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HOLOCENE VEGETATION CHANGE ON MUA

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A Holocene record of vegetation change is presented from the island of Mua, Torres Strait, Australia. Pollen analysis, charcoal analysis, stratigraphic changes and radiocarbon dating of two coastal and one inland sediment core provide evidence of vegetation cover and fire occurrence for the period 7000 years BP to present. The study shows *Rhizophora*-dominated mangrove encroaching on the coastal lowlands of Mua, periodically displacing non-mangrove taxa between 7000 and 6000 years BP until the establishment of an extensive mangrove forest after 6000 years BP. The timing of mangrove decline and pattern of coastal plain, including swamp, development is site specific, beginning after 3000 years BP. Inland and eucalypt woodland has persisted through the last 7000 years with pollen evidence demonstrating little change in structure or composition. Freshwater swamp expansion and permanency, however, is restricted to the late Holocene, and charcoal counts signal an increase in island burning within the last 1000 years. Changes in Holocene vegetation on Mua are interpreted as the result of post-glacial marine transgression and stabilisation followed by on-shore human influences. ❑ *Torres Strait, palaeoenvironments, palynology, stratigraphy, charcoal, mangroves, swamp environments*.

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The Torres Strait Islands were formed between 8500 and 6500 years before present (years BP) when rising postglacial sea levels submerged the land bridge then connecting the large islands of New Guinea and Australia. Situated in western Torres Strait, Mua lies some 60-70km north of the Australian mainland. Measuring 17 × 16km in size, it is the second largest island in the region and features a low-lying (<20m above sea level, ASL) central sand plain surrounded by a network of igneous hills and ridges (rising to 370m ASL; Fig. 1). Climate patterns are seasonally tropical (monsoonal) with relatively uniform high temperatures. An average annual rainfall of 1792mm is estimated to occur on Mua, falling predominantly in the months from December to April (Bureau of Meteorology, 2000).

Mua supports a broad suite of seasonal-tropical environments, incorporating upper and lower tidal mangroves, mudflat, sedgeland, herb- and grassland, fresh to brackish swamp habitats, a network of riparian forest and scattered vine thicket (rainforest vegetation types, see Webb & Tracey, 1994) and extensive *Eucalyptus*, *Corymbia*, and *Melaleuca* woodlands. Not all vegetation communities have been mapped given the scale used in Fig. 1. A detailed description of contemporary vegetation may be found in Neldner (in preparation), Wannan & Buosi (2003) and Wannan (chapter 20, this volume). The rainforest formations on Mua are diverse and contain a high proportion of island plant taxa, occupying alluvial systems, protected pockets at higher elevation and on granitic rocky outcrops. These habitats typically incorporate *Acacia, Alstonia, Bombax, Ficus, Welchioderdron* and *Syzygium* species in the upper canopy layer, with a shrub layer often dominated by lianas. Sclerophyll woodlands are the predominant vegetation type across much of the island. *Eucalyptus* and *Corymbia* woodlands with a subcanopy of *Acacia, Pandanus, Grevillia* and *Banksia* species occur on the upper, mid and lower hill-slopes and boulder outcrops, as well as on the sandy level plains. *Melaleuca* woodlands also occupy the lowland plains and areas of impeded drainage. Low-lying alluvial, drainage swamps and waterlogged situations are fringed with *Melaleuca* open forest with a ground cover of Cyperaceae and *Dapsilanthus* (formally known as *Leptocarpus*). On coastal sand deposits, *Casuarina* and *Cocos* grow above the high water mark; sparse grassland incorporating mixed herbaceous species also occur on foredunes and beach ridges. Secondary beach ridges are vegetated by *Eucalyptus* woodland, often with an understorey of *Cycas*. Skirting the Mua coastline, mangrove habitats occupy sheltered

situations incorporating shallow embayments and estuarine floodplains. At the seaward mangrove edge and in areas flooded by all high tides species of *Rhizophora* are common. Further inland, on deposits inundated less frequently, mangrove tree taxa include *Bruguiera*, *Ceriops*, *Avicennia* and *Lumnitzera*. With distance inland mangroves decrease in height and canopy cover to grade into mudflat, sedgeland or *Melaleuca* and *Pandanus* swamp habitats. Communities adjacent to the mangroves differ according to variations in elevation, salinity and drainage. For example, where salinities are locally moderated by poor drainage and/or freshwater seepage from nearby uplands (Grindrod, 1988), sedgeland and swamp environments prevail.

Gelam is an ancestral hero whose homeland lies on the northern shoreline of Mua. This chapter presents a summary of results from pollen and charcoal analyses undertaken on sediment cores collected from around the island of Mua, focusing on changes in the vegetation and environmental settings identified in the story of Gelam (Lawrie, 1970; Alfonso & Kershaw, 2001), namely nearshore environments and inland sclerophyll communities.

STUDY SITES

Three sites were examined for palaeoenvironmental study (Fig. 1): the Tiam Point embayment, located along the southeast coastline of Mua, incorporating a backdune swamp approximately 1km inland; a creek terrace occupied by mangroves at Talita Kupai, situated on the central west coast; and Boigu Gawat, a freshwater swamp some 3km inland and positioned within an extensive low-lying sand plain.

The Tiam Point swamp is transitional between dryland sclerophyll vegetation and mangrove communities, and is located adjacent to a predominantly seasonal creek system. At the time of coring (November 2002) the swamp was dry and the surface dominated by species of *Sporobolus* (Fig. 2). The ground fern *Acrostichum* occurs in dense clusters at the swamp margins. Stands of *Melaleuca* species fringe the landward side of the swamp and extend inland along the creekline, interspersed with riparian taxa such as *Dillenia*.
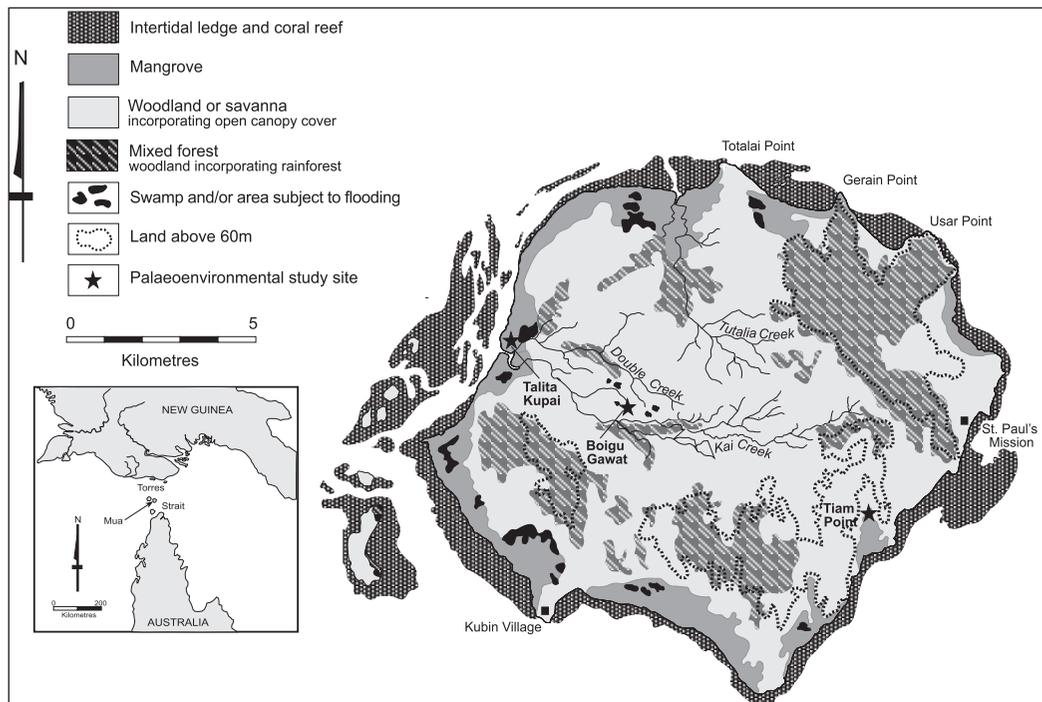

FIG. 1. Mua, showing location, major landscape and vegetation features, and place names mentioned in the text (adapted from the vegetation map of the Australian tropical savannas produced by Fox et al. (2001) and the Royal Australian Survey Corps (1995) topographic map series).

Vegetation communities across the surrounding catchment slopes include low, open eucalypt woodland. Seawards, an extensive mangrove system follows the creek to the coast. An upper intertidal community dominated by *Bruguiera* and occasional *Aegiceras* and *Avicennia* borders the swamp, extending to lower tidal environments at the open coast, colonised by *Rhizophora*.

Talita Kupai is positioned on a tidal creek channel (Fig. 3). There are numerous creeks on Mua draining from higher elevations toward the centre of the island and extending eventually to the coast. Two significant drainages, Double Creek and Kai Creek, drain westward to a common outflow at Talita Kupai. Talita Kupai supports a c.90m wide band of mangrove vegetation incorporating an embankment or 'levee' community of *Avicennia*. The *Avicennia* zone provides only a low (2-4m) sparse canopy cover about 20-25m wide and merges with a taller (4-8m) stand of *Rhizophora* approximately 60m wide. Forming a continuous canopy cover, *Rhizophora* has established an almost pure mid-zone community. *Rhizophora* then extends landward to become codominant with *Bruguiera*. At Talita Kupai, the mangrove community is devoid of any shrub layers and the ground layer is bare of herbaceous plants. The transition between mangroves and the surrounding open eucalypt woodland is abrupt.

Wetland areas and freshwater swamps are relatively uncommon vegetation community types on Mua. The Boigu Gawat swamp occupies an alluvial low point or depression with a central open water area approximately 50m in diameter (Fig. 4). *Melaleuca* (possibly *M. leucodendra*) dominates the swamp forest forming an open canopy up to 20m in height. *Dapsilanthus* occupy the swamp forest understorey, forming a continuous fringing zone where the water is shallower and/or receding. The swamp itself contains a variety of aquatic taxa, including the floating leaved herb *Nymphaea*. The Boigu Gawat swamp is not at present connected directly or linked via channels to the two creek systems to the north and south as illustrated in Fig. 1 (see Barham & Harris (1987) for a discussion on the geomorphology of the central plain). Vegetation on the dune slopes and sand plain immediately surrounding the swamp is predominantly woodland in which *Eucalyptus leptophleba* and species of *Corymbia* are characteristic trees (Fig. 5).

FIG. 2. Tiam Point swamp surface.

FIG. 3. Sediment coring at Talita Kupai.

METHODS

Sediment sampling from Tiam Point, Talita Kupai and Boigu Gawat was completed using a hand-operated D-section corer. Cores were collected from the approximate swamp centre at Tiam Point and Boigu Gawat. At Talita Kupai, core material was recovered from the landward mangrove zone, 5m from the mangrove-sclerophyll transition. Samples of one cubic centimeter were extracted at 4cm and 8cm intervals through the cores and prepared for pollen analysis using standard acetolysis methods described by Bennett & Willis (2001).

Pollen grains and pteridophyte spores were identified using light microscopy at ×400 magnification and counted until at least 200 grains at coastal sites and 100 grains within inland environments had been recorded. Identification of pollen was by comparison of morphological characters with modern reference material, either collected in the field or from regional reference

FIG. 4. Boigu Gawat swamp.

FIG. 5. Surrounding sclerophyll woodland community, Boigu Gawat swamp.

collections held at Monash University. For spore taxa, morphological characteristics have been provided to indicate a particular type. Pollen concentrations were determined by adding a known quantity of exotic pollen (*Lycopodium*). Charcoal fragments greater than 10μm maximum diameter were counted on the pollen preparation slides, also as a proportion of the exotic spike. This enabled a determination of charcoal concentrations per unit volume of sediment.

Two sums were used in constructing pollen diagrams. One sum was total pollen excluding spores, and the second sum comprised of pollen from mangrove taxa only. Each sum, where appropriate, is displayed as a summary curve. Relative abundance of individual pollen taxa are shown as percentages of the total pollen sum. Selected, prominent pollen and spore taxa, and photographs of the core sites, are illustrated in Figs 2-8. For extended discussion and the

complete pollen records from Tiam Point, Talita Kupai and Boigu Gawat, see Rowe (2005, 2007). Pollen diagrams were prepared using TILIA and TILIAGRAPH (Grimm, 1991). Results of a stratigraphically constrained cluster analysis of the pollen samples using the program CONISS (Grimm, 1991) is also given for each diagram. Bulk sediment samples from major stratigraphic breaks and on the basis of changes in the pollen spectra were selected for radiocarbon dating. Unless otherwise stated, the ages given in the text are uncalibrated years before present and the age-depth model for the pollen diagrams is based on linear interpolation between dated samples. Radiocarbon ages are presented in Table 1.

POLLEN DIAGRAMS

TIAM POINT. (Fig. 6) *Zone TP-1 (455-248cm; c.6800-5800 years BP)*. Fluctuations between pollen spectra from non-mangrove to mangrove vegetation at the core site reflect alternating periods of marine and dryland conditions. *Rhizophora* dominates the mangrove pollen sum reaching up to 85% in a series of peak values. Salt water incursions may have allowed for the periodic invasion of *Rhizophora* across the core site, although each *Rhizophora* phase appears to be short lived suggesting a variable environment as the Tiam Point region adjusts to episodes in sea level rise. Poaceae values (8-20%) and a consistency in sedge and Pteridophyta representation characterise the near-coastal swamp

TABLE 1. Radiocarbon dating results. Calibrations were undertaken on the Calib 4.4 program, following Stuvier et al. (1998), and are quoted as maximum to minimum age range; pMC = Percent Modern Carbon..

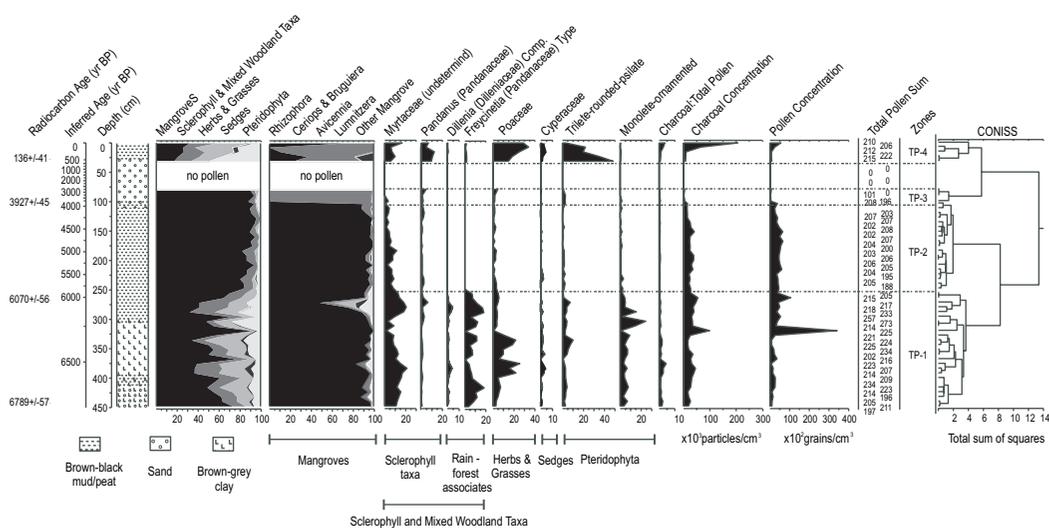| Sample	Sample depth (cm)	14C years BP	Calibrated years BP
Tiam Point			
Wk-12745	28	136±41	151-0
Wk-12746	102	3927±45	4419-4218
Wk-12747	368	6070±56	7009-6725
Wk-12748	443	6789±57	7684-7550
Talita Kupai			
OZG-589	20	modern (106.6±0.39 pMC)	
OZG-590	44	220±40	234-131
OZG-591	128	2240±50	2338-2095
Boigu Gawat			
Wk-14684	14	726±38	770-621
OZG-071	24	2560±90	2753-2357

FIG. 6. Tiam Point pollen percentage diagram plotted against depth and age (selected taxa). Percentages derived from the total pollen sum. The mangrove summary plot is calculated using the mangrove pollen sum.

surface. Periods of freshwater availability and/or moist conditions within the swamp are further signified by strong values of the *Freycinetia* type and the presence of *Dillenia*. Kershaw (1975, 1983) refers to *Freycinetia* as moisture loving and incorporates the taxon in a suite of rainforest taxa for north Queensland. *Dillenia* is known to occupy coastal monsoon forest associated with freshwater streams (Brock, 2001). In this zone Myrtaceae values are significant (21%); one component may have been derived from *Melaleuca*, but it is also likely that the pollen is from *Eucalyptus*, indicating the presence of eucalypt woodland within the embayment. Charcoal concentrations are variable, but a consistent, low charcoal:pollen ratio suggests environments at Tiam Point incorporated little burning.

Zone TP-2 (248-104cm; c.5800-3900 years BP). The development of dark organic muds, along with an increase and consistency in the representation of mangrove taxa to over 80% of the total pollen sum, indicate mangrove forest had engulfed the core site. Very high levels of *Rhizophora* (>90% of the mangrove pollen sum) show *Rhizophora*-dominated mangrove vegetated the core site during zone TP-2, and suggests a frequently inundated, low tide environment. Other mangroves, when present, are of minor importance (values <10%). Low percentages and a decline in the diversity of non-mangrove vegetation signals *Rhizophora*-forest was estab-

lished in the extra local and regional core site environments and was therefore widespread across Tiam Point. The variability evident in the period 6800-5800 years BP gave way to relative stability between c.5800-3900 years BP.

Zone TP-3 (104-80cm; c.3900-2800 years BP). In zone TP-3 mangrove values remain high (>85% of the total pollen sum) but incorporate a sharp peak in the representation of *Ceriops/Bruguiera*, supplanting the dominance of *Rhizophora* in zone TP-2. Above 112cm depth (after c.4000 years BP), zone TP-3 suggests *Rhizophora* forest declined in favour of a transition to a landward *Ceriops* and/or *Bruguiera* mangrove community, close to the upper limit of tidal inundation. Few other mangrove taxa are present. As a possible analogue, Brock (2001) observes *Ceriops tagal* var. *australis* as commonly forming dense stands on the landward margin of mangrove communities in mainland northern Australia. Non-mangrove taxa maintain a low presence in zone TP-3.

Total pollen and charcoal concentrations in zone TP-3 are the lowest for the Tiam Point record. The low concentration values precede an absence of pollen and a scarcity in charcoal particles between 80cm and 32cm depth. The lack of a record from 80cm to 32cm below the surface, dating from approximately 2800-340 years BP, is considered to be a direct result of the increased sand content. Relatively coarse sand
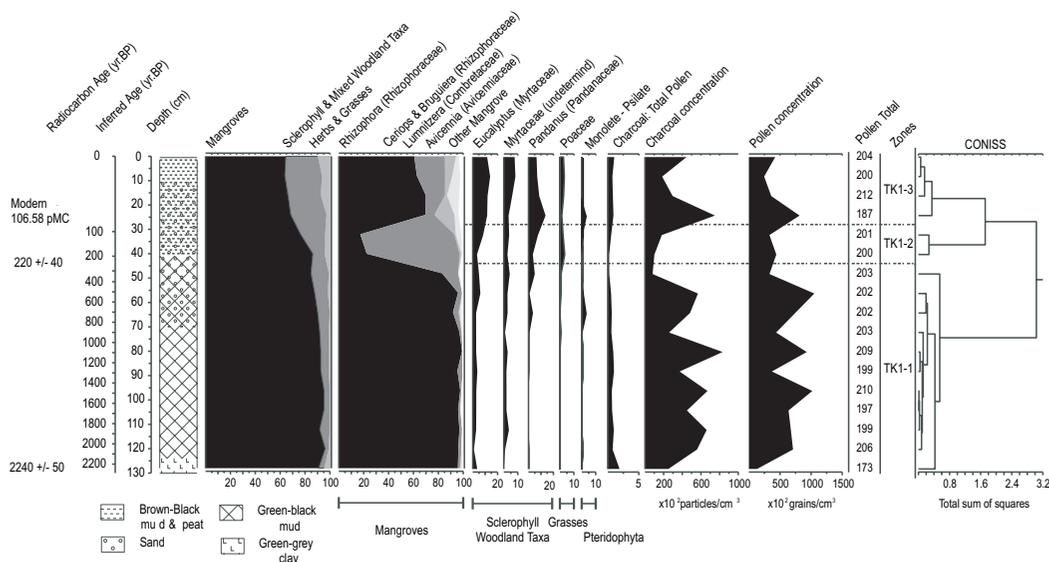
FIG. 7. Talita Kupai pollen percentage diagram plotted against depth and age (selected taxa). Percentages derived from the total pollen sum. The mangrove summary plot is calculated using the mangrove pollen sum.

sediments would be expected to drain easily and any entrapped pollen grains or charcoal particles likely to degrade easily and rapidly through abrasion. Pollen oxidation through phases of wetting and drying is also a possibility (Grindrod, 1988).

Zone TP-4 (32-0cm; c.340 years BP-modern). A decline in mangrove representation to less than 30% of the total pollen sum, in accordance with the increased representation of Myrtaceae (possibly incorporating *Melaleuca*), *Pandanus*, Poaceae (29%), sedge (10%) and Pteridophyta taxa (49%), indicate a freshening of environments at the core site, incorporating swamp forest. Following mangrove decline therefore, local core site taxa are predominantly grasses, ferns and sedges, consistent with the current swamp surface. Myrtaceae (17%) and *Pandanus* (12%) form stands lining the herbaceous swamp, just landward of a *Ceriops* and/or *Bruguiera* mangrove community, as evident today. Low values of *Rhizophora* indicate the maintenance of lower tidal *Rhizophora* forest at the coast. Extensive regional burning is only a recent phenomenon, high charcoal:pollen ratios and charcoal con-centrations restricted to this zone.

TALITA KUPAI. (Fig. 7) *Zone TK-1 (128-44cm; c.2200-220 years BP).* The strong representation of *Rhizophora* (>85% of the total pollen sum) indicates that *Rhizophora*-dominated (lower-

tidal) mangroves covered the core site through the period represented by this zone. Second to *Rhizophora*, *Ceriops* and/or *Bruguiera* values are relatively low, with a maximum of 13% at the top of the zone. That *Ceriops* and/or *Bruguiera* form a consistent, albeit small, component of the mangrove forest may relate to the presence of *Bruguiera* as a secondary tree taxon in a relatively mature *Rhizophora* forest, as is the case in the vegetation of Mua today. Few other mangrove taxa are represented in zone TK-1. Non-mangrove taxa have low percentage values, below 6% in all cases, suggesting that mangroves formed a dense, wide band of vegetation adjacent to the Talita Kupai tidal creek channel and that mangrove forest was well established in the regional environment. In accordance with a mangrove environment charcoal:pollen ratios remain low throughout this zone. Charcoal and pollen concentrations are variable.

Zone TK-2 (44-28cm; 220-50 years BP). A shift in mangrove domination from *Rhizophora* to *Ceriops* and/or *Bruguiera*, and the initiation of a decline in total mangrove representation, signals a transition from *Rhizophora* forest to a landward mangrove community at the core site, similar to that of zone TP-3 at Tiam Point. This transition at Talita Kupai has incorporated
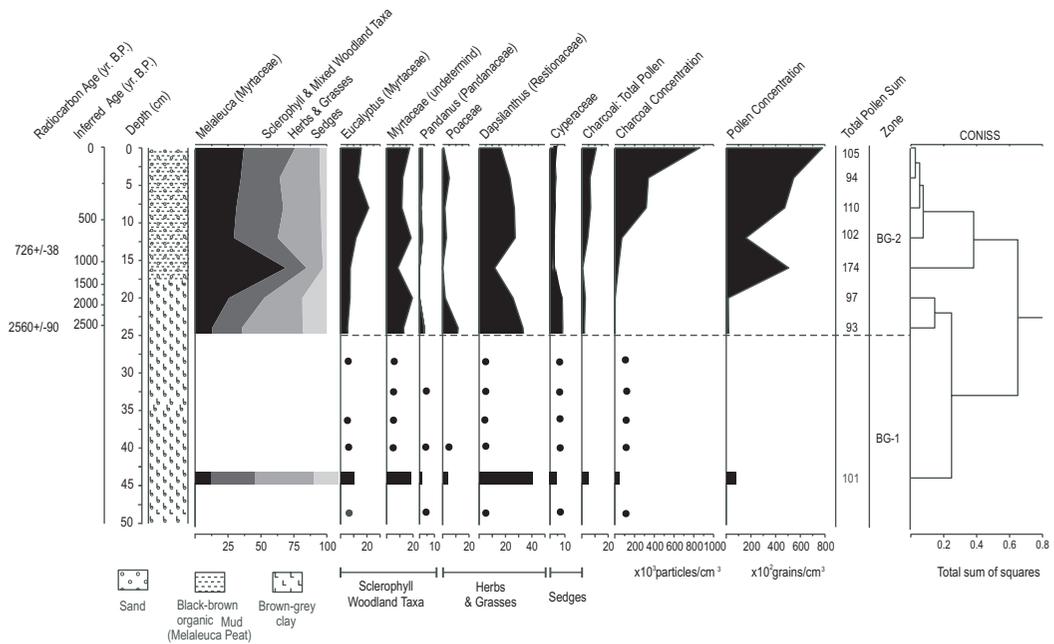
FIG. 8. Boigu Gawat pollen percentage diagram plotted against depth and age (selected taxa). Percentages derived from the total pollen sum. ● = Presence in sample with insufficient pollen to generate an adequate sum.

a change in sediment type, from a clay-based mud to a dark organic mud with sand.

Zone TK-3 (28-0cm; c.50 years BP). Higher percentage values of *Avicennia* (10% of the mangrove pollen sum)*, Lumnitzera* (16%) and other mangrove taxa than previously suggest an ongoing transition toward a mixed upper tidal mangrove habitat. Although percentage values for *Avicennia* and *Lumnitzera* are less than *Ceriops* and/or *Bruguiera* (25%), the poor pollen dispersal and strong localised portrayal of these taxa (Grindrod, 1985, 1988; Crowley et al., 1990) suggests they are important components of a landward, drier mangrove community at Talita Kupai. Interpolation between radiocarbon ages points to a relatively rapid vegetation succession from low tide *Rhizophora* forest to the upper tidal mixed mangrove community of zone TK-3. Rapid change would imply a locally unstable Talita Kupai environment away from the creek embankment, possibly associated with a decline in the extent and frequency of tidal influences; *Rhizophora* growth remaining relatively stable creekside where marine inundation remains frequent. Increased values for non-mangrove taxa from c.250 years BP and into the modern period of this zone indicate the nearing presence of

dryland sclerophyll communities to the core site, also suggesting that the mangrove band of vegetation became progressively narrow. Surrounding sclerophyll environments are dominated by *Eucalyptus* (15% of the total pollen sum) and Myrtaceae (8%), but include *Pandanus* (13% declining to 6%). The charcoal:pollen ratio and charcoal concentration curves imply fire was present within the wider sclerophyll environment, possibly of low intensity.

BOIGU GAWAT. (Fig. 8) *Zone BG-1 (50-26cm; >2500 years BP)*. Coarse sandy clay sediments and an inconsistent preservation of organic material, including pollen, are suggestive of transient water conditions with periodic drying of the core site. Within this zone only one sample achieved the desired pollen sum. The composition of sample 12, at 44cm depth, implies an herbaceous swamp environment composed predominantly of *Dapsilanthus*, sedges and grasses; *Dapsilanthus* comprises 43% of the (total) pollen sum with low values of Cyperaceae (5%) and Poaceae (4%). *Melaleuca* achieves a value of 13%, possibly growing extra-local to the core site and therefore fringing the herbaceous vegetation along swamp edge habitats or localised pools of water. Reinforcing the dominance observed in sample

12, *Dapsilanthus* is present in all other samples of zone BG-1. Myrtaceae and *Eucalyptus* are the major woodland taxa of zone BG-1. Charcoal particles are found throughout the zone.

Zone BG-2 (26-0cm; 2500 years BP-modern). The accumulation of dark organic mud and an increase in pollen concentrations suggests a change in the hydrology of the swamp. A more stable swamp boundary and increased wetness is implied from zone BG-2, incorporating a succession in swamp vegetation from c.2500 years BP. The pollen spectra show an initial transition from an herbaceous community of Cyperaceae, *Dapsilanthus* and Poaceae, to a dominant *Melaleuca* canopy, followed by a uniform representation of swamp pollen in the last c.700 years, where *Melaleuca* combines with relatively stable *Dapsilanthus* values. Away from the swamp, the pollen evidence suggests relatively little change; the Myrtaceae family (*Eucalyptus*, 20%) remain dominant and coexist with *Pandanus* (2%). Charcoal concentrations reach their highest values in this zone, suggesting greatly increased fire activity.

DISCUSSION

HISTORY OF MANGROVE DEVELOPMENT AND DECLINE. Based on pollen evidence, the reconstructed Holocene history of mangroves on Mua is one of fluctuating development, followed by a periodically strong representation before decline on an island scale. The coastal site data from Mua portray the final stages of the Postglacial Marine Transgression – rising sea levels – and a subsequent period of decline and relative sea level stability (Woodroffe et al., 2000; Hopley & Thom, 1983). Pollen data imply an erratic landward migration of mangroves with marine transgression, a possible indication that Holocene transgression across the Torres land bridge was, in itself, unsteady. At Tiam Point, palynological investigations and the results of radiocarbon dating indicate that mangroves were present and increasing, but still restricted in distribution between c.7000 years BP and 6000 years BP. Extensive mangrove communities were only established after 6000 years BP, as evident in the Tiam Point pollen assemblages and well-defined organic horizon in the sediments. Mangrove taxa are proposed to have expanded beyond the periphery of tidal creek channels and estuaries on Mua to occupy the majority of the coastal lowlands, reaching their maximum extent between 6000 years BP

and 3000 years BP. Such coastal environments were not diverse; *Rhizophora* dominance, to the virtual exclusion of other mangrove and plant genera signifies a habitat with a dense and continuous upper canopy and an absence of shrub and ground layers. These environments would presumably have been permanently wet and boggy, where tidal inundation is frequent (Adam, 1994; Grindrod, 1985). The steady maintenance of *Rhizophora* forest at Tiam Point during the mid Holocene therefore suggests the sediment surface at the core site remained close to (a higher) sea level for about 3000 years (cf. Crowley et al., 1990). At Talita Kupai, mangrove forest communities were already well established in the basal sediments of the core, indicating a wide-spread *Rhizophora*-dominated mangrove habitat and strong marine influence existed until at least 2000 years BP at this location. As such, on Mua, the initiation of the *Rhizophora*-dominated mangrove phase was roughly synchronous with the 'big swamp' mangrove expansion along the northern shorelines of mainland Australia (Crowley & Gagan, 1995; Woodroffe et al., 1985, 1986), consistent with Woodroffe's (1988) proposal that a mangrove swamp phase was probably a feature of most north Australian estuaries around 6000 years ago. The mangrove phase on Mua, however, may post-date the age of about 5300 years BP suggested by Woodroffe et al. (1986) as the end of the 'big swamp' mangrove community on the South Alligator River in the Northern Territory.

Following the extensive mangrove phase on Mua, succession through mangrove forest to upper tidal and non-mangrove communities is clearly recorded in the Tiam Point and Talita Kupai pollen records, although the timing for each successive stage differs between the study sites. Site-to-site variations in the timing of mangrove change on Mua infers mangroves were variable environments on the small, local-site scale, existing as a set of patches composed of similar taxa, but at different successional stages through time. For Mua, vegetation change at the coast seems to have been ongoing since the marine transgression, but the rate and degree of vegetation change may have varied according to local topographical, drainage and freshwater-hydrological characteristics.

The first stage of a late Holocene coastal vegetation transition on Mua is marked by a shift from *Rhizophora* to *Ceriops* and/or *Bruguiera* dominance at Tiam Point and Talita Kupai. Colonisation by *Ceriops* and/or *Bruguiera*

suggests that sea level stabilisation and/or decline, combined with ongoing sediment accretion, resulted in each core site being raised within the upper intertidal, landward mangrove zone. In turn, continued sediment accumulation in the absence of sea level rise in the late Holocene positioned each core site above marine influence. In consequence, *Rhizophora* declines in importance with distance from the coast (Crowley et al., 1990; Crowley & Gagan, 1995). In the last 500 years Talita Kupai records a transition from a *Ceriops* and/or *Bruguiera* zone to a narrow mixed *Avicennia* community where the boundary between mangrove and coastal woodland vegetation is direct, lacking the development of swamp or sedgeland communities as a type of ecotone. Sometime after c.2800 years BP, the vegetation sequence at Tiam Point suggests the establishment of freshwater swamp. Tiam Point also indicates the former presence of backdune swamps adjacent to mangrove communities prior to establishment of the extensive mangrove phase, between approximately 6800-6000 years BP. Here, the freshwater availability in the mid-Holocene coastal swamp supported a mosaic of vegetation in addition to mangroves, including rainforest taxa, *Melaleuca* forest and herbaceous swamp communities. Such mid-Holocene diversity is not recorded in the late Holocene. Backdune swamp environments established after c.2800 years BP supported *Melaleuca* and/or *Pandanus* growth and an extensive herbaceous ground cover. There is no late Holocene evidence at Tiam Point of *Avicennia* being more abundant subsequent to the demise of *Ceriops*/*Bruguiera* pollen as at Talita Kupai. At both sites, the recent return and increase of *Rhizophora* in the pollen assemblages is unlikely to represent a renewed tidal incursion. *Rhizophora* in the upper core samples is interpreted as pollen transported from the regional presence of well developed communities creekside or along the open coast, consistent with the present coastal range of *Rhizophora* on Mua.

INLAND: THE ESTABLISHMENT OF SWAMP ENVIRONMENTS. Although an interpretation is limited in detail, owing to inconsistencies in pollen preservation, the palaeoenvironmental study undertaken in the inland island environments of Mua demonstrates a two-phase transition in freshwater swamp vegetation. At Boigu Gawat, the initiation of a rise in the concentration of pollen from c.2500 years BP roughly coincides with a stratigraphic change from sandy clay to organic mud. In combination, the palynology and swamp stratigraphy may be interpreted as evidence for more consistently high inland freshwater tables through approximately the last 2500 years than previously.

Herbaceous plant communities existed on dune depression surfaces prior to, and as a precursor to, swamp forest formation on Mua. The earliest recorded vegetation communities at Boigu Gawat persisted through fluctuating moist-dry habitats. Prior to approximately 2500 years BP, Boigu Gawat may have been land subject to inundation. Here, water was not present long enough for wetland or swamp forest vegetation to develop resulting in an environment different to that of today. Locally, the open swamp depression was composed predominantly of *Dapsilanthus*, sedge taxa and grasses. *Melaleuca* maintained a presence in the vicinity of the herbaceous plant cover, but may have initially struggled to develop on the coarse inorganic sediments with only periodic moisture availability.

As water levels increased after 2500 years BP swamp vegetation was, at first, inconstant. A peak in Cyperaceae pollen types confirms the onset of more established swamp conditions in dune depressions. These conditions apparently changed further with a decline in herbaceous strata and development of swamp forest dominated by *Melaleuca*. Grindrod (1988) notes that herbaceous swamp taxa can vary in luxuriance and floristic makeup according to the amount of shading imposed by the tree canopy. A decline in *Melaleuca* at Boigu Gawat may suggest that the swamp, which had been expanding prior to this event, dried somewhat. The combined palynological/sedimentological evidence, however, does not support this notion. The Boigu Gawat zone 2 pollen record indicates a surge in colonisation by *Melaleuca* with increased water availability, followed by a re-establishment of the herbaceous understorey. Schulmeister (1992) proposes for Groote Eylandt that a Holocene decline in *Melaleuca* was associated with prolonged flooding of root systems. As Boigu Gawat became permanently waterlogged in the late Holocene, this suggestion is a possibility. More recently, strong representation of *Melaleuca*, *Dapsilanthus*, and for the most part, Cyperaceae, combined with a lack of evidence for interrupted sediment accumulation, suggests continuous, stable swamp forest conditions on Mua since at least 700 years BP.

It is unclear from Boigu Gawat alone as to what may have facilitated the onset of more

permanent swamp and swamp forest conditions on Mua. Nix & Kalma (1972), in an early simulation of palaeoclimates in the Torres Strait region, suggest extensive swamp environments after 3000 years BP, as a result of higher water tables and overall positive water balance as established in the early-to-mid Holocene. As an alternative theory, with increased disturbance in the regional environment slopewash would have mobilised exposed surface sediments. Such sediments may have accumulated in topographic depressions, altering drainage patterns thus creating habitats locally capable of holding water and conditions suitable for organic deposition and preservation (see Butler, 1998). In this context however, little pollen evidence is available to argue a case for or against disturbance, indicating for example a loss of woodland vegetation cover in the island interior or a trend toward more open sclerophyll communities at the coast. Tiam Point, Talita Kupai and Boigu Gawat have provided complimentary records regarding the nature of island sclerophyll environments during the Holocene, where the structure of the woodland does not appear to have altered. Likewise, the overall composition of woodland environments does not change dramatically. The dominance of Myrtaceae, principally *Eucalyptus*, has persisted through the last 7000 years. Widespread eucalypt woodland on Mua was therefore maintained from at least the early-to-mid Holocene, incorporating a ground cover dominated by grasses. Within this community, *Pandanus* is more prominent in the coastal lowlands than island interiors.

On Mua, an apparent trend coinciding with the development of swamp habitats, and suggestive of disturbances both coastal and inland, is a late Holocene increase in burning. Charcoal counts, performed in conjunction with pollen analysis, signal that fire has been a part of the dryland environments of Mua since at least the early Holocene. More specifically, a shift in charcoal deposition may be identified for each core, representing a distinct change in the frequency of fire through time. The Tiam Point and Boigu Gawat core records in particular are marked initially by low, fluctuating charcoal particle concentrations followed by a sharp increase in representation, and as such, reveal a shift from a dryland environment with occasional disturbance due to fire, to an environment where fire disturbance is common. Radiocarbon dating results indicate, in particular, a significant rise in charcoal toward the modern period, after around 700-500 years BP. Fire disturbance may be interpreted in terms of either a natural fire regime, such as that resulting from a drier and more variable climate (e.g. Kershaw et al., 2003; Haberle et al., 2001), or human influences. Certainly increased climatic variability such as that associated with the mid-to-late Holocene onset of the modern El Niño phenomenon would create circumstances suitable for ignition and subsequent erosion from exposed ground surface conditions. Given that recent archaeological discussions (David & McNiven, 2004; McNiven, 2006) outline permanent island occupation beginning 3000-2500 years BP, followed by major increases in human habitation c.800-600 years BP (the latter through midden and village site establishment, changes in social activity and Islander community mobility), burning and sediment transport, as representative of human activity is even more likely.

CONCLUSION

During the Holocene, the island of Mua was a dynamic environment within which to live, hunt, gather, and interact. Environmental resources, incorporating diverse mangrove communities and freshwater swamp access may have been variable up until the late Holocene, after c.2500 years BP. Palaeoenvironmental reconstructions applicable to Mua's coastline reveal a series of relatively short-lived, abrupt changes from mangrove to non-mangrove habitats after approximately 7000 years BP. The coastal lowlands were subsequently dominated by *Rhizophora* forest between 6000 years BP and 3000 years BP. With a decline in *Rhizophora* dominance beginning about 3000 years BP, nearshore vegetation succession involved lower tidal mangrove, upper tidal mangrove and backdune swamp communities, with variations according to local island geomorphological settings. It is suggested that coastal vegetation, and especially mangrove change, accompanied marine transgression before a stabilisation of sea levels and the initiation of onshore sediment accumulation. Inland of the coastal zone, and by 7000 years BP, Myrtaceae, predominantly *Eucalyptus*, woodland colonised Mua, maintaining a broad distribution with little change in structure or composition. Island woodland environments were, however, more frequently burned in the late Holocene, after 700 years BP in particular. Significantly, inland island environments reveal the deposition of organic material in low-lying depressions facilitating freshwater swamp expansion, beginning c.2500 years BP. Past vegetation and landscape change, and the occurrence of fire on Mua, may signal

initial island visitation and occupation (c.2500 years BP) and subsequent more permanent habitation (c.700 years BP).

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