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A palynological investigation of Holocene vegetation change in Torres Strait, seasonal tropics of northern Australia

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Abstract

The islands of Torres Strait occupy a shallow area of submerged continental shelf narrowly separating Cape York Peninsula, Australia, from New Guinea. The human history of Torres Strait is unique with respect to mainland northern Australia. Island vegetation, however, exhibits a strong affinity with the environments of the western lowlands regions of Cape York Peninsula and with the vegetation of seasonal tropical Australia in general. Cape York Peninsula is both climatically and biologically diverse, yet few pollen studies have been carried out in its seasonally tropical environments. A summary presentation of palynological results, tracing the nature of vegetation change in Torres Strait, offers a possible framework for vegetation changes in similar environments on mainland Australia and also provides an opportunity to explore the relationship between Quaternary change in humid–tropical Australian environments and their seasonal–tropical counterparts.

Six pollen records from Torres Strait provide evidence of vegetation change and fire history over approximately the last 8000 years. Near-shore sediments reveal a Holocene succession in vegetation incorporating lower-tidal mangrove, upper-tidal mangrove, saltmarsh and freshwater swamp communities. Extensive stable mangrove communities dominated coastal Torres Strait between approximately 6000 and 3000 radiocarbon years before present (yr BP). Inland, the strongest Myrtaceae-forest and rainforest representation occurs around the mid-Holocene only to be replaced by open sclerophyll woodlands, as tree density and diversity decline in the last 3000 years. The development of continuous island freshwater swamp conditions, at the coast and inland, is similarly restricted to the late Holocene (c. 2600 yr BP) and fire, as a prominent feature in the Torres Strait environment, is also a relatively recent phenomenon. Comparisons with regional mainland Australian palynological records reveal a degree of consistency in results from Torres Strait suggesting a similarity in late Quaternary trends through Australian humid and seasonally tropical environments. A number of differences, however, are also apparent, highlighting a degree of diversity which warrants further attention.

Keywords: Holocene; Vegetation history; Fire history; Human impact islands; Tropical Australia

1. Introduction

The Torres Strait (150 km north-to-south) narrowly separates the north-eastern tip of mainland Australia, Cape York Peninsula, from the south-central coast of New Guinea (Fig. 1). As a shallow area of submerged continental shelf, Torres Strait contains more than 100

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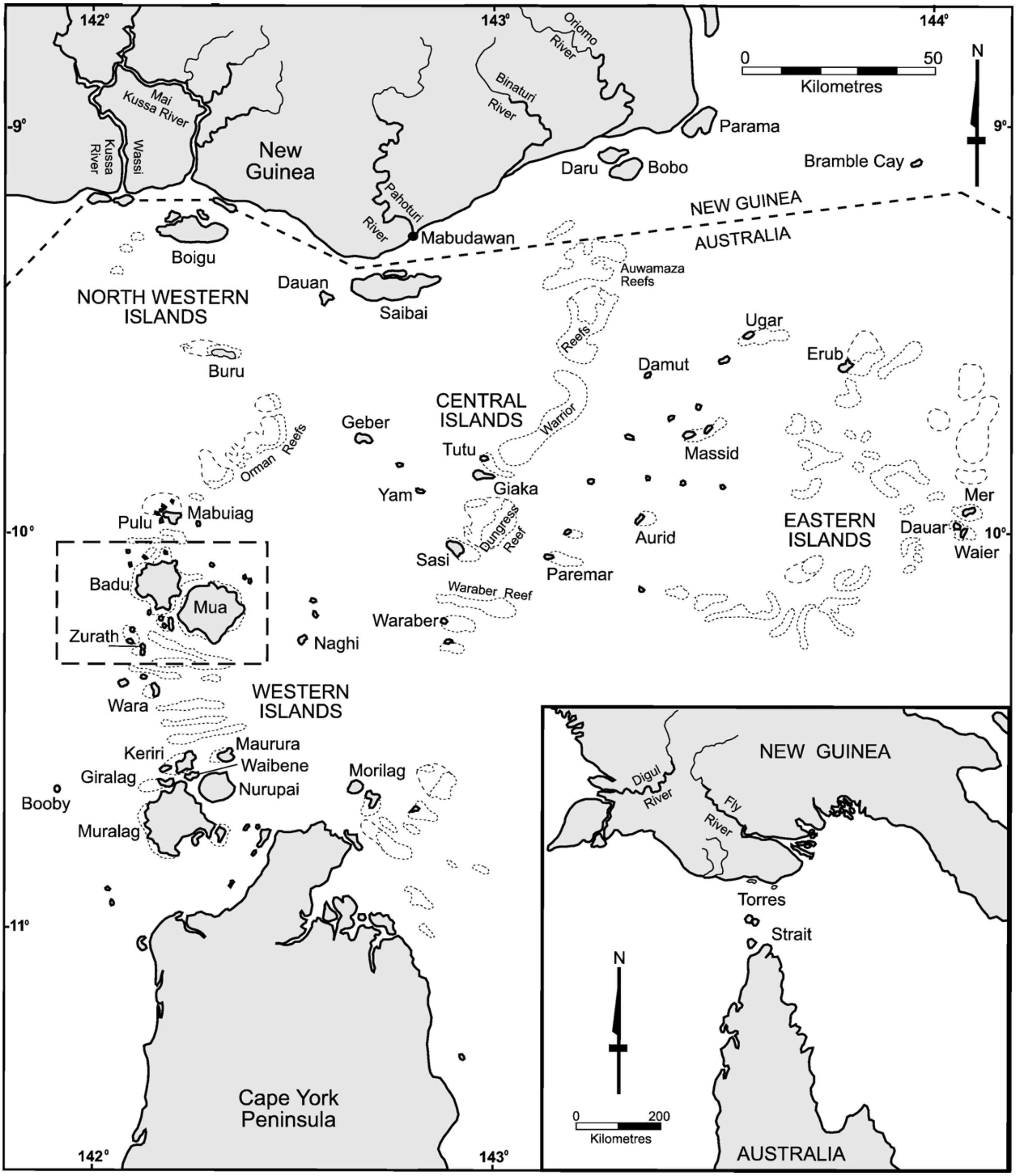

Fig. 1. Map of Torres Strait showing location of island study sites, Mua, Badu and Zurath.

islands, comprising a discontinuous chain of largely granitic islands in the west, isolated volcanic islands in the east and scattered coral and higher islands in the centre. These islands are interspersed with a complex network of an estimated 600 reefs, numerous shoals and channels (Huber, 2000; Woodroffe et al., 2000). The Strait has been exposed as dry land during glacial periods. Estimates of global eustatic relative sea level

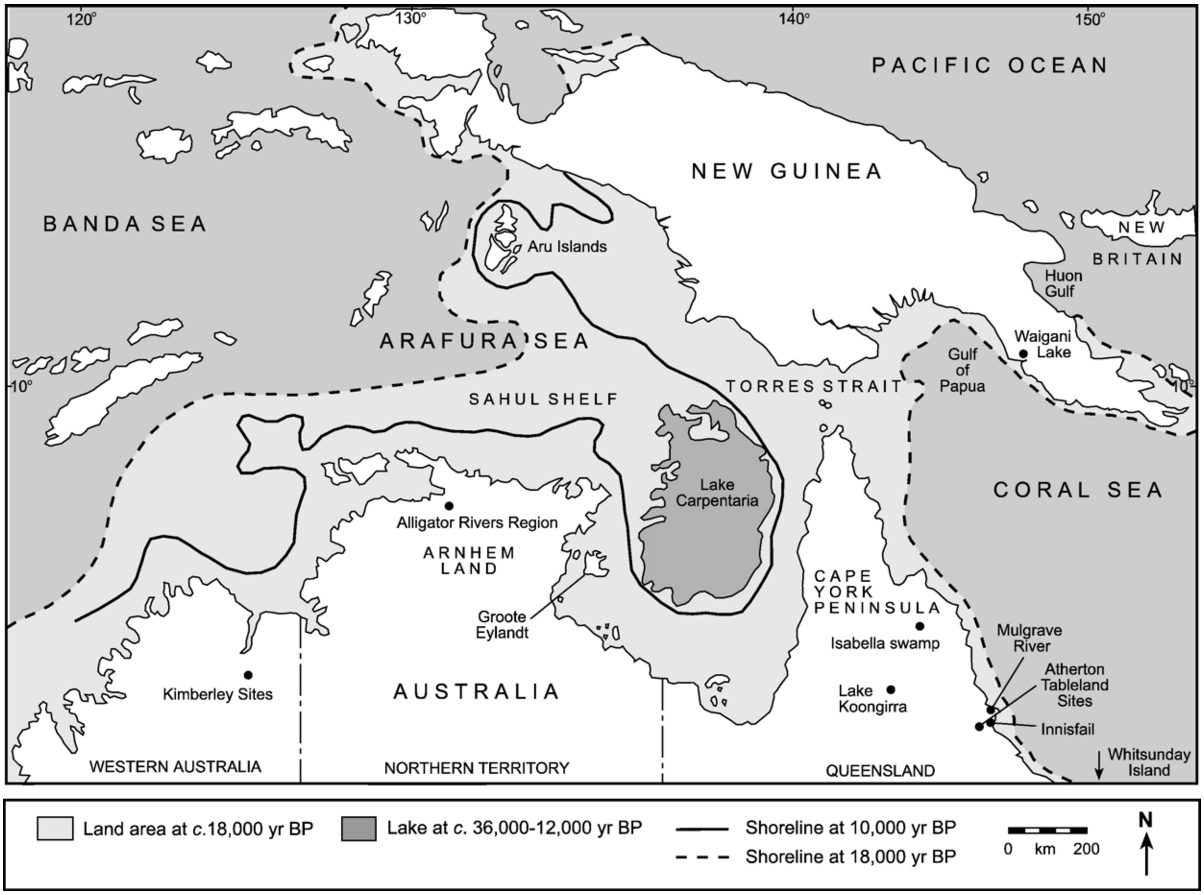

Fig. 2. Location map of Torres Strait in relation to regional Quaternary shoreline changes and sites discussed in the text (adapted from Barham, 1999; Rowe, 2005).

suggest that the shallow shelf topography of Torres Strait was dryland for most of the last 100,000–80,000 years, lying on the eastern margin of the lake Carpentaria drainage catchment (Fig. 2). The most recent resubmergence occurred in the Holocene. Post-glacial transgression of the shelf commenced c. 8000 yr BP (radiocarbon years before present) and present high sea levels and insular geography were attained by approximately 6000–5800 yr BP (Barham, 1999; Woodroffe et al., 2000).

Palaeoenvironmental change in Torres Strait is the subject of this paper, presented as a step toward greater understanding of the vegetative diversity of Cape York Peninsula. It is the intention of this paper to reveal the (palaeo)environmental information which may be gained from Torres Strait, when an examination is taken beyond traditional 'bridge or barrier' debates and in accepting the relatively recent appearance of the islands. An introductory review of research interests in Torres Strait, and of the region's standing in biogeographic discussions is first presented.

Vegetation patterns and biodiversity within Cape York Peninsula and the wider northern Australia cannot be interpreted without reference to Quaternary influences. In relation to past climates and vegetation, existing palaeoecological knowledge is restricted largely to the late Quaternary sites of the Atherton Tableland within the humid tropics of eastern Cape York Peninsula. Little is known palaeoecologically of the drier north and west, and of their relationships with trends as deduced from the east. However, it has been proposed that similar magnitudes of change in climate, fire and vegetation to those of the wet tropics may have been experienced throughout tropical Australia (Kershaw, 1985). Similarly, a good correspondence between climatic inferences from the Atherton Tablelands (Lynch's Crater data) and simulated palaeoclimatic and vegetation regimes for the whole of northern Australia has been suggested by Nix and Kalma (1972) and Webster and Streten (1972). Schulmeister (1992) was able to conclude on the general regional reliability of reconstructions based on the Atherton

Tablelands, from palynological investigations of Groote Eylandt in the Gulf of Carpentaria. Yet, regional differences are also highlighted. Recorded variations from Groote Eylandt appear to be in response to both local geomorphological processes (such as the effect of early Holocene transgression) and possible climatic signals (an apparent effective precipitation recovery in the last 1000 years). Given the paucity of data, and uncertainty about the degree of similarity in environmental change between existing sites across northern Australia, further study is clearly needed.

This paper provides additional evidence in the form of summary palynological records for Holocene vegetation, landscape and climatic change on the islands of Mua, Badu and Zurath in western Torres Strait. Three coastal sequences and three records from inland island environments are presented. The islands of Mua, Badu and Zurath allow for a reflection back onto similar environments in continental Cape York Peninsula, contributing to a picture of regional environmental change and the extent of local variability within this (cf., Stephens and Head, 1995).

2. A region of interest: Torres Strait

The geographical positioning of Torres Strait has long generated archaeological discussion as to the region's role as bridge or barrier to cultural, genetic and linguistic forces between Australia and New Guinea (Harris, 1995; David et al., 2004; see also Walker, 1972). The Torres Strait islands are home to Australia's only indigenous population of Melanesian decent, which at European contact demonstrated levels of marine resource exploitation, canoe technology and seafaring skills, inter-island and mainland trade, and use of agriculture/horticulture to a degree unparalleled elsewhere in Australia. How long such a distinct cultural complex has existed in Torres Strait, the onset dates for human occupation, and the cultural impact of the so-called 'connectedness' of Torres Strait (the exchange and diffusion of cultural traits across Torres Strait to adjacent mainlands) remain ongoing questions for archaeological research (McNiven, 1998; Barham et al., 2004). Most recent archaeological investigations (David et al., 2004; David and McNiven, 2004; McNiven, 2006) reveal a time of permanent occupation of the Torres Strait region between 8000 and 6000 yr BP, replaced by periodic visitation during 6000 to c. 3000 yr BP. Permanent island occupation, the commencement of regional demographic increases and an intensification of occupation occurred after c. 3500–3000 yr BP. This latter phase incorporated sustained increases in social activity and site use during the last 1000 years with a consolidation of cultural/ritual practices c. 700 yr BP. After c. 3500–3000 yr BP the islands of Torres Strait became occupied, in the majority, by speakers of languages with concentrated Papuan and Austronesian elements from the north and north-east. David et al. (2004) argue for Austronesian influences at the tip of Australia during the late Holocene.

Torres Strait's role as bridge or barrier to environmental processes between mainland Australia and New Guinea (and wider Melanesia) has also been the subject of much discussion (e.g. Walker, 1972; Barham and Harris, 1983; Mackey et al., 2001). A broad spectrum of views on the relationship of the Australian flora with that of New Guinea have been expressed (Barlow, 1993). Steenis (1950, cited in Webb and Tracey, 1972; Balgooy, 1987) deemed Torres Strait to be one of the 'principal floristic demarcation knots' of the Old World tropics (a demarcation knot is defined in relation to the total number of genera which reach their limits in the area of interest; in the case of Torres Strait, 984 genera; Barlow, 1993). Good (1960, p. 207, and cited in Webb and Tracey, 1972) proclaimed that 'no-where else in the world is there so great a difference, over a similar distance, in flora as there is between the island of New Guinea and the continent of Australia, separated as they are by less than 100 miles of shallow island-studded sea'. Hoogland (1972) proposes the absence of a substantial number of Australian plant families from New Guinea and of a similar number *vice-versa* suggests a distinct barrier to dispersal in the Torres Strait area (with a comparable picture for plant genera).

Alternatively, and more recently, those biotic discontinuities which do exist between New Guinea and Australia are seen as unrelated to Torres Strait *per se*; the relatively recent appearance of Torres Strait being largely irrelevant to what are long-term biotic features. Here, inter-habitat comparisons (comparing plant communities structurally and physiognomically similar and believed to reflect equivalent physical environments) reveal more than regional comparisons (Webb and Tracey, 1972). Rainforest, *Melaleuca*-dominated savannas and heath ecosystems occurring in Cape York Peninsula have counterparts in the Western District of Papua New Guinea. Likewise, *Eucalyptus*-dominated savannas further to the east in the dry zone around Port Moresby have parallels in Cape York Peninsula (Mackey et al., 2001). This places the main floristic break between 'typically Australian' and 'typically New Guinean' vegetation at the foot of the central highlands of New Guinea. This floristic break follows the boundary of lowland rainforest environments, rather than the environment that is Torres Strait (Walker, 1972). In northern mainland Australia itself greater discontinuities are also apparent. The structural and floristic differences between adjacent rainforest and sclerophyll forests, for example, are greater than those between structurally related vegetation community pairs separated on both sides of Torres Strait, such as those listed above. The disjunctions between rainforests in north Queensland and south Queensland are also just as great as those between north Queensland and New Guinea. The reduction in number and diversity of rainforest species from New Guinea to north Queensland and southwards is primarily in response to loss (in size and number) of favourable habitat. Cape York Peninsula, climatically variable (see below) and also incorporating infertile soils which do not permit edaphic compensation, provides a rigorous separation of the rainforest vegetation and wider flora of northern Australia and New Guinea, more so than Torres Strait (Webb and Tracey, 1972, Webb and Tracey, 1994; Barlow, 1993). Preoccupation with the disjunction of plant taxa at Torres Strait may therefore distract attention from past/present relationships between vegetation groups and of the disjunctions within Cape York Peninsula and northern Australia (Wace, 1972).

Mackey et al. (2001) map and describe Cape York Peninsula as including three well-defined bioclimates: the drier western lowlands and a wetter region to the north, both characterized by markedly seasonal moisture regimes with a significant wet and prominent dry season; and the east, which includes the Wet Tropics bioregion, that have a warm, wet climate featuring non-seasonal temperatures and uniformly wet conditions (with at most a short dry season). The bioclimates of Cape York Peninsula are reflected in a distinctive complement of flora, so the region, both climatically and in vegetation, is far from homogeneous. Neldner and Clarkson (1995, and cited in Mackey et al., 2001) detail the results of a vegetation survey of the Peninsula culminating in the identification of 21 structural formations and 207 vegetation units (agglomerated into 30 broad vegetation units). *Eucalyptus*-dominated woodlands are the most extensive. Such woodlands are prevalent in the western and northern subregions of Cape York Peninsula along-side low open woodlands and shrublands dominated by *Melaleuca*, grasslands as well as heathlands. Locations that contain permanent flowing streams, groundwater discharge and other forms of waterholes support vegetation differentiated from the surrounding sclerophyll landscape (Mackey et al., 2001). According to Neldner and Clarkson (1995) rainforests currently occupy 5.6% of the Cape York Peninsula region. A significant wet rainforest massif is contained within the eastern subregion, the boundary of which ends abruptly, formed by regular fire and correlated with rain shadow effects behind the dividing mountain range. Pockets of dry semi-evergreen rainforest types and araucarian vine-thickets occur fragmented amongst the woodlands in the west and north (Web and Tracey, 1994).

The western Torres Strait islands (Mua, Badu and Zurath; Fig. 3) show an affinity with the western lowland sector of Cape York Peninsula and also with mainland environments extending further west into the northern extremity of the Northern Territory and state of Western Australia. As continental islands, the western Torres Strait islands support what Quammen (1996, pp. 53–54) describes as ‘carry-over ecosystems’, the notion being that ‘any land–bridge island begins its insular existence with all that is evident on the mainland’. The western islands incorporate steep slopes and poor soils with broad plains of sand and clay–silt. The sandy, acidic soils are covered with eucalypt open woodlands, occasional swamp habitats, isolated monsoonal forest and vine-thicket (rainforest), and riverine forest along creek embankments. Alternating mudflats, mangroves and rocky peninsulas fringe the islands. Fire is a prominent feature of dryland environments, principally through Islander burning practices. Neldner (1998) has made the observation that rainforest vegetation types are threatened by too frequent fires, and replaced by grassland in numerous places. The dominant climatic feature is the seasonal alteration of wet (December to April) and dry (May to November) periods; the wet season coinciding with the north-west monsoon in contrast to the dry season which corresponds to the time of the southwest trade winds. El Niño–Southern Oscillation events constitute a source of interannual climatic variability (Lawrence, 1994; Sturman and Tapper, 2001).

3. Methodology

The selection of field sites was governed by sediment type, dominant vegetation, proximity to archaeological research (as conducted under the Western Torres Strait Cultural History Project, see David and McNiven, 2004), as well as logistics. Swamp and mangrove sediments were collected using a 50 × 500 mm^2 D-section corer, wrapped in plastic and sealed in split polyvinyl chloride tubing for transport. Core depth was determined by underlying bedrock, hard rock or compact clay. Core descriptions were performed prior to subsampling; sediment subsamples of 1 cm^3 were collected at 4 cm or 8 cm intervals. At archaeological

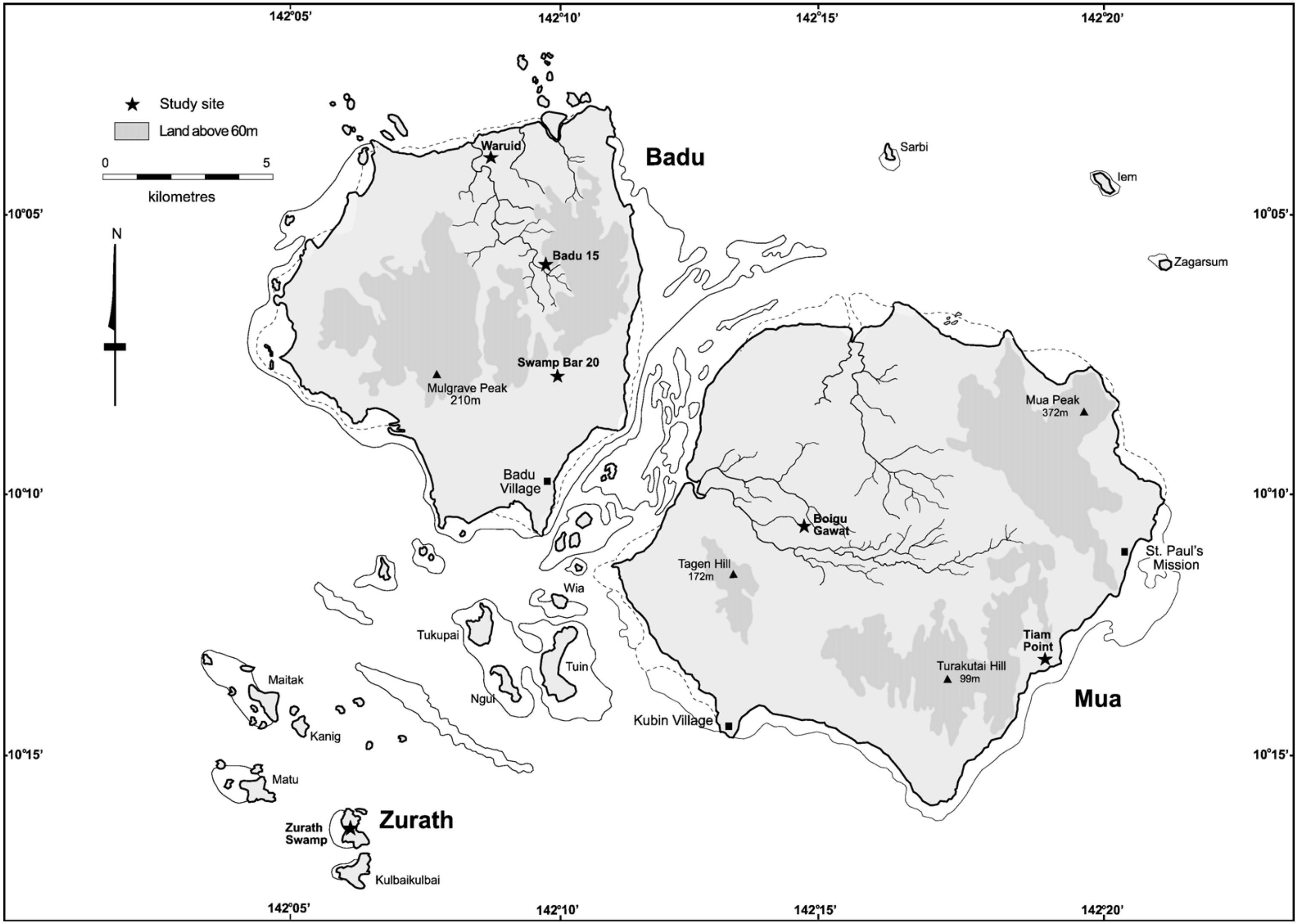

Fig. 3. The islands of Mua, Badu and Zurath showing location of palaeoenvironmental study sites.

site Badu 15, 100-g samples were obtained from the post-sieving <3 mm sediment residue from each excavation unit. A representative sample of 1 cm^3 was taken from the <3 mm fraction.

Laboratory pollen extraction followed standard acetolysis methods as outlined by Bennett and Willis (2001). Where possible, 200 pollen grains were counted at ×400 magnification under oil-immersion. Identification of pollen was by comparison with modern reference material, collected while in the field or held as regional slide collections at Monash University. Black, angular microscopic charcoal fragments (<125 μm) were counted as they appeared on the prepared pollen slides.

All pollen diagrams were created using the spreadsheet program TILIA and graphing counterpart TILIAGRAPH (Grimm, 1999–2002). Division of the pollen diagrams into zones was guided by CONISS with squared-root transformation of the percentage data. A total pollen sum was used for the percentage calculation of all taxa. A second mangrove sum was used for mangrove taxa only, to highlight patterns of succession within the mangrove environment. Bulk sediment samples were submitted for radiocarbon analysis and dated using accelerator mass spectrometry (AMS). Core chronology is presented as uncalibrated radiocarbon dates, written as 'yr BP'. The age–depth models for all pollen diagrams is based on linear interpolation between dated samples.

4. An examination of near-shore environments

Holocene transgressive sediments are widespread across Mua, Badu and Zurath, locally achieving considerable thickness, and composed mainly of dark, uniform organic muds with degraded plant fragments and a small component of sand. Such description and occurrence is consistent with sedimentary deposits on mainland northern Australia, particularly well known for their provision of an environment well suited to the entrapment and preservation of pollen (Chappell and Grindrod, 1985; Grindrod, 1988b).

4.1. Tiam Point

Tiam Point is located along the southeast coastline of Mua (Fig. 3). A small swamp is situated approximately 1 km inland (10°12′S; 142°18′E). The Tiam Point swamp rests at an outpoint of a predominantly seasonal creek system, where it enters the head of a tidal mangrove community. The swamp is covered with *Sporobolus virginicus* and patches of *Acrostichum aureum*. Stands of *Pandanus* and *Melaleuca* species fringe the landward swamp side and expand into a sparse eucalypt woodland across the surrounding catchment slopes. Seawards, mangroves prevail; an upper-tidal zone consisting of *Bruguiera* (with species of *Aegiceras* and *Avicennia*) borders the swamp, extending creekside into lower-tidal environments where *Rhizophora*-dominated mangrove abuts onto a raised reef flat.

Coring at Tiam Point extended to 4.55 m in depth. Sediments consisted of compact sandy clays overlain by organic muds, coarse sands and an upper organic clay unit. Core recovery terminated in gravel-like material and the basal sediments have been dated at 6789±57 yr BP (WK-12748). Pollen assemblages from Tiam Point (Fig. 4) principally reflect shifts in the extent of mangroves at the coast, but also provide good indication of the character of more regional catchment vegetation.

Zone TP1 shows a number of marked fluctuations in the representation of taxa. Variations in the mangrove group in particular characterise changes in the pollen assemblage between about 6800 and 6000 yr BP. Here, *Rhizophora* pollen is abundant relative to other mangrove pollen types. Significant percentages of Poaceae and Cyperaceae, including *Eleocharis* and *Cyperus* pollen, and fern spore types, indicate together, herbaceous swamp conditions at the core site. Fluctuations, therefore, between swamp elements and *Rhizophora* reflect alternating periods of saline and freshwater conditions over this period. Salt-water incursions with sea level rise likely allowed for the invasion inland of *Rhizophora* before a withdrawal as tidal influences intermittedly diminished. Zone TP1 suggests that each mangrove to non-mangrove phase at the core site was short-lived, presenting a picture of a highly variable environment.

After 6000–5800 yr BP, *Rhizophora* pollen increases in percentage representation and record consistency to dominate zone TP2. As such, the variability evident in the period prior to c. 6000 yr BP gives way to large-scale stability in mangrove forest cover. *Rhizophora* has expanded to engulf the core site, and establish in the extra-local and regional environments, to dominate the coastal lowlands of Mua between c. 6000–4000 yr BP. A decline in *Rhizophora* pollen in favour of a *Ceriops* pollen type in zone TP3 signals a successive reduction of the lower tidal *Rhizophora* forest and transition to a landward mangrove community closer to the upper limits of tidal inundation. Data informing on the path of mangrove succession to eventual cessation of mangrove growth inland and at the core site has not been obtained, however, given the dearth of pollen between 70 cm and 30 cm depth. Pollen assemblages in zone 4 reflect non-saline late

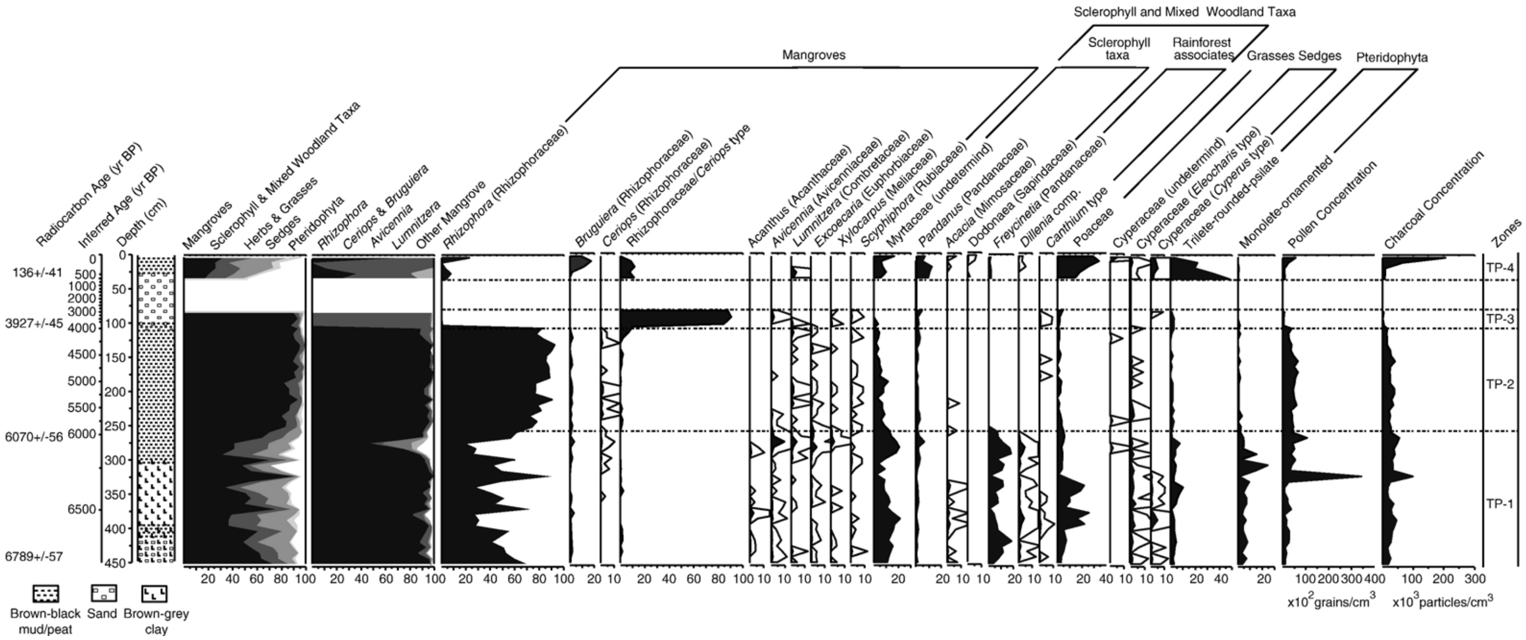

Fig. 4. Tiam Point pollen percentage diagram plotted against depth and age (selected taxa). Inferred age is based on linear interpolation between radiocarbon dated sediment samples. Diagram exaggeration values are ×10.

Holocene environments at the core site. *Rhizophora* and mangrove pollen are interpreted as the regional presence of mangrove communities, at the shoreline and only extending inland along creek embankments.

Away from the mangrove community the pollen assemblages show high frequencies for Myrtaceae and *Freycinetia* pollen early in the diagram, and fairly consistent representation of *Pandanus*, *Acacia*, *Dillenia* and *Canthium*. Poaceae, Cyperaceous and spore types have already been mentioned. All of these listed taxa must have been present at, or in the vegetation surrounding the core site during the early-mid-Holocene, suggestive of both the above-mentioned freshwater herbaceous swamp conditions and a possible mosaic of rainforest and Myrtaceae-dominated forest in the extra-local and regional catchment surrounds.

In view of the dominance of Rhizophoraceae pollen, it is difficult to make a decisive interpretation of zones TP2 and TP3 in terms of regional terrestrial vegetation. Of greater note is the manner in which non-mangrove assemblages change between the early-mid and late Holocene, following mangrove forest decline. Zone TP4 displays a lower taxon diversity than that of zone TP1; maximum *Pandanus* pollen coincides with increased trilete spores, Poaceae and the return of Cyperaceae pollen. This suggests the redevelopment of swamp vegetation at the core site with *Pandanus* in the surrounding local swamp vegetation canopy. Zone TP4 is consistent with the current swamp environment. Myrtaceae pollen percentages are lower in zone TP4 than for zone TP1 and *Freycinetia*, *Canthium*, *Dillenia* and *Acacia* pollen are virtually absent. By contrast, *Dodonaea* has become a component of the vegetation. These pollen trends are indicative of a decline in regional tree cover in the late Holocene, as sclerophyll forest and rainforest are replaced by open woodland. It is likely pollen from Poaceae within zone 1 is derived from a grassy woodland understory as well as the herbaceous swamp at the core site. The climate of zone TP4 would appear to be less moist than that of zone TP1. Increased burning is also evident towards present.

4.2. Zurath

Zurath is a small, elongate island 1.5 km long by 0.6 km at its widest point, located approximately 9.5 km south of Badu (Fig. 3). The vegetation exists within a series of distinctive topographic units, of which a sand beach, sand ridge, central sand flat and rock slopes occur as successive zones from the shoreline to the hills of the east and west island interior. Zurath swamp (10°16′S; 142°06′E) is contained within the central deposits of the sand flat. At the time of sampling the site was covered by low herbaceous species including *Sporobolus* and surrounded by *Pandanus* spp. A 3.10-m core was retrieved from the swamp centre. Sediments are increasingly clay-based with depth and at 240 cm have been dated at 6520 ± 40 yr BP (OZG-597). A Holocene age is assumed for the length of the core.

Pollen trends and radiocarbon dating results from Zurath swamp (Fig. 5) are similar to those recorded at Tiam Point, but with a less diverse suite of taxa than that from the larger island of Mua. The pollen profile is dominated by *Rhizophora* and Poaceae pollen and the relative shifts between the two. Such shifts are viewed as representative of adjustments in saline and freshwater influences on the island within the Holocene. Pollen of Rhizophoraceae/*Ceriops*, *Bruguiera*, *Lumnitzera*, *Excoecaria*, *Pandanus*, *Freycinetia*, Chenopodiaceae, Asteraceae and *Cyperus* are relatively well represented, and at times, also important taxa in the vegetation of Zurath.

Prior to 6500 yr BP *Rhizophora* pollen is well represented, and associated with high Poaceae values. A fluctuating setting similar to that of zone TP1 at Tiam Point is suggested. However, if a swamp was to exist on Zurath, brackish conditions are more probable given *Rhizophora* and Poaceae are coupled with the presence of Chenopodiaceae pollen in zone Zur1. After 6500 yr BP *Rhizophora* increased to become extensively represented around the core site. High percentages of *Rhizophora* pollen and low representation of non-mangrove pollen in zone Zur2 suggests that *Rhizophora*-dominated mangrove was not restricted to establishing a dense cover locally, but in the extra-local and regional Zurath environment. In view of the small size of Zurath islet, this *Rhizophora* forest probably covered most of the available lowland surface. It is not until c. 4000–3600 yr BP that *Rhizophora* declines rapidly as a *Ceriops* type pollen increases in abundance for a short period in the late-mid-Holocene. In the last 3000 years mangroves are negligible on Zurath.

Pollen zone Zur3 is characterized by a return of high Poaceae pollen percentages as well as increasing *Pandanus* pollen. Cyperaceae pollen types and Asteraceae are also present in low frequencies. Zone Zur3 is reflective of the current Zurath swamp and open vegetation habitat, estimated to have been present on the islet for the last 2500–2400 years. Burning on Zurath was relatively low until some time after 500 yr BP.

4.3. Waruid

Waruid is the local Badu Islander (Badulgal) name for the northern sector of the island (Fig. 3). Waruid

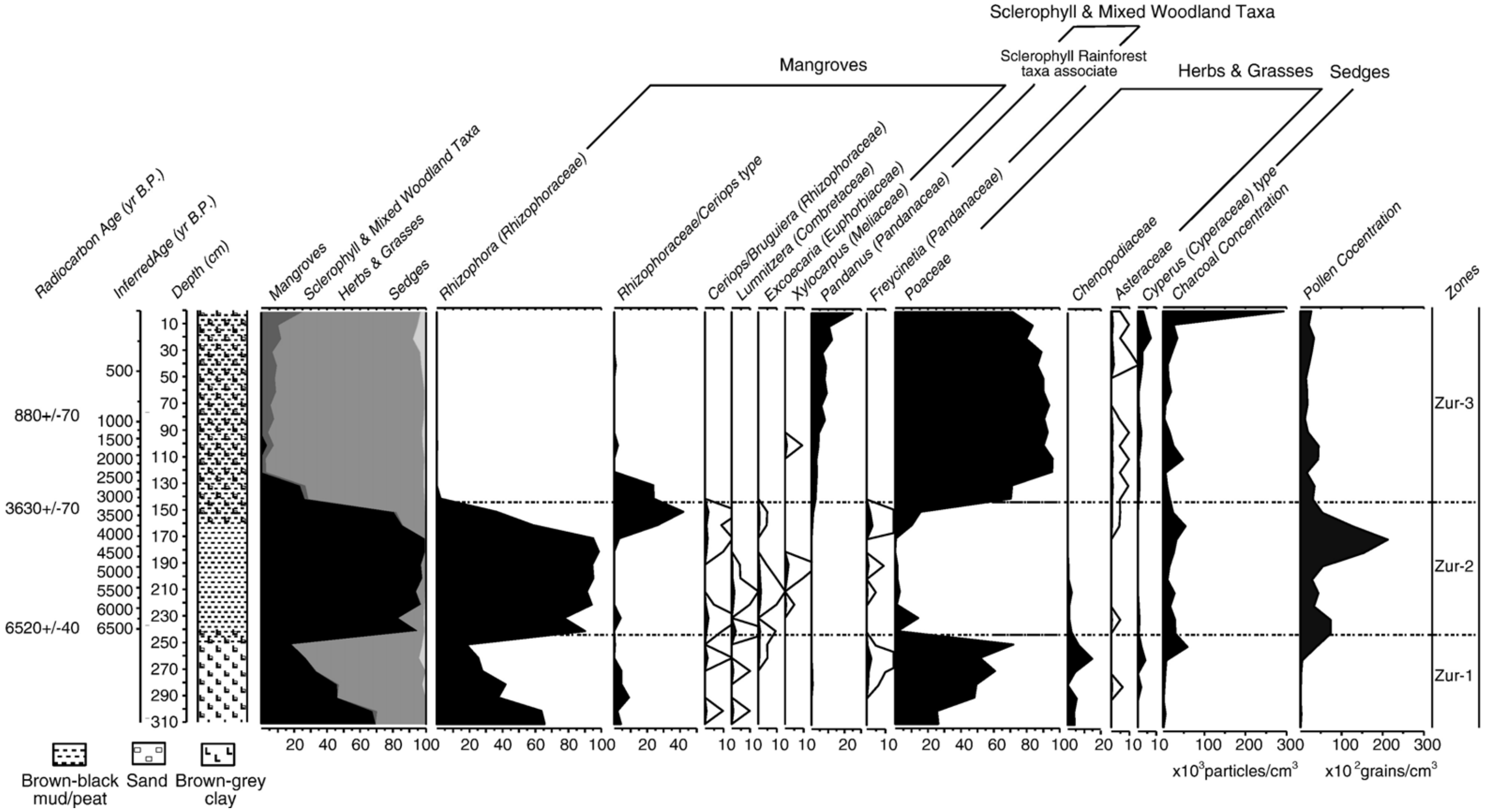

Fig. 5. Zurath swamp pollen percentage diagram plotted against depth and age (selected taxa). Inferred age is based on linear interpolation between radiocarbon dated sediment samples. Diagram exaggeration values are ×10.

contains an extensive mangrove community along its northern coastline. An open, low energy coastal environment is occupied by a dense seaward stand of *Rhizophora* spp. in which other taxa are infrequent. Landward, species of *Ceriops* and *Avicennia* dominate over *Rhizophora*. A 1.5 m core was collected c. 60 m inland of the mangrove communities (10°04′N; 142°09′ E). At the core site a saline mudflat maintains only a sporadic cover of vegetation. A concentrated fringe of cyperaceous species, grasses and *Melaleuca* trees mark the inland limit of the mudflat, forming a transition into eucalypt woodland.

The Waruid core exceeds 4000 years in age, based on a radiocarbon date of 3960±40 yr BP (OZF-879) at 88 cm depth. The core is estimated to reach close to 6000 yr BP in age in view of the pollen trends at Tiam Point and Zurath. The pollen diagram (Fig. 6) shows high, consistent frequencies of *Rhizophora* pollen in zone War2-1 prior to 4000 years suggesting an extensive mangrove forest dominated by *Rhziophora* was already established by the time represented in basal core sediments. Zone War2-1 therefore places the Waruid *Rhizophora* forest much further inland during the mid-Holocene than at present. The lack of significant non-mangrove pollen percentages indicates terrestrial taxa have been displaced some distance inland of the core site.

A fluctuating decline in *Rhizophora* pollen from zone War2-1 into zone War2-2 represents the beginning of a successional withdrawal in the extent of mangrove communities at Waruid. Close to 2500 yr BP *Rhizophora* pollen declines rapidly, whereas pollen of Rhizophoraceae/*Ceriops* shows a sharp increase, peaking between 2200 and 2000 yr BP in zone War2-2. This shift toward landward mangrove communities continues into zone War2-3. After c. 2000 yr BP *Avicennia* pollen increases to dominate the mangrove taxa, coupled with the presence of *Lumnitzera*, *Excoecaria*, *Aegiceras* and *Ceriops*/*Bruguiera*. Although *Rhizophora* pollen increases in zone War2-2 to zone War2-3, it is suggested that this taxon did not occupy the area immediately surrounding the core site, but remained prominent some distance seaward in the last 1000 years. With diverse mangrove pollen types in zone 3 and increased abundance of non-mangrove pollen (including *Eucalyptus*, Myrtaceae, Asteraceae and Poaceae), the core site lay near the upper limit of mangrove growth after 2000 yr BP, adjacent to the vegetation of the sclerophyll coastal lowlands. Peak values in Chenopodiaceae and Cyperaceae pollen indicate a transition to saltmarsh and sedge communities of the previous upper lowland mangrove zone.

The main difference between Tiam Point and Zurath and the Waruid site is in the vegetation transformation following the extensive *Rhizophora* mangrove forest phase. In documenting Holocene coastal and mangrove vegetation change across different geomorphological settings in Torres Strait, there appears no marked difference in the importance of *Rhizophora*. The succession through mangrove forest to upper intertidal mangrove habitat is also similar and relatively clearly recorded in all three diagrams. Local succession at Waruid lacks the development of a freshwater swamp community, favouring *Rhizophora* to *Ceriops* mangrove to mixed *Avicennia* and saltmarsh/sedgeland. At Waruid, positioned on the open coast, increased desiccation through a loss of tidal inundation and lack of freshwater input appears to have led to locally raised soil salinity at the landward extent of the mangrove belt.

5. The study of island interiors

Palaeoecological evidence preserved in the inland island habitats of Torres Strait is limited in comparison with near-shore island environments. Good long-term pollen preservation is sensitive to sedimentary conditions. In order to discuss in some way the nature of change in freshwater swamp, inland vegetation groups and fire, a presence/absence record of pollen types and charcoal fragments was adopted.

5.1. Boigu Gawat and Bar-20

Boigu Gawat is the Mua Islander (Mualgal) name referring to the environments of the island interior, which incorporate a number of freshwater swamp depressions (centered on 10°10′S; 142°14′E; Fig. 3). These swamps lie within an extensive area of quartzose sand plain and dune system dominated by *Corymbia* and *Eucalyptus* woodland and savanna. The Boigu Gawat swamp selected for study consists of an open water area of c. 50 m in diameter with a zone of swamp forest extending approximately 80 m to the water edge. *Melaleuca leucodendra* dominates the swamp forest canopy. Species of *Leptocarpus* occupy the swamp forest understory. A 50-cm core was recovered from within the *Melaleuca* canopy, but free from *Leptocarpus* growth.

Swamp Bar-20 is situated approximately 2 km inland of the southeast coastline of Badu (10°08′S; 142°09′E; Fig. 3). Like that of Boigu Gawat, this swamp occupies a topographic hollow in an undulating sand dune landscape, surrounded by eucalypt woodland. Swamp Bar-20 is fringed by *Melaleuca leucodendra* and *Melaleuca dealbata* with a discontinuous understory of *Leptocarpus* and cyperaceous type species. A 75-cm

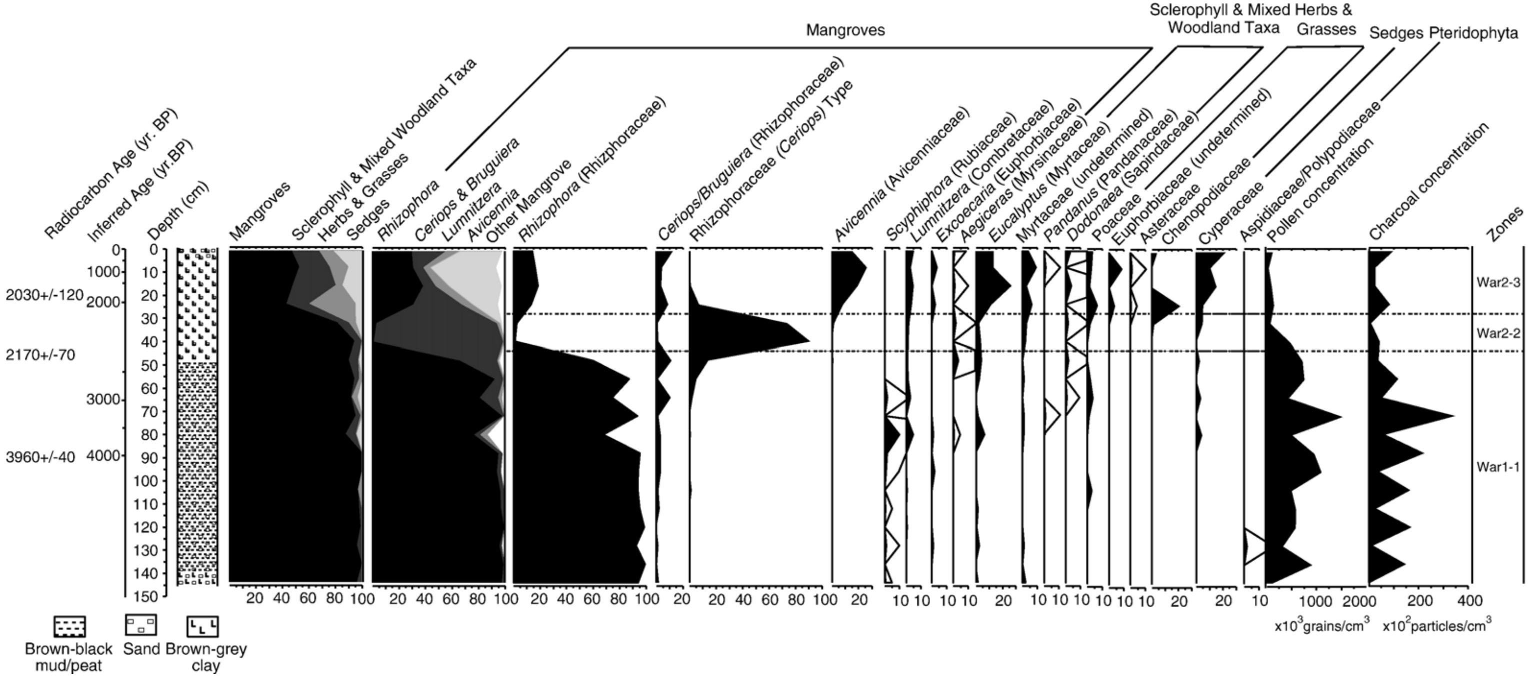

Fig. 6. Waruid pollen percentage diagram plotted against depth and age (selected taxa). Inferred age is based on linear interpolation between radiocarbon dated sediment samples. Diagram exaggeration values are ×10.

core was collected from an area of open water away from the tree canopy, close to the swamp centre.

Similarities between the topographic contexts and ecology of Boigu Gawat and Bar-20 suggested that the two swamps may permit a controlled palynological comparison of vegetation changes on the two adjacent islands of Mua and Badu, over equivalent timescales (cf., Barham and Harris, 1987). In confirmation, the similarities evident in the pollen diagrams of Fig. 7 permit Boigu Gawat and Bar-20 to be discussed together, as below. In particular, each pollen diagram shows a single major shift approximately halfway through the core, dated at 2560±90 yr BP (OZG-071) at Boigu Gawat and 2610±80 yr BP (OZG-069) at Bar-20.

Pollen zones BG2-1 and B20-1 coincide with firm grey sandy–clay lithologies, deposited prior to 2600–2500 yr BP and associated with a poor preservation of pollen. The properties of these zones suggest transient water conditions. Initial water levels recorded at each site fluctuated regularly, drying out for long enough periods to oxidize the majority of pollen (cf., Head and Fullagar, 1992; Schulmeister, 1992). The clay sediments may have impeded drainage with increased precipitation resulting in pools of water, but are likely to have developed into a hard cracked clay surface during dryer times.

The pollen assemblages of zones BG2-1 and B20-1 are characterized by the presence of a suite of herbaceous and sedge pollen. *Leptocarpus* pollen is present in all samples and is abundant in the lower sediments of zone 1 at Boigu Gawat. Cyperaceae pollen, including *Cyperus*, *Schoenus* and *Eleocharis* pollen types, is recorded. Spore types are sporadic. The clay sediments appear only able to support herbaceous and occasional fern colonization in an establishment of marsh-like growth at each site. Water was not present long enough for open-wetland or swamp–forest vegetation to develop. Compared with zones BG2-2 and B20-2, the low presence and percentage representation of *Melaleuca* pollen in zones BG2-1 and B20-1 indicates this taxon's presence in the vicinity of the herbaceous plant cover, but *Melaleuca* may have initially struggled to develop extensively on the coarse inorganic sediments with only periodic moisture availability. *Melaleuca* is present as a fringing tree, prior to 2600–2500 yr BP.

Developments in dryland vegetation surrounding Boigu Gawat and Bar-20 are not clear prior to 2600–2500 yr BP. *Eucalyptus* and Myrtaceae pollen are commonly present, probably forming the dominant canopy component over *Pandanus*, *Acacia*, *Banksia* and *Hibiscus* (as secondary tree taxa extra-local and regional to the core sites). Charcoal particles are present in each of the zone BG2-1 and B20-1 samples suggesting that fire was at least a part of the dryland environment.

At Boigu Gawat and Bar-20 dark organic sandy muds overlie the firm grey clays. Greater organic deposition coincides with higher concentrations of well preserved pollen at both sites. In zones BG2-2 and B20-2, during the last 2600–2500 years, pollen assemblages show changing patterns of dominance in swamp taxa. *Melaleuca* pollen increases in representation, suggesting that during the late Holocene herbaceous swamp communities were replaced by *Melaleuca*-dominated swamp forest. *Melaleuca* encroaches on the core sites from approximately 2600 yr BP, increasing further at Boigu Gawat close to 1200 yr BP and in the last 700 years at Bar-20. *Pandanus* pollen is consistently represented in zones BG2-2 and B20-2, possibly alongside *Melaleuca* to form a mixed swamp canopy. *Pandanus* is common today at the margins of island swamps, often forming dense stands and extending into open-woodland (personal observation). Herbaceous swamp pollen has not been lost from the zone BG2-2 and B20-2 records. *Melaleuca* and *Pandanus* are associated with *Leptocarpus*, *Cyperus*, *Schoenus*, and *Eleocharis*, and intermittedly with fern growth. Sedge pollen does decline in representation more recently at Boigu Gawat. As Grindrod (1988a) notes, herbaceous swamp taxa can vary in luxuriance and floristic makeup according to the amount of shading imposed by the tree canopy.

After 2600–2500 yr BP changes in lithology, pollen preservation and representation are thought to reflect a change in the hydrology of Boigu Gawat and Bar-20. Increased, continuous water availability and stable swamp–forest communities are argued to have occurred in the late Holocene. Standing water is more likely to lead to the promotion of plant growth and the accumulation of organic mud and material. The process here may be somewhat of a positive feedback loop; plant and particularly tree expansion is encouraged by organic sediments with a greater moisture content, but in themselves facilitate organic accumulation. A change in sediment colour (from grey to black, see Schulmeister, 1992) and greater organic/pollen preservation after 2600 yr BP signals a shift from oxic to anoxic conditions.

Through the Boigu Gawat and Bar-20 pollen records, sclerophyll woodland dominates the surrounding vegetation on the sand plains and dunes slopes. The nature of the woodlands, including composition and structure, does not change dramatically through the late Holocene.

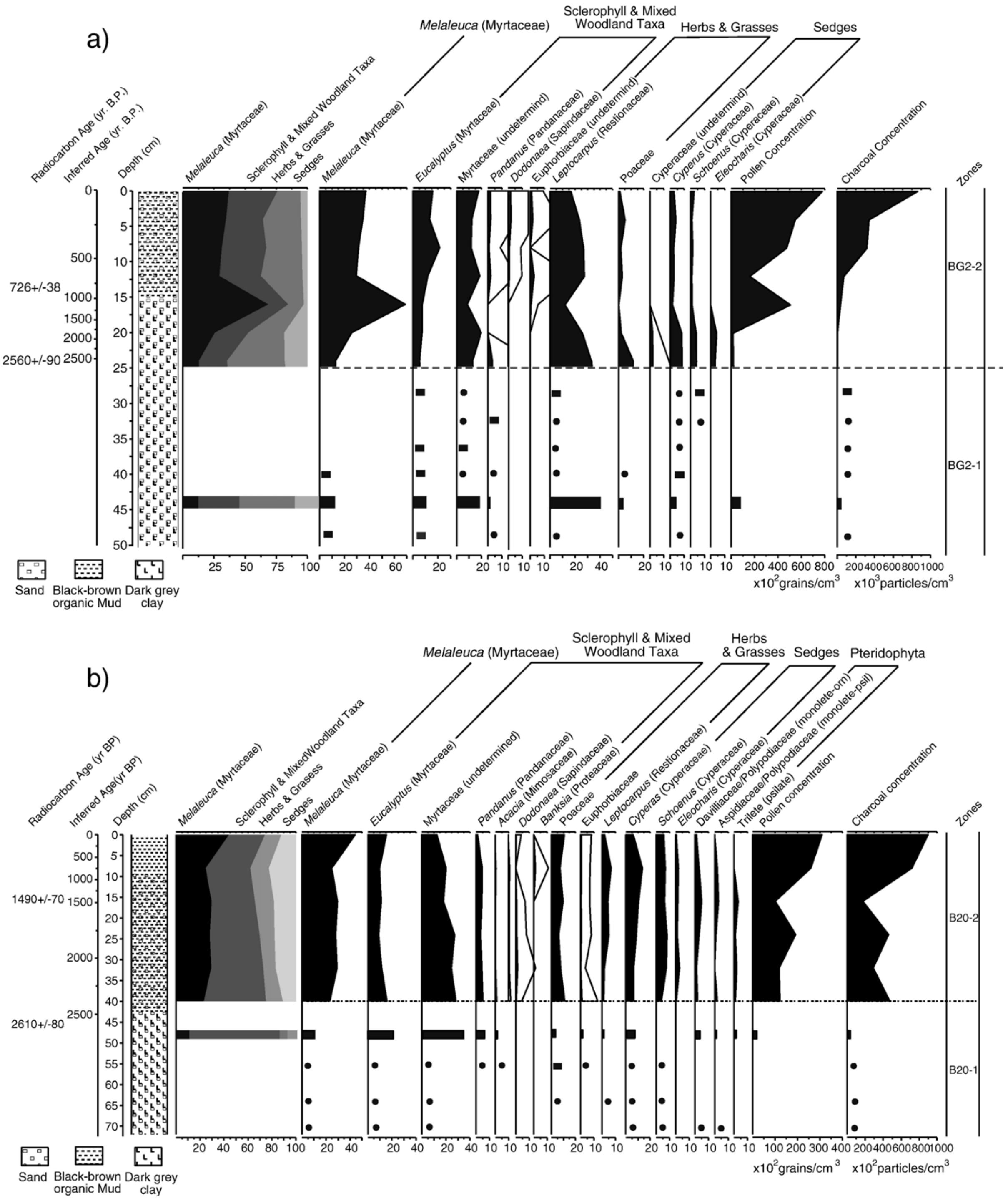

Fig. 7. Inland island percentage pollen diagrams (selected taxa): (a) Boigu Gawat; (b) Swamp Bar-20. Inferred age is based on linear interpolation between radiocarbon dated sediment samples. Diagram exaggeration values are ×10. (●) Presence in samples with insufficient pollen to generate an adequate sum.

The dominance of Myrtaceae, including *Eucalyptus*, in the dryland vegetation communities has persisted through at least the last 2600 years. Myrtaceae and *Eucalyptus* co-occur with the pollen of *Acacia* and *Dodonaea*, although the minor representation of the latter suggests that secondary tree taxa are not extensively represented in

Myrtaceous woodlands at any stage in the late Holocene. Although burning is ongoing across the inland environments of Mua and Badu throughout the last 2600–2500 years, greater fire activity is recorded through high microcharcoal concentrations in the last c. 1000 years.

5.2. Badu 15

Badu 15 is a rockshelter site located 3 km inland of the eastern Badu coastline, positioned at the junction of a sandy lowland plain and steep rocky incline (10°06′E; 142°09′S; Fig. 3). The site is located at the ecotone between vine thickets (incorporating *Cappais* spp. and *Similax australis*) occupying the upper slopes and eucalypt woodland (dominated by *Eucalyptus* spp., but including *Melaleuca* spp, *Banksia dentata* and *Cycas media*) at lower elevation. The site consists of a series of large overhanging boulders forming a sheltered area c. 6 m deep from the drip line to the back wall. The floor of the rockshelter consists of soft loam-type sediments, becoming increasingly compact with depth and transitional to clay deposits interspersed with granitic rock material. Sediments at Badu 15 do not contain a significant quantity of organic material. Pollen was found to be well preserved in the upper 60 cm of sediment, only to decline in abundance with depth. A more detailed presentation of palynological results from Badu 15 is presented in Rowe (2006). An archaeological discussion of the site is made in David et al. (2004). Excavation at Badu 15 yielded basal sediments of 8053±42 yr BP (WK-11947) in age. The pollen diagram which was produced from this site (Fig. 8) is therefore important as it provides information concerning environments older than any existing palaeoenvironmental sites within the island interiors of Torres Strait (see Rowe, 2005). A curve of recovered Badu 15 stone artifacts is included in Fig. 8 as a summary proxy of site use and island occupation.

The presence/absence pollen profile of zone B15-1 shows Myrtaceae is recorded in all samples. Poaceae pollen is intermittent in its representation but dominates the herbaceous component of the zone. Spore types are diverse in comparison with the pollen, incorporating numerous monolete and trilete types. From 8500 to about 4300 yr BP, Myrtaceae, probably *Eucalyptus*, dominated the canopy of the local vegetation, associated with a graminacous and fern understory, although the latter is likely to have been restricted to the immediate rocky outcrops surrounding the excavated site. Charcoal particles throughout the zone 1 sediments imply the presence of fire.

Between approximately 4300 and 3000 yr BP zone B15-2 is characterized by abundant Myrtaceae pollen. *Pandanus* pollen is also present in low frequencies;

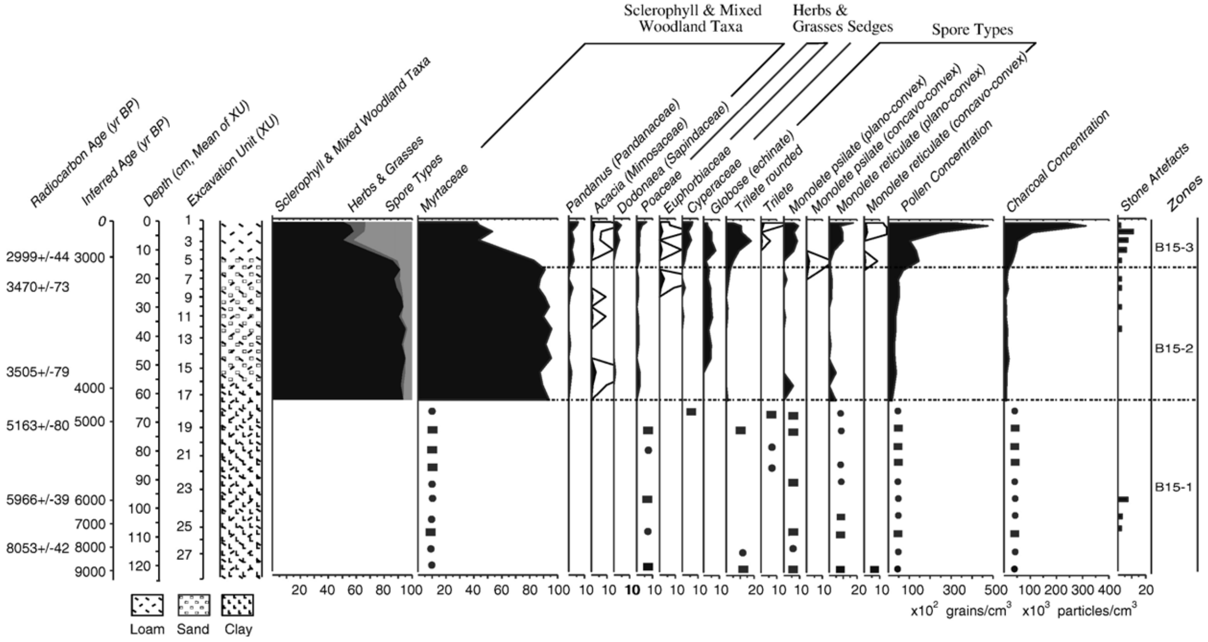

Fig. 8. Site Badu 15 pollen percentage diagram (selected taxa). Inferred age is based on linear interpolation between radiocarbon dated sediment samples. Diagram exaggeration values are ×10. (●) Presence in samples with insufficient pollen to generate an adequate sum.

Acacia more sporadically. The pollen of these three tree taxa is recorded with Poaceae in consistent, albeit low percentage concentrations. Diversity and abundance in spore types is low, dominated by a globose (echinate) type. High percentages of Myrtaceae pollen confirm Myrtaceae forest was locally extensive by at least 4300 yr BP. A significant forest canopy cover likely restricted secondary tree taxa and shrub occurrence; it also proved ill-suited to the maintenance of a dense growth of herbs, grasses and ferns. Minor amounts of preserved charcoal suggest that fire was a part of the Badu 15 environment at this time, but was relatively infrequent and/or of low intensity. Zone B15-2 is considered to reflect a stable vegetation community, spanning the mid-Holocene.

After about 3000 yr BP pollen of Myrtaceae declines rapidly, suggesting that the forest at Badu 15 is replaced by an open woodland. In the face of Myrtaceae decline, zone B15-3 shows an increased representation and/or consistency in the pollen of *Pandanus*, *Acacia*, *Dodonaea*, Poaceae, Cyperaceae, Euphorbiaceae and a significant rise in the presence of spore types. A loss of the dominant tree density has facilitated greater diversity in the upper and secondary canopy, also promoting more prominent ground cover. Pollen and spore assemblage changes in zone B15-3 and the Badu 15 profile in general coincide closely with peak values in charcoal concentration, associated with more recent increases in regional burning. Stone artifacts are also present, in higher numbers and with greater consistency. The Badu 15 pollen and charcoal profile demonstrates increasing disturbance of the island inland vegetation through time, resulting in the loss of continuous forest cover from approximately 3000 yr BP to the present. Palynological data combined with archaeological results suggest a human role in vegetation disturbance.

6. Discussion

This paper reviews palynological evidence for the Holocene history of vegetation change in Torres Strait, as one component of Cape York Peninsula. Data is available from two different sources; cores collected from tidal muds and coastal swamps provide a relatively detailed account of coastal lowland vegetation during and subsequent to the post-glacial marine transgression of Torres Strait. The oldest sediments for which data is available are inland, and although analyses of the inorganic/organic sediments of island interiors provide information on moisture availability and climate at the time of deposition, reveal only broad conditions regarding vegetation.

The reconstructed Holocene history of mangroves in Torres Strait is one of fluctuating development followed by periodically strong representation before decline on a regional western island group scale.Mangroves were present and increasing, but still restricted in distribution, between approximately 7000 and 6000 yr BP. Extensive expansion is demonstrated around Mua, Badu and Zurath during the time period 6000 to 3000 yr BP. A characteristic feature of coastal environments is the manner in which *Rhizophora* mangrove species dominate through the mid Holocene, to be succeeded by a *Ceriops*-type mangrove toward the late Holocene (the similarity between coastal pollen diagrams in this respect may indicate a predictable regional sequence). Beginning c. 4000–3000 yr BP *Rhizophora* declines in representation, giving way to landward associated mangrove taxa and terrestrial communities. Palynological data from Tiam Point, Zurath and Waruid suggest a landward migration of a mangrove fringe with marine transgression, after at least 7000–6800 yr BP. Extensive lowland tidal environments were established as sea level rose to or above present c. 6000 yr BP, supporting mangrove communities which left a well-defined organic horizon in the sediments and a strong *Rhizophora* pollen signature. Mangrove taxa encouraged and established during drowning of the Torres Strait plain, therefore, continued to expand across island lowlands where sedimentation rates probably kept pace with sea level rise, maintaining tidal conditions. Much of the island lowlands in Torres Strait were likely to have been mangrove swamps until shortly after sea level stabilisation. Such a landscape does not exist in the Torres Strait region today. It would not have been until after sea level stabilisation that ongoing sedimentation raised the gradient of island lowlands above that of extensive tidal inundation where-upon *Rhizophora* was effectively out competed.

Broad mangrove trends on Mua, Badu and Zurath can be said to be the insular equivalent to the big (mangrove) swamp model postulated for northern mainland Australia and used to explain the onset of estuarine and mangrove swamp development in the South Alligator River region in particular (Woodroffe et al., 1986; Barham, 1999; Hiscock, 1999). On the Northern Territory coast the development of widespread mangrove forest dates from approximately 6800–5300 yr BP and Woodroffe (1993) suggests that a ‘big swamp’ phase was probably a feature of most northern Australian estuaries around 6000 years ago. Studies on the east coast of Queensland reveal an extensive Rhizophoraceae mangrove phase between 7000 and 5900 yr BP (Mulgrave River Valley, Crowley et al., 1994; Innisfail coastal plain, Crowley and Gagan, 1995). Recent records available from southern New Guinea show similar high *Rhizophora* pollen percentages in association with a rise in Holocene sea level (Ellison, 2005). In detailed comparison the mangrove phase in Torres Strait appears to have been more persistent in its existence into the late Holocene (c. 3000 yr BP), but nonetheless fills the gap in a now transect-like regional picture of post-glacial mangrove communities.

Inland island environments during the Holocene incorporate an initiation or expansion of freshwater swamp forest within the last 2600 years. Sites at Boigu Gawat on Mua and Bar-20 on Badu reveal an expansion in *Melaleuca* accompanied by a rise in the diversity of herbaceous swamp flora and sub-canopy taxa. A notable rise in the concentration of pollen from c. 2600 yr BP roughly coincides with a stratigraphic transition from sandy clay to organic mud. Pollen evidence in conjunction with swamp stratigraphy implies an increase and consistency in inland freshwater availability through approximately the last 2500 years than previously. In Torres Strait the development of coastal backdune swamps has occurred within a late-Holocene time frame similar to that in the freshwater swamps positioned within island interiors. The Tiam Point and Zurath swamps also indicate the former presence of backdune swamps adjacent to mangrove communities prior to establishment of the extensive *Rhizophora* phase, from approximately 6800–6000 yr BP. These early to mid Holocene coastal swamps supported a mosaic of vegetation including mangroves, rainforest taxa, *Melaleuca* forest and herbaceous swamp communities, a diversity not recorded in the late Holocene. Backdune swamp environments established after c. 3000–2500 yr BP supported *Melaleuca* and/or *Pandanus* growth with herbaceous ground cover. Well-developed saltmarsh communities appear to have been absent during the period 6800–6000 yr BP, only to subsequently form in the coastal littoral fringe following mangrove decline, also within the last 2500 years.

The archaeological, inland and coastal study site investigations have provided a complementary record regarding the nature of island sclerophyll environments during the Holocene. While the pollen records suggest changes in the structure of sclerophyll communities, the overall composition of the vegetation has not altered considerably. Myrtaceae, principally *Eucalyptus*, has persisted through the last 8000–7000 years. Pollen spectra tend to suggest that *Melaleuca*, *Acacia*, *Casuarina* and *Banksia*, although present, have not been extensively represented in the sclerophyll environment, with *Pandanus* more prominent in the coastal lowlands than the island interiors. Widespread Myrtaceae forest was maintained from at least 7000 yr BP to 3500–3000 yr BP in Torres Strait. A decline in Myrtaceae and eucalypt pollen indicates a reduction in canopy cover and/or forest fragmentation from c. 3500 yr BP, suggesting a change from forest to open woodland; herbaceous pollen increases slightly relative to Myrtaceae within the same timeframe. Parallel with the late Holocene transition to open woodland is the loss of rainforest taxa (and included here are *Freycinetia*, *Dillenia*, *Canthium* and possibly *Acacia*). The Tiam Point record suggests that rainforest elements in Torres Strait achieved their maximum representation during the period 6800–6000 yr BP (extending to >6800 yr BP), rainforest possibly co-dominant with sclerophyll forest both inland and nearer to the coast. The existence of coastal swamp environments between 6800 and 6000 yr BP may have proved particularly favourable for the establishment of rainforest. Rainforest taxa are not extensively represented during any other period of time in the above presented pollen records. Rainforest communities, therefore, became marginal, limited to sub-canopy taxa under sclerophyll woodland or restricted to protected pockets, during the late Holocene.

Charcoal counts signal that fire has been a part of the dryland environments of Torres Strait since at least the early Holocene, but that the frequency of fire may have changed through time, leading into the modern period. Core records are marked initially by low charcoal particle concentrations followed by a two-step increase in representation. Such increase reveals a shift from a dryland environment with occasional disturbance due to fire, to an environment where fire disturbance is common. Radiocarbon dating indicates an initial rise in charcoal centered on 3000 yr BP, followed by a further increase in the last 1000 years.

The prominence of island rainforest elements during the early-mid Holocene likely reflects the timing and influence of a higher rainfall, humid climate in Torres Strait. Sclerophyll forest cover, as opposed to woodland communities, between approximately 6800 and 3500 yr BP is representative of an additional function of a relatively moist climate. Kershaw and Nix (1988) advocate for northern mainland Australia higher than present wet season temperatures and higher dry season precipitation through the mid-Holocene. Extending such a proposal to incorporate Torres Strait, less pronounced seasonality in precipitation has also resulted in a lower potential for burning, further maintaining vegetation cover. As rainforest and Myrtaceae forest, combined with low charcoal concentration, argue for humid early-to-mid Holocene climate for Torres Strait, the region in this respect likely held some capacity as an early-mid Holocene 'bridge' between New Guinea and Australia, the western Torres Strait islands demonstrating suitable habitats for rainforest taxon migration.

Rainforests reach their maximum extent on the Atherton Tableland by around 6500–5900 yr BP (Hiscock and Kershaw, 1992). Pollen records from New Guinea, as reported by Harrison and Dodson (1993), indicate a similar time span (8600 to 5000 yr BP) for the greatest development of rainforest. Maximum rainforest development in the Whitsunday Islands is tentatively estimated from at least 7000 yr BP to approximately 4500 yr BP (Genever et al., 2003).Western Torres Strait supports the notion that maximum mid-Holocene rainforest development and higher rainfall were regional phenomena and suggests that the Atherton Tableland records demonstrate some implications for the Holocene history of rainforest occurrence in the western and northern seasonal tropics of Australia – rainforest expansion can be expected to be roughly synchronous with changes as they occur around Atherton and in eastern Cape York Peninsula. Prominent early to mid-Holocene wet eucalypt forest on Mua and Badu is consistent with the dominance of Myrtaceae in dryland vegetation after 9000 yr BP in southern (Isabella Swamp, Stephens and Head, 1995) and western (Lake Koongirra, Butler, 1998) Cape York Peninsula. Schulmeister (1992) also argues for the arrival of 'Holocene vegetation' on Groote Eylandt by 7500 yr BP, in view of highest values for all palynomorphs including both eucalypt open forest and vine-thicket types.

Evidence and derived discussions from Lees (1992), Schulmeister (1999), Gagan et al. (2004) and Haberle et al. (2001) all point to conditions in northern Australia at the mid-to-late Holocene as much drier than the previous early-to-mid Holocene phase. Not a single discrete shift toward changed drier environmental conditions is implied, but a shift incorporating, overall, heightened climatic variability. For northern Australia, the late Holocene incorporated not only a less reliable monsoon system but also pronounced El Niño events. In western Torres Strait, humid, equable conditions in the mid Holocene are likewise considered to have given way to a late Holocene drier, variable climate. A decline in tree abundance and diversity over the last c. 3000 years, toward a prominence and uniformity in woodland habitats incorporating a higher proportion of herbaceous pollen, proclaim drier conditions. The late Holocene also appears to have created circumstances suitable for ignition (natural or anthropogenic). On Mua, Badu and Zurath, a general increase in charcoal concentration is evident at various times after 3500–3000 yr BP suggesting that the influence of fire has increased from this time, with a negative relationship between fire and tree abundance apparent. The trend toward more open sclerophyll communities may, in turn, have facilitated the onset of swamp conditions due to increased erosion and sediment input from more exposed ground surfaces. Here, exposed and mobile sediments within a sparsely vegetated environment accumulated in topographic depressions, altering drainage patterns and creating habitats locally capable of holding water for longer periods (Butler, 1998; Haberle, 2003).

The interpretation of swamp vegetation history on Mua, Badu and Zurath is that water reliability after c. 2600 yr BP is generally good. Overall increase and reduced fluctuation in water levels promoted forests with a relatively dense *Melaleuca* canopy, particularly around low-lying depressions. This is in accord with the suggestion of swamp forest expansion in western and southern Cape York Peninsula after 2700 yr BP (Butler, 1998; Stephens and Head, 1995), the initiation of late Holocene herbaceous swamp communities at Waigani in southern New Guinea (Osborne et al., 1993) and for the onset of organic swamp deposition as far reaching as the Kimberley (Head and Fullagar, 1992). Such results, now including Torres Strait, do not coincide with climatic inferences from the east coast of Queensland. The Atherton Tablelands proclaim a reduction in lake/swamp water levels and decreases in precipitation beginning 3000 yr BP, with driest Holocene conditions between 2600 and 1400 yr BP (Hiscock and Kershaw, 1992, p. 58). Early research problems associated with collection of the top-most sediments, or disturbances to the most recent sediments in the Atherton Tableland sites, have prevented full confident documentation of the last one or two thousand years (Hiscock and Kershaw, 1992). A recent presentation of a pollen record from Lake Euramoo on the Atherton Tableland does provide a pollen diagram (zone 4) description spanning 5000–70 cal. yr BP, but with no mention in interpretation of a possible precipitation recovery or return to more fluvial conditions (Haberle, 2005). The Torres Strait may be incorporated within and signal a rainfall event or phase from c. 2600 yr BP not recorded around Atherton and the Wet Tropics region.

That the pollen, charcoal and sedimentary evidence from Mua, Badu and Zurath provides an additional example of drier late Holocene conditions with more consistent swamp habitats is a significant outcome, noteworthy for the long-term history of northern Australia and for Cape York Peninsula as an interconnected set of systems. Questions as to the signature and geographical distribution of climatic variability across northern Australia, and potential underestimation of climatic variability are exposed. 'Variability' may be interpreted to incorporate not only increased aridity but also periods of increased precipitation, enough to maintain freshwater ecosystems. Stephens and Head (1995) discuss variation in the geographic penetration of the monsoon system over time (a failure to extend south and east, for example). Similarly, Nott and Price (1999) observe phases in monsoon intensification in northern Australia, but across latitudinally restricted regions during the Quaternary. Clearly the late Holocene onset of swamp formation in Torres Strait requires further investigation (Rowe, in preparation).

In exploration, the possibility also needs to be raised that increased open woodland, fire and the movement of surface sediments are reflective of human activity, or human impacts exaggerated by climatic change. Loss of vegetation cover and swamp formation as a function of human impact is feasible. Vegetation and landscape change within the last 3000 years coincide with the proposed final phase of permanent island occupation, incorporating sustained site use and wider Islander social activity and trade practices (David et al., 2004). Increased stone artifact recovery and the unparalleled decline of zone B15-3 Myrtaceae pollen at Badu 15 hint at human factors in island change. Fire is a strong component of modern Islander/environment interaction and historical ethnographic texts describe burning (clearing) as one means of preparation in plant cultivation (Haddon, 1912, p. 148). More of such evidence is required for the documentation of causation. An aligned scenario of human activity and of a consistency in freshwater ecosystems in Torres Strait may in turn help to explain the re-arrival and ongoing presence of people in the late Holocene, freshwater improving the habitability of the islands.

7. Conclusion

The Torres Strait should not be viewed as a separate entity to northern mainland Australia. From the palaeoenvironmental research conducted in the western group islands, no single late Quaternary environmental trend and underlying mechanism would appear to encapsulate the diversity in vegetation patterns geographically across Cape York Peninsula. In this paper parallels have been drawn between the palynological records of western Torres Strait and the Wet Tropics of Cape York Peninsula together with the northern and eastern coastlines. The latter two have assisted in the interpretation of the former. Differences, however, are also apparent. Less consensus between sites is evident toward the late Holocene, although potential relationships between sites is perhaps complicated by human impact. Any application of the palaeoenvironmental records as carried out on the humid plateau of eastern Cape York Peninsula to the seasonal tropics of northern Australia should proceed with some caution. This is especially true for regions such as the Torres Strait which host a unique human history in relation to the remainder of northern Australia, requiring locally based palaeoenvironmental research as context. The knowledge base from research on the Atherton Tableland region has set a high priority on finding equivalent sites in seasonal tropical, lowlands environments (Mackey et al., 2001).

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