanense</i> Elmer	Euphorbiaceae
<i>Euphorbia trigona</i> Mill.	Euphorbiaceae
<i>Excoecaria philippinensis</i> Merr.	Euphorbiaceae
<i>Homonoia riparia</i> Lour.	Euphorbiaceae
<i>Jatropha curcas</i> L.	Euphorbiaceae
<i>Macaranga tanarius</i> (L.) Müll.Arg.	Euphorbiaceae
<i>Mallotus</i> sp.	Euphorbiaceae
<i>Melanolepis multiglandulosa</i> (Reinw. ex Blume) Rchb. & Zoll.	Euphorbiaceae
<i>Antidesma buniis</i> (L.) Spreng.	Phyllanthaceae
<i>Antidesma ghaesembilla</i> Gaertn.	Phyllanthaceae
<i>Aporosa symplocifolia</i> Merr.	Phyllanthaceae
<i>Breynia</i> sp.	Phyllanthaceae
<i>Cleistanthus</i> sp.	Phyllanthaceae
<i>Glochidion coronulatum</i> C.B.Rob.	Phyllanthaceae
<i>Glochidion</i> sp.	Phyllanthaceae
<i>Phyllanthus niruri</i> L.	Phyllanthaceae
<i>Phyllanthus</i> sp.	Phyllanthaceae

<b>Taxon</b>	<b>Family</b>
<i>Acacia mangium</i> Willd.	Fabaceae
<i>Afzelia rhomboidea</i> (Blanco) S.Vidal	Fabaceae
<i>Alysicarpus</i> sp.	Fabaceae
<i>Archidendron clypearia</i> (Jack) I.C.Nielsen	Fabaceae
<i>Archidendron</i> sp.	Fabaceae
<i>Bauhinia aherniana</i> Perkins	Fabaceae
<i>Bauhinia</i> sp.	Fabaceae
<i>Calopogonium mucunoides</i> Desv.	Fabaceae
<i>Cassia javanica</i> subsp. <i>nodosa</i> (Roxb.) K.Larsen & S.S.Larsen	Fabaceae
<i>Cassia</i> sp.	Fabaceae
<i>Crotalaria incana</i> L.	Fabaceae
<i>Derris trifoliata</i> Lour.	Fabaceae
<i>Desmodium</i> sp.	Fabaceae
<i>Entada rheedii</i> Spreng.	Fabaceae
<i>Erythrina variegata</i> L.	Fabaceae
<i>Intsia bijuga</i> (Colebr.) Kuntze	Fabaceae
<i>Mimosa pudica</i> L.	Fabaceae
<i>Pachyrhizus</i> sp.	Fabaceae
<i>Pongamia pinnata</i> (L.) Pierre	Fabaceae
<i>Pterocarpus indicus</i> Willd.	Fabaceae
<i>Senna alata</i> (L.) Roxb.	Fabaceae
<i>Senna occidentalis</i> (L.) Link	Fabaceae
<i>Senna tora</i> (L.) Roxb.	Fabaceae
<i>Sesbania</i> sp.	Fabaceae
<i>Xanthophyllum</i> sp.	Polygalaceae
<i>Prunus</i> sp.	Rosaceae
<i>Rosa</i> sp.	Rosaceae
<i>Ventilago dichotoma</i> Merr.	Rhamnaceae
<i>Ziziphus talanae</i> Merr.	Rhamnaceae
<i>Celtis</i> sp.	Cannabaceae
<i>Trema orientalis</i> (L.) Blume	Cannabaceae
<i>Artocarpus altilis</i> (Parkinson ex F.A.Zorn) Fosberg	Moraceae
<i>Artocarpus blancoi</i> (Elmer) Merr.	Moraceae
<i>Artocarpus heterophyllus</i> Lam.	Moraceae
<i>Ficus nota</i> (Blanco) Merr.	Moraceae
<i>Ficus punctata</i> Thunb.	Moraceae
<i>Ficus septica</i> Burm.f.	Moraceae
<i>Ficus</i> spp.	Moraceae
<i>Ficus variegata</i> Blume	Moraceae
<i>Streblus asper</i> Lour.	Moraceae
<i>Streblus ilicifolius</i> (Vidal) Corner	Moraceae
<i>Trophis philippinensis</i> (Bureau) Corner	Moraceae
<i>Dendrocnide</i> sp.	Urticaceae
<i>Leucosyke</i> sp.	Urticaceae
<i>Poikilospermum</i> sp.	Urticaceae
<i>Cucurbita maxima</i> Duchesne	Cucurbitaceae
<i>Lagenaria siceraria</i> (Molina) Standl.	Cucurbitaceae
<i>Momordica</i> sp.	Cucurbitaceae
<i>Octomeles sumatrana</i> Miq.	Tetramelaceae
<i>Begonia</i> sp.	Begoniaceae

<b>Taxon</b>	<b>Family</b>
<i>Lumnitzera</i> sp.	Combretaceae
<i>Terminalia catappa</i> L.	Combretaceae
<i>Ludwigia</i> spp.	Onagraceae
<i>Lagerstroemia speciosa</i> (L.) Pers.	Lythraceae
<i>Sonneratia alba</i> Sm.	Lythraceae
<i>Psidium guajava</i> L.	Myrtaceae
<i>Syzygium calubcob</i> (C.B.Rob.) Merr.	Myrtaceae
<i>Syzygium cumini</i> (L.) Skeels	Myrtaceae
<i>Syzygium nitidum</i> Benth.	Myrtaceae
<i>Syzygium</i> spp.	Myrtaceae
<i>Xanthostemon speciosus</i> Merr.	Myrtaceae
<i>Melastoma malabathricum</i> L.	Melastomataceae
<i>Canarium asperum</i> Benth.	Burseraceae
<i>Canarium</i> sp.	Burseraceae
<i>Garuga floribunda</i> Decne.	Burseraceae
<i>Anacardium occidentale</i> L.	Anacardiaceae
<i>Buchanania</i> sp.	Anacardiaceae
<i>Dracontomelon dao</i> (Blanco) Merr. & Rolfe	Anacardiaceae
<i>Koordersiodendron pinnatum</i> Merr.	Anacardiaceae
<i>Mangifera altissima</i> Blanco	Anacardiaceae
<i>Mangifera indica</i> L.	Anacardiaceae
<i>Semecarpus cuneiformis</i> Blanco	Anacardiaceae
<i>Lepisanthes fruticosa</i> (Roxb.) Leenh.	Sapindaceae
<i>Lepisanthes rubiginosa</i> (Roxb.) Leenh.	Sapindaceae
<i>Aglaia grandis</i> Korth. ex Miq.	Sapindaceae
<i>Azadirachta indica</i> A.Juss.	Meliaceae
<i>Chisocheton</i> sp.	Meliaceae
<i>Sandoricum koetjape</i> (Burm.f.) Merr.	Meliaceae
<i>Swietenia macrophylla</i> King	Meliaceae
<i>Xylocarpus granatum</i> J.Koenig	Meliaceae
<i>Citrus japonica</i> Thunb.	Rutaceae
<i>Citrus maxima</i> (Burm.) Merr.	Rutaceae
<i>Citrus</i> sp.	Rutaceae
<i>Clausena</i> sp.	Rutaceae
<i>Melicope</i> sp.	Rutaceae
<i>Micromelum molle</i> Turcz.	Rutaceae
<i>Micromelum</i> sp.	Rutaceae
<i>Bixa orellana</i> L.	Bixaceae
<i>Dipterocarpus gracilis</i> Blume	Dipterocarpaceae
<i>Dipterocarpus grandiflorus</i> (Blanco) Blanco	Dipterocarpaceae
<i>Dipterocarpus hasseltii</i> Blume	Dipterocarpaceae
<i>Shorea contorta</i> S.Vidal	Dipterocarpaceae

<b>Taxon</b>	<b>Family</b>
<i>Corchorus aestuans</i> L.	Malvaceae
<i>Corchorus capsularis</i> L.	Malvaceae
<i>Corchorus olitorius</i> L.	Malvaceae
<i>Hibiscus rosa-sinensis</i> L.	Malvaceae
<i>Hibiscus tiliaceus</i> L.	Malvaceae
<i>Kleinhovia hospita</i> L.	Malvaceae
<i>Pterocymbium tinctorium</i> Merr.	Malvaceae
<i>Sida acuta</i> Burm.f.	Malvaceae
<i>Sida rhombifolia</i> L.	Malvaceae
<i>Sterculia foetida</i> L.	Malvaceae
<i>Sterculia philippinensis</i> Merr.	Malvaceae
<i>Sterculia</i> sp.	Malvaceae
<i>Urena lobata</i> L.	Malvaceae
<i>Moringa oleifera</i> Lam.	Moringaceae
<i>Carica papaya</i> L.	Caricaceae
<i>Capparis</i> sp.	Capparaceae
<i>Decaisnina cumingii</i> (Tiegh.) Barlow	Loranthaceae
<i>Persicaria barbata</i> (L.) H.Hara	Polygonaceae
<i>Celosia argentea</i> L.	Amaranthaceae
<i>Deeringia</i> sp.	Amaranthaceae
<i>Bougainvillea spectabilis</i> Willd.	Nyctaginaceae
<i>Pisonia umbellifera</i> (J.R. Forst & G. Forst.) Seem.	Nyctaginaceae
<i>Glinus oppositifolius</i> (L.) Aug.DC.	Molluginaceae
<i>Barringtonia racemosa</i> (L.) Spreng.	Lecythidaceae
<i>Chrysophyllum cainito</i> L.	Sapotaceae
<i>Palaquium</i> sp.	Sapotaceae
<i>Diospyros cauliflora</i> Blume	Ebenaceae
<i>Diospyros maritima</i> Blume	Ebenaceae
<i>Diospyros</i> sp.	Ebenaceae
<i>Ardisia grandident</i> Mez	Primulaceae
<i>Ardisia paniculata</i> Roxb.	Primulaceae
<i>Aidia</i> sp.	Rubiaceae
<i>Atractocarpus</i> sp.	Rubiaceae
<i>Coffea</i> sp.	Rubiaceae
<i>Gardenia elata</i> Ridl.	Rubiaceae
<i>Gardenia jasminoides</i> J.Ellis	Rubiaceae
<i>Gardenia merrillii</i> Elmer	Rubiaceae
<i>Gardenia</i> sp.	Rubiaceae
<i>Hedyotis</i> sp.	Rubiaceae
<i>Hymenodictyon</i> sp.	Rubiaceae
<i>Ixora</i> sp.	Rubiaceae
<i>Morinda citrifolia</i> L.	Rubiaceae
<i>Mussaenda grandifolia</i> Elmer	Rubiaceae
<i>Nauclea orientalis</i> (L.) L.	Rubiaceae
<i>Neonauclea</i> sp.	Rubiaceae
<i>Oxyceros bispinosus</i> (Griff.) Tirveng.	Rubiaceae
<i>Psychotria</i> spp.	Rubiaceae
<i>Randia</i> sp.	Rubiaceae
<i>Sulipa pseudopsidium</i> Blanco	Rubiaceae
<i>Uncaria</i> sp.	Rubiaceae
<i>Wendlandia</i> sp.	Rubiaceae

<b>Taxon</b>	<b>Family</b>
<i>Alstonia macrophylla</i> Wall. ex G.Don	Apocynaceae
<i>Alstonia scholaris</i> (L.) R. Br.	Apocynaceae
<i>Asclepias curassavica</i> L.	Apocynaceae
<i>Calotropis gigantea</i> (L.) Dryand.	Apocynaceae
<i>Cerbera manghas</i> L.	Apocynaceae
<i>Hoya el-nidicus</i> Kloppenb.	Apocynaceae
<i>Parameria laevigata</i> (Juss.) Moldenke	Apocynaceae
<i>Plumeria</i> sp.	Apocynaceae
<i>Tabernaemontana pandacaqui</i> Lam.	Apocynaceae
<i>Ipomoea aquatica</i> Forssk.	Convolvulaceae
<i>Ipomoea batatas</i> (L.) Lam.	Convolvulaceae
<i>Ipomoea triloba</i> L.	Convolvulaceae
<i>Merremia</i> sp.	Convolvulaceae
<i>Capsicum annuum</i> L.	Solanaceae
<i>Physalis angulata</i> L.	Solanaceae
<i>Solanum americanum</i> Mill.	Solanaceae
<i>Solanum melongena</i> L.	Solanaceae
<i>Cordia dichotoma</i> G.Forst	Boraginaceae
<i>Heliotropium nidicum</i> L.	Boraginaceae
<i>Jasminum elongatum</i> (P.J.Bergius) Willd.	Oleaceae
<i>Jasminum sambac</i> (L.) Aiton	Oleaceae
<i>Scoparia dulcis</i> L.	Plantaginaceae
<i>Avicennia</i> sp.	Acanthaceae
<i>Radermachera</i> sp.	Bignoniaceae
<i>Duranta erecta</i> L.	Verbenaceae
<i>Stachytarpheta jamaicensis</i> (L.) Vahl	Verbenaceae
<i>Clerodendrum</i> sp.	Lamiaceae
<i>Clerodendrum villosum</i> Blume	Lamiaceae
<i>Hyptis capitata</i> Jacq.	Lamiaceae
<i>Hyptis suaveolens</i> (L.) Poit.	Lamiaceae
<i>Leucas</i> sp.	Lamiaceae
<i>Premna</i> sp.	Lamiaceae
<i>Symphorema luzonicum</i> (Blanco) Fern.-Vill.	Lamiaceae
<i>Vitex parvifolia</i> A.Juss.	Lamiaceae
<i>Ageratum conyzoides</i> (L.) L.	Asteraceae
<i>Blumea balsamifera</i> (L.) DC.	Asteraceae
<i>Chromolaena odorata</i> (L.) R.M.King & H.Rob.	Asteraceae
<i>Cyanthillium cinereum</i> (L.) H.Rob.	Asteraceae
<i>Eclipta prostrata</i> (L.) L.	Asteraceae
<i>Vernonia</i> sp.	Araliaceae
<i>Polyscias nodosa</i> (Blume) Seem.	Araliaceae
<i>Schefflera</i> sp.	Araliaceae
<i>Centella asiatica</i> (L.) Urb.	Apiaceae



## Appendix 2 – Field reports for PIPRP

### Draft contribution for 2011 PIPRP field report

#### *Introduction*

This report documents and summarises initial field surveys into the potential for reconstructing past landscapes and environments in the Dewil Valley near the Barangay of New Ibajay, El Nido Municipality, NE Palawan Island, the Philippines. The aim of such work is to situate the results of past, present and future archaeological excavations and surface surveys across the valley (1998-Present) within a catchment-scale environmental context. The anticipated value of this work is its potential to reveal localised and regional relationships between changes internal to the cultural sequences with trends in external factors such as climate, ecological setting and sea level fluctuations thought to have occurred within the broader region contemporaneous with human occupation [citation(s) needed].

These surveys were conducted during the second half of the 2011 field season of the Palawan Island Palaeohistoric Research Project (15-30 April 2011). The core group of this project is based within the Archaeological Studies Program of the University of the Philippines Diliman (UP-ASP), and is led by Dr. Victor Paz (UP-ASP) and Dr. Helen Lewis (University College Dublin). The author's involvement is as part of an ongoing PhD project within the Department of Archaeology at the University of Cambridge (UK) and which aims to examine human-environment interactions across the Palaeolithic-Neolithic transition in Island Southeast Asia. Vito Hernandez (UP-ASP), Emil Robles (UP-ASP) and the author undertook the field surveys described herein, whilst members of the local team from New Ibajay provided invaluable assistance.

The author's primary intent in participating in these surveys was to assess the potential for palaeoecological reconstruction based upon plant remains - both microscopic (pollen) and macroscopic (seeds, fruits and waterlogged/charred tissues) - which might be preserved within depositional settings near to excavated archaeological sites. As such, this report is, in its present form, biased towards this end. It is anticipated that Vito Hernandez, Emil Robles and myself will combine our individually authored

summaries into a co-authored report to be appended to this year's comprehensive project field report. Vito's contribution should add a micromorphological spin, while Emil's will include results of mapping and augering surveys.

**\*\*Proper figures, tables, plates, maps and references to be added\*\***

### ***Palaeoecological potential***

The following section begins with a few comments on previous palaeoenvironmental work within the valley. Augering surveys, conducted this season at potential coring sites found and located near the Makangit karst complex and within the Miniano Bog north of Ille karst, are then described. The aim of these surveys was to determine the state of preservation of botanical remains within these sediments, and, where possible, to draw inferences regarding the time-depth of the deposits. As described below, the surveys generally achieved this goal.

Whilst palaeoecological inferences can be drawn indirectly from the archaeobotanical and zooarchaeological assemblages already analysed (Paz; Carlos; Piper; \_\_\_\_), detailed catchment-scale palaeoenvironmental reconstructions for the valley and northern Palawan region are still wanting. In 2006, Janelle Stevenson – a palynologist from the Australian National University – did some exploratory coring in various depositional settings within the valley and at the present landward edge of the adjacent mangrove complex [map with plotted GPS waypoints needed from Emil]. According to Vito, Emil and others, Janelle's focus was on obtaining a single continuous sequence for palynological analyses rather than on a broader approach with an explicitly archaeological focus. The author still needs to read Janelle's report and converse with her, but word is that her cores contained very little well-preserved pollen, and were thus not dated nor analysed further. The broader approach alluded to above could be one which might facilitate analyses of multiple palaeobotanical proxies depending upon localised taphonomy and preservation, and which would – in the absence of a continuous sequence - avail a piecemeal of cores from various deposits that span chunks of the temporal sequence of archaeological interest. Such an approach is what has guided the author in the surveys described here. Also along these lines and of note is Michael Bird's pioneering work (2007; forthcoming) in which he analysed isotopic signatures of bat/swiftlet guano deposits from caves within the Makangit and

Ille karsts to infer regional vegetation. Bird's study represents a valuable start at piecing together past environments of the Dewil Valley and of northern Palawan, upon which the author's present work aims to build.

The approach to the search for depositional settings likely to preserve plant remains within the valley was guided by the logic and assumptions that: acidic sediments and anoxic/reducing microenvironments are the best bets; such environments are most likely to occur as stream cut-offs, oxbows or perennially marshy areas sustained either by rain-fed percolation through nearby porous karst towers or by shallow water tables caused by topographic position/lithologic context; pollen preservation even in such settings is likely to be less than ideal valley-wide (Stevenson, \_\_\_\_); continuous Holocene sequences may be elusive; modern vegetation cover/ecology and land use may be useful informants of past and present depositional settings. As such, pedestrian surveys focused along the Dewil Valley articulated drainage network and around the base of the low-lying karsts. Additionally, it is the author's running hypothesis that patches of mangrove complex vegetation (i.e. *Avicennia* sp. and *Nipa* sp., as well as various pandans, ferns and rattans identified by local guides to be typical of back mangrove environments nearby today) which we encountered in swampy areas along streams near the Makangit karsts represent relict patches/refugia of the mangrove systems which are posited to have occupied at least the topographically-lower portion of the valley at the mid-Holocene high sea level stand (E. Robles, *pers. comm.*). If this be the case, it is possible that this vegetation complex's geomorphic function as a sediment trap may yield continuous organic-rich deposits spanning at least the mid-Holocene to present.

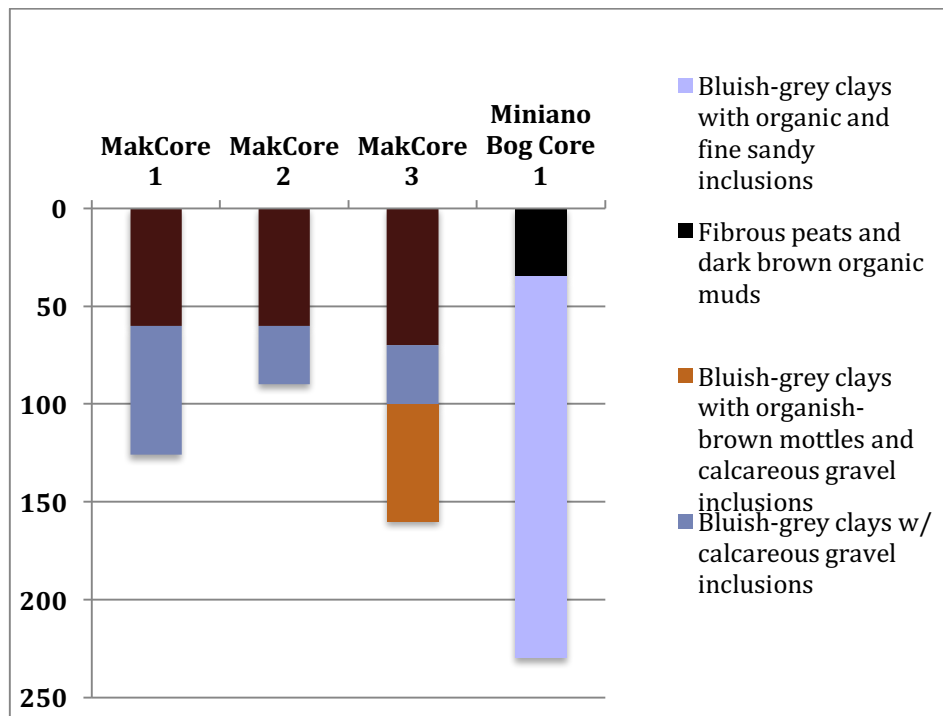
The first stage of the palaeoecological surveys involved coring one of these hypothesised relict mangrove patches immediately west of the Makangit karst complex. A clay auger with a 40 cm shoe was used to extract bulk samples in increments of 40 cm depth. The core named "MakCore 1" consisted of: about 60 cm of black organic muds, overlying a further 66 cm of grey clays with gravel inclusions, bottoming out on alluvial gravels at 126 cm below the surface [get notes from Vito for table]. These bulk samples were then processed via bucket flotation, with the organic remains thus recovered all appearing to be relatively modern. A further two cores were extracted from a more extensive patch of *Avicennia* and pandans just off the SW edge of Makangit [once again,

map needed from Emil with all these coring waypoints plotted]. “MakCore 2” and “MakCore 3” yielded different stratigraphy from that of MakCore 1, with a series of bluish-grey clays and orangish-brown clays with bluish-grey mottles underlying approximately 40 cm of dark brown organic muds within both of these cores. MakCore 3 spans a total depth of 160 cm, while MakCore 2 is only 90 cm. The transition from the bluish-grey clays to orangish-brown clays with bluish-grey mottles occurs in both cores between 60 and 70 cm depth, with the MakCore 3 stratigraphy revealing that this lowest unit becomes more orangish-brown and contains fewer bluish-grey mottles with increasing depth [insert table]. Sediments from MakCore 2 and MakCore 3 were wet sieved – first through nylon mesh of 1 mm<sup>2</sup> spacing, then through nylon mesh of 300 μm<sup>2</sup> - as bulk samples in the 40 cm depth increments by which they were extracted. Much organic remains were recovered, including various macroscopic plant remains as well as small gastropods and invertebrates. Unlike the stratigraphy of MakCore 1, those of MakCore 2 and MakCore 3 imply a significant time depth. It is presumed that pollen preservation might also be decent at these sites.

In addition to the augering at the Makangit sites, we sampled a bog north of Ille karst and located on the Miniano property [map from Emil here]. According to our local guides, this bog has never been converted to rice paddies nor cultivated in any manner. This is also one of the general areas in which Janelle Stevenson cored during her visit in 2006; she recovered little or no pollen from within her core. First, we probed the depth of the deposit along a cross-stream transect originating at the stream along the northern edge of the bog and terminating on its southern edge (towards Ille). We found the deposit to be deepest in roughly the centre of the bog, though the stratigraphies from different portions of the bog need to be compared in order to assess the continuity and completeness of these deposits. We began augering this site with a 10 cm long circular gouge head. The top 20 cm were discarded due to evident trampling and the prevalence of the root mat from the modern bog surface vegetation. Samples from 20-30 cm and 30-40 cm were extracted and bagged for macrofossil processing. The organic-rich dark brown peats and muds of the upper samples graded into a bluish-grey clay with organic and fine sandy inclusions at a depth of only 35 cm (the 30-40 cm depth sample was split according to this diffuse stratigraphic change). During the auger plunge to extract the 40-50 cm depth sample, we encountered the underlying water

table. Due to the open nature of the auger head, as well as that of the other two auger heads that we brought (40 cm clay auger and 20 cm Dutch auger), we were unable to recover samples from depths below the water table – the suction created by the spongy overlying peats combined with the groundwater through which we were pulling the sediments conspired to empty the sediment chamber during each attempt at extraction with all three of our different auger heads. This auger exercise then became simply one of probing depth. We were able to determine that, with the proper coring equipment (either a Livingstone or Russian D-section corer, both of 80 mm width to facilitate macrofossil sampling), upwards of 230 cm can be recovered from this site. Also, in light of Janelle's lack of success in recovering pollen from these deposits, a less destructive method for pollen preparations can be researched and implemented to give the best chance of recovering these remains from this site.

In summary, new coring sites were located off the western and SW edges of the Makangit karst complex, as well as within a bog north of the Ille karst. Deposits in both areas appear to house decent preservation of macrobotanical remains and, by extension, the potential for pollen recovery. These sites need to be revisited with the proper coring equipment and processed with Janelle's past attempts at pollen recovery in mind. As potential supplements to the palaeoecological information contained therein, the author intends to prepare pollen slides from augering samples obtained in previous seasons from: a 5 metre core extracted from beneath the excavated sequences of the Deep Trench just inside the East Mouth of Ille Cave; and a 10 m core extracted from a rice field about 100 m west of Ille karst.



**Figure A2.1** *Stratigraphy of auger cores referenced in text.*

### ***Geomorphic indications***

The pedestrian surveys that followed the Dewil Valley drainage network (main Dewil River, as well as tributaries to the north which drain sub-catchments within which archaeological sites have been excavated and/or identified) allow for some preliminary geomorphologic interpretations. Exposed undercut riverbanks, alluvial terraces and terrace-like formations are testament to a dynamic fluvial landscape within the valley (across what time period??). By walking the length of the Makangit River bed from its southward-flowing emergence from between the Istar and Diribungan karsts to its passage along the NE edge of the Makangit karst complex, a general picture of long-stream stratigraphy and deposits was gleaned. A layer of light-brown silts sits atop the majority of these sequences, and this silt deposit thins in the downstream direction. These silts presumably represent alluvial fans which originate from the steeper hill slopes bordering the valley to the north and are associated with the initial widespread clearance/management of this landscape following modern settlement by immigrants from Panay Island and surrounds in the early 1960s. Below these silts are a sequence of clayey silts, rounded gravels and more clayey silts, which

are interpreted to be deposits from the meandering stream. At the base of most exposed sequences are deposits of bluish-grey clays, and these same clays mottled with orangish-brown clays, which seem to be thickest around the Makangit karst complex. These deposits are indicative of variably reducing and oxidising environments, possibly related to sea-level fluctuations, climatic changes and/or fluctuating water tables.

**\*\*See Postscript, as well as Vito's report, for more detail/notes.**

### ***Archaeological implications***

Refinement of the archaeological record for the Dewil Valley, and indeed for this part of the world, can be furthered through the identification of open sites. The results from the surveys described in this report may prove fruitful in this respect. In past searches for open sites within the Dewil Valley, progress has been hindered by the realisation that deposits of ages of archaeological interest in open contexts underlie many metres of relatively recent alluvial deposits. However, the identification this year during the above described surveys of a set of well-defined river terraces along the upper stretches of the Kulanga River about 250 m SSW from ongoing excavations at Pasimbahan Cave and Rockshelter, represent the opportunity to explore deposits which potentially span a large time slice of archaeological relevance and which may sit relatively close to the surface. Additionally, these terraces are, by definition, within spatial proximity of a past consistent water source, and are also nearby to cave sites with established archaeology, thus increasing the chances for locating a site within the terrace deposits.

If it is assumed that the settlement pattern chronology in a potential site within these terrace deposits is similar to those reconstructed from other significant sequences within the broader region, such as at Niah Caves in lowland Malaysian Borneo, then the most interesting portion of these terrace deposits might be that which covers 4000 – 1500 BP. In a very general sense, it is during this time period within the region that the dominant component of cave sequences changes from that of occupation to one of mortuary/ceremonial use, implying that people generally moved out of caves and settled in open landscapes. This is also the time period of interest to the author in examining the environmental sequences. If this change in settlement pattern occurred within the Dewil Valley, did management of the landscape also change? If so, in which

ways did it change? What were the environmental context and consequences? How are settlement pattern, subsistence and cosmology related to/entwined with ecology, as seen in the comparison of the archaeological and environmental records?

The surveys described in this report represent the potential to make headway into answering some of these questions. The archaeological sequences within the Dewil Valley excavated over the past 13 years can be situated squarely within discourses related to prehistoric development of subsistence, settlement patterns and cosmologies in the region, as well as within those pertaining to regional connections and theorised human migrations from surrounding Island and Mainland Southeast Asia. Additionally, contemporary islands such as Palawan and Borneo, which sit on the now-inundated Sunda shelf and were at times of lower sea level a part of the continental landmass referred to as Sundaland, house some of the world's most diverse remaining ecosystems with numerous endemic species (cf. Wallace, 1869) and a wide range of human subsistence methods with large (and ancient??) vegecultural components. These ecological and cultural systems are increasingly under threat from modern mining, logging, industrial and agroforestry (specifically oil palm plantations) development. Much can be learned from the successes and failures of prehistoric land management models, with the potential for contemporary application.

#### ***Future work directly associated with these surveys***

After their transport back to Manila / UP-ASP, the wet-sieved remains from the Makangit Cores need to be further processed, sorted based upon broad class of remains, and some preliminary identifications made in order to properly assess the palaeoecological potential of these sites. Identification of remains are intended to be made with the aid of reference material in UP-ASP and/or UP Los Banos.

Pollen slides need to be prepared from subsamples of the auger cores from the Deep Trench at Ille Cave, as well as from Emil's core from the rice field west of Ille, to determine whether or not pollen is preserved within these sediments. As this will entail merely identifying the presence or absence of pollen, and perhaps an idea of pollen concentrations and relative state of preservation, the author can undertake this endeavour in the lab at Cambridge. However, this will require that small subsamples (approx 2 cubic centimetres) be sent from Manila to Cambridge. The samples from the



Deep Trench core are with Vito, whereas Emil knows the whereabouts of the rice field samples. The author will liaise with both Vito and Emil to arrange for this.

Janelle Stevenson needs to be contacted, informed of the author's work and intent, and her 2007 report obtained.

### ***Long-term plan and recommendations***

The coring sites identified and augered during these surveys need to be revisited and recored with proper coring equipment. Specifically, a Livingstone or Russian D-section corer with 80+ mm diameter barrel would facilitate sub-sampling for both pollen and macrobotanical remains. Upon return to the UK, the author plans to look into potential funding avenues for return visits to Manila / Palawan in order to spend time recoring sites and in the lab with the existing reference material housed in UP-ASP / Los Banos (parenchyma, seeds, fruits) and the National Museum in Manila (pollen). It would be ideal to coordinate the author's next visit with that of the geomorphologist, Jez Foster, when he comes to the Dewil Valley to do some landscape-scale mapping of landforms and deposits. This is tentatively slated for October 2011. Helen Lewis will facilitate contact between Jez Foster, Vito, Emil and the author in order for us to potentially arrange a visit in which all of us are in the Dewil Valley simultaneously.

### ***Postscript to contribution to 2011 PIPRP field report***

#### ***Field notes from Sinilakan karst & Makangit River – 19 April 2011***

Bunso as guide. River bed on northern and western fringes of karst seems to be ephemeral. River bed covered in angular stone approximately 10 cm in diameter. Seasonal stream at this point within the catchment, but possibly subject to high energy flows in heavy rains (??). Base of karst appears to be too high within the catchment above the water table on the alluvial valley below to have any perennial marshy areas in immediate vicinity which might be worth coring for botanical remains (macros or pollen).

Bunso pointed out Pacaldero Cave on SE face of Sinilakan – narrow entrance and narrow deep chamber, with what appear to be a few natural deposits of animal bones (like from an individual animal) on surface.

“Istar RivBank1” GPS waypoint: Undercut bank on outside of river bend, just downstream from river’s emergence from between Istar and Diribungan. Approximately 2 m of profile is exposed. Upper meter is light brown silts, almost certainly recent (within the last 50 years) erosion from initial widespread clearance along valley-fringing slopes for swiddens following Cuyonin settlement in early 1960s. Lower meter are typical stream and floodplain deposits. Rounded gravels 2-4 cm in diameter with intervening matrix of red and grey mottled silts and clays (redox). Lowest 30 cm are these red and grey mottled silts and clays in the absence of gravel inclusions (again, redox – seasonal stream/floodplain).

The streams along these higher gradient slopes on northern fringe of the alluvial landscape of the valley appear to be mainly seasonal at the upper stretches. Once the gradient / upstream catchment area / underlying water table depth permit perennial stretches of these same streams just downstream of the very edge of the alluvial landscape of the Dewil Valley, people within the past 50 years have modified these drainages / hydrological systems for irrigation, diverting all of the dry season base flows.

“Istar RBndForm” GPS waypoint: Istar River bend formation. Either an abandoned river bend with eroded outside bank or a possible terrace. This formation is at the same longstream position as the set of 3 terraces along the larger Kulanga River that drains the adjacent sub-catchment to the west. The present channel no longer follows this bend (if this is indeed what this formation is). Bananas, pineapple and star apple (*Chrysophyllum cainito* L., Sapotaceae) now planted on abandoned stream channel & eroded bank. Looks like prime location for a small oxbow, but this abandoned river bend has been drained by a linear cut, presumably to create favourable growing conditions for banana.

“IstarRBnd&Well” GPS waypoint: Small well in actual stream channel, revealing water table is less than 1 m below stream bed this time of year. Eroded bank on outside of bend just next to well may contain a buried soil (photos taken). Difference between this profile and those upstream is that 2 mature trees (probably 50+ years old) sit atop the bank, so the thick layer of inwashed silts from clearance over the past 50 years is absent here. Below the trees are typical meandering stream deposit sequences:

silt/clay, gravel, silt/clay. However, below that is a lens of variable thickness, but up to 70 cm thick and at least 3 m in longstream dimension, which appears to be a partially podzolised silty loam (photo taken) – upper 20 cm are dark greyish-brown, lower 40 cm are light yellowish-brown. Below this are more stream deposit sequences, with the same red and grey mottled silts and clays as further upstream. Same mottled clays without gravel inclusions underlie these.

“IstarR YlwClay” GPS waypoint. Yellow clay with white mottles and no inclusions underlying blue-grey and red mottled clay alluvial sequence, just downstream from IstarRBnd&Well waypoint and just upstream from Makangit karst (photo taken). This is the only place I have observed this unit over the past week or so of landscape surveying. It happens to lie at a similar depth as the coral which Janelle Stevenson found at the base of her core in the boggy area north of Ille.

- S.A. O'Donnell

## Draft contribution to 2012 PIPRP field report

### *Introduction*

After nearly fifteen years of ongoing excavations at Ille Cave, we still lack a detailed vegetation reconstruction at any spatial scale for the time period corresponding to past human habitation of the cave and the surrounding alluvial landscape. The Ille Cave excavation sequence suggests relatively continuous human occupation since the terminal Pleistocene extending throughout the Holocene (Lewis *et al.*, 2008). Previous researchers' attempts at gathering relevant palaeoenvironmental data have been successful on a general level. Typical Pleistocene-Holocene transitional sequences are represented by the zooarchaeological (Piper *et al.*, 2011) and archaeobotanical (Carlos, 2010) remains. These studies infer a trend in vegetation change from a more open savanna-like landscape in the area to that of a more closed forest environment across the Pleistocene-Holocene boundary centred around ~12 ka BP. These data are corroborated by Bird *et al.*'s (2007) isotopic work on guano deposits in the adjacent Makangit karst complex. Bird *et al.* suggest a shift in the predominant photosynthetic pathway of surrounding vegetation from C4 during the LGM to C3 by the mid Holocene, which indicates an expected climatic movement from cooler and drier conditions to warmer and wetter. Additionally, Maeda *et al.* (2004) show that mid Holocene average sea levels along the coast of northern Palawan were up to 1.3 m higher than they are at present, the implications of which for past human activity in the Dewil Valley are manifest in the dense marine shell midden within the Ille Cave excavation sequence dated to ~5-7 ka BP. Despite this existing data, however, previous research has failed to establish neither a full suite of floral resources available to past inhabitants of Ille Cave nor a detailed human ecological dynamic through time.

Janelle Stevenson's unsuccessful attempt during the 2005 season to redress this deficiency with palynological investigation proved that locating organic-rich deposits in the broader Dewil Valley landscape of comparable time-depth to that of the Ille Cave sequence is a difficult task (Stevenson, 2006). As such, an aim of my ongoing PhD research is to move beyond the orthodox

palaeoecological approach by expanding the spatial scope of the search for suitable deposits to encompass adjacent sub-catchments, as well as considering acceptable a temporally-piecemeal record conflated from fragmentary deposits of varying ages. This report summarises the associated field sampling and subsequent labwork which I completed in 2012 followed by a preliminary assessment of the palaeoenvironmental potential of the material gathered therein and a proposed programme of future work.

### ***Summary of samples***

During April of 2012, I collected two sediment cores from sub-catchments adjacent to the Dewil Valley, as well as two sample columns from sedimentary sequences within the Valley itself. Figure A2.2 shows the locations of each of these sampling sites. Descriptions of the physiographic setting of each of these locations, the sediments that comprise the samples and photos of the sites and sediments are included in the Appendix to this report. As such, I will only briefly mention them here.

The most promising material is a 2.5 m core from a peaty deposit surrounding a hot spring called Makinit. The Makinit site is located about 7 km northwest of Ille in the adjacent catchment to the Dewil Valley. This hot spring sits within an alluvial landscape dominated by rice paddies, but is immediately surrounded by a relict patch of mangrove vegetation. In terms of elevation and distance from the present coast, Makinit is comparable to Ille. The upper 225 cm of this core are variably humified red-brown peats with occasional large woody inclusions throughout and a sandy lens at about 12 cm depth. The basal 25 cm consist of alternating grey and brown-grey laminated clays with numerous charcoal bands. The second core is a 1 m sequence consisting mostly of laminated minerogenic clays from a notional palaeolake feature near Kagbanaba. This site, called Baryaw-baryaw, is high up in the sub-catchment to the south of Ille Cave. The core itself comes from the deposit beneath a roughly circular patch of rushes and ferns, once again within a landscape dominated by wet rice cultivation. In addition to these two cores, I took a series of eight samples from a river terrace sequence on the upstream edge of New Ibajay, just downstream

from Ille Cave. This terrace sequence is the type-site for Terrace 3, as defined by Gez Foster and Vito Hernandez' landscape survey work and which they have named DR1. Victor also sampled the Pasmibahan-Magsanib excavation sequence both by context and at regular depth intervals, providing the fourth set of samples for palaeoenvironmental analyses.



**Figure A2.2** Map of northern Palawan showing the locations of the five palaeoenvironmental sampling sites mentioned in this text. Map: E. Robles.

### ***Labwork undertaken***

I collected all of the abovementioned material with the intent to analyse the plant microfossils (pollen and, time permitting, phytoliths) they might contain. After sampling in the field, I wrapped each 50 cm core segment from the two cores (from Makinit and Baryaw-baryaw) in foil and taped them inside PVC piping for protection during transit from Palawan to Manila. Once in the UP-ASP labs, I then photographed and described the lithology and stratigraphy of both

cores via visual and tactile examination prior to sub-sampling. Both cores were sub-sampled at 10 cm depth intervals throughout their entireties. One centimetre thick slices were removed from the D-section cores at each sub-sampling point. Additionally, I sub-sampled the basal clay unit of the Makinit core at stratigraphic changes. Figure A2.3 shows the basal 50 cm (depths 200-250 cm) of this core after sub-sampling. Two large woody fragments were removed from respective depths of 76-79 cm and 129-132 cm of the Makinit core for radiocarbon dating. This strategy yielded a total of 24 sub-samples for microfossil processing from the Makinit core and 10 sub-samples from the Baryaw-baryaw core.



**Figure A2.3.** Basal 50 cm of the Makinit core, with top of core section at left and bottom at right. Eight 1 cm thick slices were removed from this 50 cm long core section (one each from top and bottom, as well as at the six intervening gaps).

In the Geography Department labs at the University of Cambridge, I have processed initial batches for pollen analyses – each consisting of 8 sub-samples – from the two cores described above, as well as from the DR1 terrace sequence. Pollen processing followed the standard procedure devised by the Geography Department at Cambridge, which can be found here:

<http://www.geog.cam.ac.uk/facilities/laboratories/techniques/pollen.html>.

These initial batches were used to assess the pollen preservation throughout each of the sedimentary sequences that were sampled. As such, I scanned one 22 mm x 22 mm slide (400 fields of view at 400x magnification under refracted light microscopy). I counted total pollen grains, exotic *Lycopodium* spores (spike for concentration calculations; see Geography Department's pollen processing methodology) and 'robust' grains (heavily ornamented pollen grains, as well as fern spores with thick exines). I then used these counts to estimate pollen

concentrations, as well as to determine whether or not any differential preservation of more robust grains exists.

### ***Preliminary assessment***

As described above, I have processed batches – each consisting of 8 sub-samples – from the Makinit and Baryaw-baryaw cores, as well as from the 8 DR1 samples for pollen and scanned them under refracted light microscopy to determine pollen concentrations and the state of pollen preservation throughout each of these sequences. Of these 24 initial samples, only 5 contain well-preserved pollen in countable concentrations. All 5 of these sub-samples come from the Makinit core. I have thus decided to focus my future labwork on the Makinit sequence. I have begun the process of counting, describing and photographing the grains contained in these initial Makinit assemblages; however, to date too few samples have been counted and only descriptive classifications assigned to the constituent grains for results to be presented here.

### ***Future steps***

In relation to the Makinit sequence, I will process the remaining 16 sub-samples for pollen. I will continue with my system of describing, sketching and photographing each new grain I encounter, and assigning a general name (such as Type 1, Type 2, etc) to each grouping of similar grains. Assigning taxonomic names awaits access to suitable reference material. Potential reference material exists in the form of: a partially published Philippine pollen flora by the late palynologist Bulalacao; Bernard Maloney's reference collection from lowland Borneo, housed at Queen's University Belfast (QUB); and the online Australasian Pollen and Spore Atlas (APSA), maintained by the ANU working group PalaeoWorks. Ascribing ecological significance to the microfossil assemblages can then proceed, the first step of which is the compilation of a training set from surface sampling, and use of this training set to calibrate the fossil assemblages with likely vegetation types that may have produced them. It is my plan to return to Palawan, perhaps during the 2013 season of the Palawan Island Palaeohistoric Research Project, to conduct a programme of surface sampling within



environments that span a gradient in degree of human impact and across a spectrum of human landuse.

In relation to the samples from the cave sediments, I will process these for both pollen and phytoliths according to a less destructive procedure devised by Chris Hunt at QUB and used for his palynological work on the Niah Cave sediments. These samples include: the abovementioned 31 samples from the Pasimbahan-Magsanib excavation sequence; a series of 37 samples from the East Mouth Trench of Ille Cave spanning the entire excavated sequence, collected by Janelle Stevenson in 2005 but never analysed; and a single environmental sample from context 2161 in the East Chamber Trench associated with a few lithic flakes and a core. The speculative idea is that Makinit may yield a late Holocene record of vegetation changes, while the pollen from the cave sediments will supplement this with a record spanning the terminal Pleistocene to mid Holocene. Additionally, the phytolith analyses have the potential to bolster our relatively sparse archaeobotanical record which, to date, is based solely upon a macrobotanical assemblage of only a handful of taxa.

### ***Conclusion***

Great potential to expand upon and refine our understanding of how past human populations existed within the environments of northern Palawan remains in the form of, and indeed necessitates, an unorthodox approach to palaeoecological research. Such an approach can paint a more complete picture of the suite of floral resources available to past inhabitants of Ille Cave, as well as establish a human ecological dynamic through time. Preliminary assessment of the material gathered during the 2012 season of the Palawan Island Palaeohistoric Research Project provides for optimism that this potential will soon be realised.

### ***Postscript to contribution to 2012 PIPRP field report***

#### ***Inventory and descriptions of 2012 samples taken to Cambridge***

I have taken the samples described and listed below during the April 2012 fieldseason of the Palawan Island Palaeohistoric Research Project in the Dewil Valley for use in my PhD. Graeme has intimated that there may potentially be funds / resources for radiocarbon dates on sequences from which I analyse material for my PhD. I plan to process all of the following samples for pollen analysis. In addition, I plan to process the samples from Pasimbahan-Magsanib and Ille Cave excavations samples for phytoliths. I have accessioned all of these samples (save for the 1 m core from Kagbanaba, which I will accession as a series of sub-samples once I sub-sample the core at ASP after the fieldseason), and I will be taking them back to the UK with me. From this year's fieldwork, these include:

- the section of T3 on the south bank of the Dewil River just downstream from the bridge under reconstruction. Vito and Gez have assigned a site name of DR1 to this section;
- the short (1 m) core which I took from a marshy area surrounding a spring high up in the Kagbanaba River catchment (southern sub-catchment of the Dewil River Valley – the Kagbanaba River flows into the Dewil River just upstream from the present mangrove complex);
- two columns of samples which Victor took from the Pasimbahan excavation sequence in Trench A/B, one column at regular depth intervals and the other sampled by context number. These will be used in a contained study on post-depositional mobility of microfossils within cave sediments;
- a single sample which I took from context 2161 in the East Chamber Trench where Archie found a few flakes and a core; and
- a core which I plan to take on 29 April (Bunso is picking me up in a trike from Calitang) in the catchment to the north of the Dewil Valley where Emil – through word of mouth from Jojo – prospected a 2 m+ deep organic deposit near a hot spring (close to Happy Valley).

Below are short descriptions and/or field notes for each of these groups of samples. Emil has GPS points for all sites. Gez and Vito have detailed notes and

photos of the DR1 site. Victor should have notes on the series of samples taken from the Pasimbahan-Magsanib sequence.

### **DR1**

Refer to Vito and Gez's field notes. This site is an exposed section (Figure A2.4) on the outside of a small meander on the Dewil River just downstream from the main bridge into New Ibajay which is currently under reconstruction. Vito and Gez have interpreted this section to be representative of the T3 sequence. The whole 3.9 m sequence appears to be fluvially deposited. The upper ~2.5 m consist of bedded light brown silts which Vito and Gez ascribe to the past 60 years following widespread logging within the catchment which dramatically increased sediment supply to Dewil Valley waterways. Vito and Gez have labelled this as Unit 2. The lower ~1.5 m consist predominantly of clays, but interspersed with thin lenses of silts and sands (Figure A2.5). Time-depth unknown, but Vito and Gez believe this may represent the past 300 or so years of deposition during which landuse within the catchment was dominated by swiddening (Vito says this is supported by ethnographic sources). Samples for radiocarbon dating were taken by Vito and Gez, but may end up with me to take back to the UK for dating. A ~15 cm thick layer of clays with a high concentration of organic debris is at the base of this lower unit. This entire clay unit is labelled Unit 1, which is further broken down into sub-units based mainly upon changes in colour. The predominant colour is grey, with sub-units of solid grey, grey with orange mottles (owing to either redox or bioturbation), and light brown-grey (the aforementioned organic-rich sub-unit at the base). I took a series of 8 samples from sub-units 1b-1f (Figure A2.6). We took heights from the base of the exposed sequence (*not* depths from the terrace surface!). Table 1 shows the accession numbers, sub-units from which they come and heights for each of these 8 samples.

**Table A2.1** Accession numbers, sub-units of origin and height from the base of the exposed section for each of the 8 sub-samples.

Accession number	Sub-unit	Height from base of section
IV-2012-___-1	1b	12-13 cm
IV-2012-___-2	1b	18-19 cm
IV-2012-___-3	1c	26-27 cm
IV-2012-___-4	1c	34-35 cm
IV-2012-___-5	1d	50-51 cm
IV-2012-___-6	1e	70-71 cm
IV-2012-___-7	1e	78-79 cm
IV-2012-___-8	1f	96-97 cm



**Figure A2.4** DR1 section.



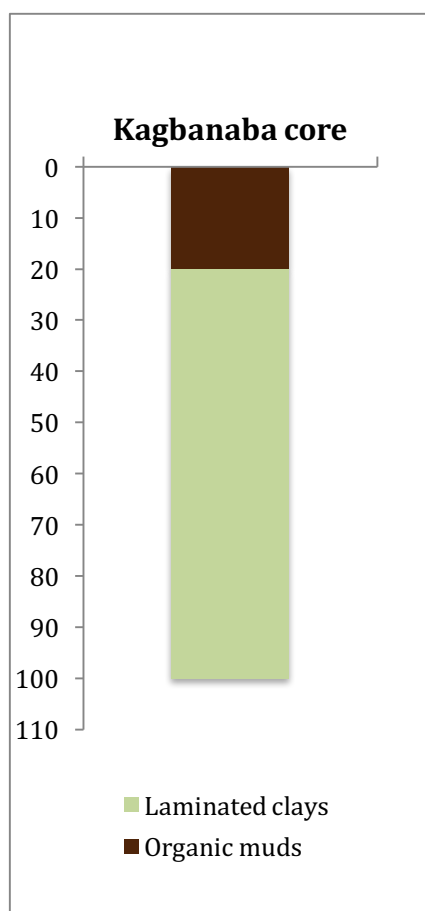
**Figure A2.5** Unit 2 at DR1.



**Figure A2.6** Sub-sample positions.

### ***Kagbanaba (Baryaw-baryaw) core***

I took a 1 m core with a Russian (D-section) corer from within a patch of aquatic vegetation (dominated by a rush with a local name of “baryaw-baryaw” and ferns) surrounding a spring high up in the Kagbanaba River catchment. Emil took an exact GPS waypoint and will plot this on a map once he has a functional laptop. This patch of aquatic vegetation is roughly circular, with a diameter of ~50 m. It sits within what is presumably an alluvial landscape surrounded by rice paddies (Figure A2.8), though Emil and I both got the visual impression that this area is somewhat basin-like, delimited by hills on nearly all sides. The sediments are quite different to those encountered elsewhere in the Dewil Valley. The stratigraphy of the core consists of two units (Figures A2.7, A2.9, and A2.10): the uppermost 20 cm are brown organic-rich muds, presumably modern marsh deposits; the underlying 80 cm consist of green-grey clays with inclusions of highly-weathered angular coarse sands and fine gravels, green and white in colour and with apparent laminations of some sort. This lower unit appears to be quite minerogenic, though visually it looks like some portions may contain an organic fraction. A more detailed strat will be compiled in the ASP lab once I return to Manila. I will also sub-sample this core, probably at 10 cm intervals, and take the sub-samples back to the UK with me to process for pollen analysis. Once it is sub-sampled, I will accession each sub-sample individually and leave the remaining sections of the core in Manila.



**Figure A2.7** Kagbanaba core stratigraphy.



**Figure A2.8** Kagbanaba coring area.



**Figure A2.9** Upper 50 cm of Kagbanaba core.



**Figure A2.10** Lower 50 cm of Kagbanaba core.

### ***Pasimbahan-Magsanib excavation sample columns***

Victor took two vertical series of environmental samples from Trench A/B of the Pasimbahan-Magsanib excavation sequence, with the idea that -- preservation willing -- I will extract and analyse both pollen and phytoliths from them for my PhD. The first sequence of samples were taken from selected contexts, in profile; the second sequence of samples formed a vertical column with even spacing between sub-samples at 20 cm depth intervals, once again in profile. The idea behind this sampling strategy is to test whether microfossils are vertically mobile within these cave sediments. If these two sample columns produce similar microfossil curves, then this homogenization would imply post-depositional mobility of the microfossils; conversely, if the resultant microfossil curves differ significantly between those sampled by context and those sampled

in a vertical column by depth, then post-depositional immobility of microfossils in cave sediments will be supported. This methodological test could potentially form a publishable contained study in itself. The palaeoenvironmental and archaeobotanical data produced is of obvious value to the project. Victor also took a few samples from the notional hearth feature (context 444) and associated layers with burnt bone and shell fragment scatters (contexts 446 & 447) for the process for phytoliths and to radiocarbon date back in the UK. Table A2.2 shows

**Table A2.2** Accession numbers, contexts / depths and descriptions of Pasimbahan samples.

<b>Accession number</b>	<b>Context / Depth (cm)</b>	<b>Description</b>
IV-2007-Q-2167	c. 446	West wall (sample 1)
IV-2007-Q-2168	c. 446	West wall (sample 2)
IV-2007-Q-2169	c. 447	Top of context
IV-2007-Q-2170	c. 447	Middle of context
IV-2007-Q-2171	c. 447	Bottom of context
IV-2007-Q-2172	Surface (223 cm bDP)	Column sample
IV-2007-Q-2173	243 cm bDP	Column sample
IV-2007-Q-2174	263 cm bDP	Column sample
IV-2007-Q-2175	283 cm bDP	Column sample
IV-2007-Q-2176	303 cm bDP	Column sample
IV-2007-Q-2177	323 cm bDP	Column sample
IV-2007-Q-2178	343 cm bDP	Column sample
IV-2007-Q-2179	363 cm bDP	Column sample
IV-2007-Q-2180	383 cm bDP	Column sample
IV-2007-Q-2181	403 cm bDP	Column sample
IV-2007-Q-2182	c. 50, under rock	Sample by context
IV-2007-Q-2183	c. 51	Sample by context

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IV-2007-Q-2184	c. 64	Sample by context
IV-2007-Q-2185	c. 68	Sample by context
IV-2007-Q-2186	c. 76	Sample by context
IV-2007-Q-2187	c. 339	Sample by context
IV-2007-Q-2188	c. 412	Sample by context
IV-2007-Q-2189	c. 414	Sample by context
IV-2007-Q-2190	c. 416, feature	Sample by context
IV-2007-Q-2191	c. 428	Sample by context
IV-2007-Q-2192	c. 438	Sample by context
IV-2007-Q-2193	c. 441, surface	Sample by context
IV-2007-Q-2194	c. 444, North – bottom1	Sample by context
IV-2007-Q-2195	c. 444, North – top	Sample by context
IV-2007-Q-2196	c. 444, Mid – top	Sample by context
IV-2007-Q-2197	c. 444, North – bottom2	Sample by context
IV-2007-Q-2198	c. 444, South – bottom	<sup>14</sup> C sample
IV-2007-Q-2165	c. 446, 404 cm bDP	<sup>14</sup> C sample
IV-2007-Q-2166	c. 446, 405 cm bDP	<sup>14</sup> C sample

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### ***East Chamber sample***

I took one environmental sample from the north wall profile of the East Chamber Trench within context 2161 where Archie found a few lithic flakes and a core. Archie was excited for me to have a look at phytoliths from this sample in order to see if there is any evidence of hafting or plant processing associated with the lithics. This sample comes from a depth of 148-154 cm below the site datum point. I have accessioned this sample as **IV-1998-P-48682**.



***Core from catchment to the north of Dewil Valley***

After failing to locate suitable pollen coring sites within the Dewil Valley itself, Emil and I expanded our search to neighbouring catchments. As mentioned above, we cored a marsh in the Kagbanaba River sub-catchment to the south. Additionally, Jojo told Emil of a “peaty” deposit in the catchment to the north of the Dewil Valley, which Emil augered a few days later. According to Emil, there are 2+ m of organic deposits within a large patch of aquatic and mangrove vegetation surrounding a hot spring. I plan to core this site with a Russian (D-section) corer on 29 April when we are in Calitang. Emil has arranged to have Bunso take me from Calitang to the site on a trike on the 29<sup>th</sup>.



## Appendix 3 - Palawan-relevant pollen images






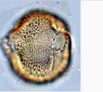


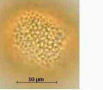











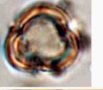


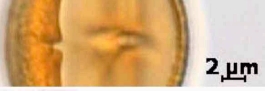










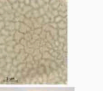


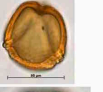







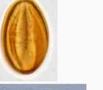





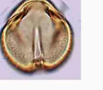
Family	Genus	Species	1	2	3
Selaginellaceae	Selaginella	wildenovii			
Nephrolepidaceae	Nephrolepis	biserrata			
Lygodiaceae	Lygodium	microphyllum			
Pteridaceae	Acrostichum	aureum			
Pteridaceae	Pteris	tripartita			
Pteridaceae	Pteris	vittata			
Aspleniaceae	Asplenium	nidus / australasicum			
Aspleniaceae	Asplenium	unilaterale			
Blechnaceae	Stenochlaena	palustris			
Gnetaceae	Gnetum	gnemon			
Myristicaceae	Myristica	lancifolia			
Annonaceae	Annona	sp.			
Annonaceae	Polyalthia	longifolia			
Lauraceae	Cinnamomum	burmannii			
Lauraceae	Persea	americana			
Piperaceae	Piper	sp.			
Araceae	Alocasia	macrorrhizos			
Araceae	Colocasia	esculenta			

Taccaceae	Tacca	leontopetaloides			
Dioscoreaceae	Dioscorea	glabra			
Pandanaceae	Freycinetia	angustifolia			
Pandanaceae	Freycinetia	scandens			
Pandanaceae	Pandanus	tectorius			
Smilacaceae	Smilax	australis			
Agavaceae	Dracaena	angustifolia			
Arecaceae	Calamus	javensis			
Arecaceae	Cocos	nucifera			
Arecaceae	Corypha	sylvestris			
Arecaceae	Licuala	peltata			
Bromeliaceae	Ananas	comosus			
Flagellariaceae	Flagellaria	indica			
Commelinaceae	Aneilema	siliculosum			
Commelinaceae	Commelina	benghalensis			
Commelinaceae	Cyanotis	axillaris			
Pontederiaceae	Monochoria	cyanea			
Musaceae	Musa	sp.			

Costaceae	Cheilocostus	speciosus			
Ceratophyllaceae	Ceratophyllum	demersum			
Menispermaceae	Tinospora	smilacina			
Dilleniaceae	Dillenia	suffruticosa			
Dilleniaceae	Tetracera	akara			
Vitaceae	Cissus	adnata			
Leeaceae	Leea	rubra			
Oxalidaceae	Averrhoa	carambola			
Oxalidaceae	Oxalis	corniculata			
Elaeocarpaceae	Elaeocarpus	grandiflorus			
Rhizophoraceae	Bruguiera	cylindrica			
Rhizophoraceae	Bruguiera	gymnorhiza			
Rhizophoraceae	Bruguiera	parviflora			
Rhizophoraceae	Carallia	brachiata			
Rhizophoraceae	Ceriops	tagal			
Rhizophoraceae	Rhizophora	apiculata			
Rhizophoraceae	Rhizophora	mucronata			
Clusiaceae	Calophyllum	inophyllum			

Clusiaceae	Calophyllum	soulattri			
Clusiaceae	Garcinia	bancana			
Clusiaceae	Garcinia	havilandii			
Clusiaceae	Garcinia	rostrata			
Passifloraceae	Passiflora	foetida			
Euphorbiaceae	Acalypha	grandis			
Euphorbiaceae	Acalypha	indica			
Euphorbiaceae	Acalypha	insulana			
Euphorbiaceae	Breynia	cernua			
Euphorbiaceae	Codiaeum	variegatum			
Euphorbiaceae	Excoecaria	agallocha			
Euphorbiaceae	Glochidion	littorale			
Euphorbiaceae	Jatropha	curcas			
Euphorbiaceae	Macaranga	tanarius			
Euphorbiaceae	Mallotus	floribundus			
Euphorbiaceae	Mallotus	nesophilus			
Euphorbiaceae	Mallotus	paniculatus			
Euphorbiaceae	Mallotus	philippinensis			



Euphorbiaceae	Mallotus	repandus			
Euphorbiaceae	Melanolepis	multiglandulosa			
Euphorbiaceae	Trigonostemon	heteranthus / longifolius			
Euphorbiaceae	Wetria	insignis / macrophylla			
Phyllanthaceae	Antidesma	bunius			
Phyllanthaceae	Antidesma	ghaesembilla			
Phyllanthaceae	Antidesma	montanum			
Phyllanthaceae	Aporosa	papua			
Phyllanthaceae	Cleistanthus	myrianthus			
Phyllanthaceae	Phyllanthus	maderaspitensis			
Phyllanthaceae	Phyllanthus	vulcani			
Fabaceae	Alysicarpus	ovalifolius / vaginalis			
Fabaceae	Bauhinia	merrilliana			
Fabaceae	Bauhinia	variegata			
Fabaceae	Calopogonium	mucunoides			
Fabaceae	Cassia	fistula			
Fabaceae	Cassia	javanica			
Fabaceae	Cassia / Senna	tora			

Fabaceae	Crotalaria	verrucosa			
Fabaceae	Derris	sp.			
Fabaceae	Desmodium	gyroides			
Fabaceae	Desmodium	heterocarpon			
Fabaceae	Desmodium	tortuosum			
Fabaceae	Entada	rheedii / scandens			
Fabaceae	Mimosa	pudica			
Fabaceae	Pterocarpus	indicus			
Rosaceae	Prunus	javanica			
Rhamnaceae	Ventilago	viminalis			
Ulmaceae	Trema	orientalis			
Urticaceae	Denrocnide	photinophylla			
Cucurbitaceae	Cucurbita	maxima			
Cucurbitaceae	Lagenaria	siceraria			
Cucurbitaceae	Momordica	charantia			
Datisceae	Octomeles	sumatrana			
Combretaceae	Lumnitzera	racemosa			
Combretaceae	Terminalia	catappa			









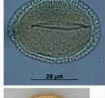



Onagraceae	Ludwigia	octavalis			
Lythraceae	Lagerstroemia	reginae			
Myrtaceae	Psidium	guajava			
Myrtaceae	Syzygium	cumini			
Melastomataceae	Melastoma	malabathricum / affine			
Burseraceae	Canarium	asperum			
Burseraceae	Canarium	littorale			
Anacardiaceae	Anacardium	occidentale			
Anacardiaceae	Buchanania	arborescens			
Anacardiaceae	Mangifera	indica			
Sapindaceae	Sapindus	saponaria			
Meliaceae	Chisocheton	cumingianus / morobeanus			
Meliaceae	Swietenia	macrophylla			
Meliaceae	Xylocarpus	granatum			
Rutaceae	Citrus	sp.			
Rutaceae	Clausena	excavata			
Rutaceae	Melicope	simplex (NZ)			
Rutaceae	Micromelum	minutum			

Bixaceae	Bixa	orellana			
Dipterocarpaceae	Dipterocarpus	gracilis			
Malvaceae	Hibiscus	tiliaceus			
Malvaceae	Kleinhovia	hospita			
Malvaceae	Sida	acuta			
Malvaceae	Sida	rhombifolia			
Malvaceae	Sterculia	foetida			
Malvaceae	Urena	lobata			
Caricaceae	Carica	papaya			
Capparaceae	Capparis	callophylla			
Capparaceae	Capparis	sepiaria			
Loranthaceae	Decaisnina	signata			
Amaranthaceae	Celosia	argentea			
Nyctaginaceae	Bougainvillea	spectabilis			
Nyctaginaceae	Pisonia	umbellifera			
Molluginaceae	Mollugo	molluginia			
Lecythidaceae	Barringtonia	racemosa			
Sapotaceae	Chrysophyllum	roxburghii			

Sapotaceae	Palaquium	morobense			
Ebenaceae	Diospyros	andamanica / malyana			
Ebenaceae	Diospyros	microphylla			
Primulaceae	Ardisia	crenata			
Rubiaceae	Aidia / Randia	cochinchinesis			
Rubiaceae	Aidia / Randia	racemosa			
Rubiaceae	Gardenia	lamingtonii			
Rubiaceae	Hedyotis	auricularia			
Rubiaceae	Ixora	grandifolia			
Rubiaceae	Ixora	lobbii			
Rubiaceae	Morinda	citrifolia			
Rubiaceae	Mussaenda	macrophylla			
Rubiaceae	Nauclea	orientalis			
Rubiaceae	Neonauclea	forsteri			
Rubiaceae	Psychotria	leptothyrsa / beccaroides			
Apocynaceae	Alstonia	macrophylla			
Apocynaceae	Cerbera	sp.			
Apocynaceae	Plumeria	clusoides			



Apocynaceae	Tabernaemontana	orientalis			
Convolvulaceae	Ipomoea	batatas			
Convolvulaceae	Ipomoea	indica			
Convolvulaceae	Merremia	peltata			
Solanaceae	Capsicum	frutescens			
Solanaceae	Physalis	angulata			
Solanaceae	Solanum	americanum			
Solanaceae	Solanum	torvum			
Boraginaceae	Cordia	dichotoma			
Boraginaceae	Cordia	subcordata			
Boraginaceae	Heliotropium	indicum			
Oleaceae	Jasminum	didymum			
Scrophulariaceae	Scoparia	dulcis			
Acanthaceae	Avicennia	alba			
Acanthaceae	Avicennia	integer			
Acanthaceae	Avicennia	marina			
Acanthaceae	Avicennia	officinalis			
Lamiaceae	Hyptis	suaveolens			

Lamiaceae	Leucas	javanica			
Lamiaceae	Premna	herbacea			
Lamiaceae	Premna	serratifolia			
Lamiaceae	Vitex	glabrata			
Lamiaceae	Vitex	rotundifolia			
Lamiaceae	Vitex	trifolia			
Lamiaceae	Volkameria / Clerodendrum	inermis / inermis			
Araliaceae	Polyscias	multijuga			
Apiaceae	Centella	asiatica			



## Appendix 4 – Bandong (2013) report

***\*Scanned, verbatim reproduction of text only portion of report; complete species list with IPNI-accepted spelling and nomenclature appears in Appendix 1***

The Botanical Survey was conducted from April 6-13, 2013 in Ille cave and the adjacent vicinity of El Nido, Palawan in connection with the Archaeological exploration sponsored by the Archaeological Studies Program, University of the Philippines Diliman, Quezon City.

- I. Matanagin site is an open grass land dominated by *Schizostachyum lumampao* and mixed with *Dinorchloa palawanensis* which was endemic to the island, three species of invasive plants namely *Pachyrrizus* sp. or Wild turnip of (Leguminosae) Fabaceae family, *Chromolaena odorata* Asteraceae and *Lantana camara* of Verbenaceae family. Also recorded was a pioneering species of Euphorbiaceae, *Macaranga tanarius* and *Melanolepis multiglandulosa*. Also recorded in this area are *Melastoma malabathricum* L. Ssp. *malabathricum*, *Axonopus cumpresus*, *Urena bobata*, *Hyptis* sp., *Phyllanthus* sp., *Phyllanthus niruri*, *Ageratum conyzoides* and some *Lagerstroemia speciosa* (Banaba).
- II. Adjacent to this Matanagin area are wetland rice paddies which indicate plant species *Ludwigia* spp., 2 species of Oragraceae family and Cyperaceae. Also recorded were *Ipomia aquatica* (edible) of Convolvaceae, another evidence of wetland vegetation is the *Monochoria hastata* with purple-blue flowers at the petioles which belongs to the Pontederiaceae family. Also recorded were *Oryza sativa*, *Cyperus rotundus* (Mutha) *Cyperus* sp. 1, *Cyperus* sp. 2, and *Fimbristylis* sp. *Heliotropium indicum*, *Desmodium* sp., and *Polygonum barbatum* of Polygonaceae.
- III. The Calawag site has brackish water associated with mangroves. *Bruguiera* sp. which is probably a gymnorhiza of the Rhizophoraceae family is the dominant species in the area. *Nypa fruticans* of Palmae was also recorded. There is *Acrostichum aureum*, a mangrove fern, in the area as well as *Acrostichum* sp. of Pteridaceae. *Derris trifoliata* of (Leg-Pap) Fabaceae is used as insecticide and fish poison (contains rotenone) in South East Asia. *Xylocarpus granatum* of Meliaceae family which bears big fruits and multiple seeds was also recorded.
- IV. Nagsanib to Pasimbahan site: Recorded plants species were *Streblus asper* and *Streblus elicifolius* of the Moraceae family, *Ficus* sp., *Ficus septica*, *Goniiothalamus* sp. of Annonaceae, *Clerodendron* sp., of Verbenaceae, *Acalypha* sp. of Euphorbiaceae,

Koordersiodendron pinnatum (amugis) Anacardiaceae, Pterocarpium tinctorium (Taluto) Malvaceae a Greek word for “winged boat”. Piper sp. which creeps on limestone wall. Leea sp. shrub, Polyscias nodosa (mala papaya) of Araliaceae which is a soft wood. Parameria leu-vegeta of Apocynaceae bark decoction is given as a cure for dysentery and is used on wounds. A common name of Atay baboy or pig liver, based on the pictured specimen and description of sample material collected in the site is referring to Balakata luzunica (formerly Sapium luzunicum) official c. name Balakat gubat endemic to the Philippines.

- V. The Diribongan site lowland forest has the presence of Dipterocarpus grandiflorus (Blanco) Blanco. Apitong and other Dipterocarpus species associated with Vitex parviflora Juss. (Molave). This suggests that the area was once covered by a lowland dipterocarp forest. Also recorded in the area was a dominant leguminous species such as Intsia bijuga (Ipil), Afzelia rhomboidea (Tindalo) and Pterocarpus indicus (Narra). Also recorded in the area was Pisonia umbellifera (J.R. et G. Forster) Seeman. common name Anuling (Philippines). Economic importance: In Malaysia the natives use the fruits to catch birds and the soft branches are eaten by elephants.
- VI. Ille cave limestone vegetation: The presence of Begonia sp. Begoniaceae and Dracaena multiflora of Agavaceae is indicative of a vegetation type growing over limestone –derived soil. Also recorded in this type of vegetation were Euphorbia trigona of Euphorbiaceae family, Piperomia sp. of Piperaceae, Amorpophalus sp. of Araceae, Sterculia foetida and another Sterculia sp. formerly (Sterculiaceae) Malvaceae seed which is dispersed by bats and birds. Also in the area are wind dispersed Plumeria sp. of Apocynaceae which is also used as ornamental plants in the city. Also recorded in the area were Ficus sp., Garcinia sp., Canarium sp., Drynaria quercifolia (fern) of Polypodiaceae which creeps on limestone wall with its dry scale leaves.
- VII. Makangit site: A wetland and fish pond area which indicates the dominance of Cyperaceae family. Cyperus 2 species, Fimbristylis sp., and Eleocharis dulcis. Also recorded in the area were Barringtonia racemosa, Nauclea orientales, Neonauclea sp., and Elaeocarpus sp. with white flowers which at the same time was fruiting. Three ferns were also recorded – Stenochlaena palustris (climbing), Nephrolepis sp. and Azolla pinnata (floating). Also, Alocasia sp. (Badyang), Alocasia machroriza, and Colocasia esculenta (edible) which belong



to Araceae family. *Nipha fruticans* of Palmae and *Acrostichum aureum* of Pteridaceae which belong to the mangrove species were recorded.

- VIII. The Makinit site is an open area surrounded by rice paddies and some *Corypha utan* Lam (Buri). Recorded in the area were two beach forest species namely *Hibiscus tiliaceus* of Malvaceae and *Cerberia manghas* of Apocynaceae family. *Palaquium* sp. of Sapotaceae is dominant in the area, *Glochidion* sp., *Flagilaria indica*, *Hoya el nidiensis* which is endemic to the island, *Ficus* sp., *Radermachera* sp., and Orchid. Also in the area are plant species that belong to mangrove namely *Sonneratia alba*, *Bruguiera* sp., and *Acrostichum aureum*.
- IX. Sitio Kagbanaba II (Baryao baryao) is a wetland dominated by Cyperaceae family. *Typha angustifolia* Linn. *Fimbristylis* sp., *Cyperus* sp. 2 and *Furcraea* sp., *Oryza sativa*, *Colocasia esculenta*, and genus of Begoniaceae *Radermachera* sp. Note: Baryao baryao is referring to *Typha angustifolia*.
- X. Sitio Talisay mangrove site: Recorded species are *Rhizophora mucronata*, *R. apiculata*, *Bruguiera cylindrica*, *Ceriops tagal*, *Sonneratia alba*, *Avicennia* sp., and *Lumnitzera* sp.
- XI. Stream near Ille cave and adjacent area: Plants having high fidelity to waterways were also present which include *Nauclea orientalis*, *Barringtonia racemosa*, *Pandanus tectorius*, and *Pestis stratiotes* Linn. which floated around. Adjacent to the stream were mixed vegetation of *Coffea* sp. *Ficus* sp., *Ficus septica*, *Mangifera indica*, *Anacardium occidentale*, *Chrysophyllum cainito*, and *Cocos nucifera*.
- XII. Star site wet and dry rice paddies: Recorded plant species – *Ageratum conyzoides*, *Eclipta alba*, *Heliotropium indicum*, *Ipomoea aquatica*, *Cynodon dactylon*, *Axonopus compressus*, *Imperata cylindrica*, *Aneilema* sp., *Commelina benghalensis*, *Oryza sativa*, *Cymbopogon aciculatus*, *Mimosa pudica*, *Scoparia dulcis*, *Ludwigia* ssp. 2sp., *Centilla asiatica*, *Cyperus* 3 species, *Hyptis* sp., *Vernonia cinerea*, *Vernonia* sp., *Phyllanthus niruri*, *Phyllanthus* sp. *Hedyotis* sp., *Desmodium* sp., *Chromolaena odorata*, *Alysicarpus* sp., *Calopogonium* sp., *Fimbristylis* sp., *Corchorus acutangulus*, *C. capsularis*, *C. olitorius*, *Asclepias curassavica*, *Stachytarpheta jamaicensis*, *Euphorbia* sp., *Senna tora*, *S. occidentalis*, *Sida acuta*, *Sida rhombifolia*, *Uraria lobata*, *Crotalaria* sp., *Physalis angulata*, *Leucas* sp., *Sesbania* sp., *Glinus*

oppositifolius, *Passiflora foetida*, *Tabernaemontana pandanacea*, and some trees *Cordia dichotoma*, *Streblus asper*, *Nauclea orientalis*, *Mangifera indica*, *Lagerstroemia speciosa*, and *Antidesma gaesembellia*. (See the attached plant checklist)

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