Environmental Context for Late Holocene Human Occupation of the South Wellesley Archipelago, Gulf of Carpentaria, Northern Australia

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ABSTRACT

A 2,400 year record of environmental change is reported from a wetland on Bentinck Island in the southern Gulf of Carpentaria, northern Australia. Three phases of wetland development are identified, with a protected coastal setting from ca 2,400 to 500 years ago, transitioning into an estuarine mangrove forest from ca. 500 years ago to the 1940s and finally to a freshwater swamp over the last +60 years. This sequence reflects the influence of falling sea-levels, development of a coastal dune barrier system, prograding shorelines and an extreme storm (cyclone) event. In addition, there is clear evidence of the impacts that human abandonment and resettlement have on the island's fire regimes and vegetation. A dramatic increase in burning and vegetation thickening was observed after the cessation of traditional Indigenous Kaiadilt fire management practices in the 1940s, and was then reversed when people returned to the island. In terms of the longer context for human occupation of the southern Wellesley Archipelago it is apparent that the mangrove phase provided a stable and productive environment that was conducive for human settlement of this region over the last 1,000 years.

Keywords: palynology, fire regimes, abandonment, cyclone, Indigenous, islands.

INTRODUCTION

The South Wellesley Archipelago, located in the Gulf of Carpentaria, provides a unique opportunity to investigate late Holocene human-environment interactions in northern Australia. This island chain contains a dense archaeological record juxtaposed against rich and high integrity palaeoecological deposits for the last 2,000 years, as well as a detailed ethnographic history of the traditional Indigenous community, the Kaiadilt people. The 10 islands of the archipelago, dominated by Bentinck Island (~150 km^2) formed between 8,000 and 6,500 years ago, as they were isolated from mainland Australia by rising sea-levels (Reeves et al., 2008). Previous research and geophysical models indicate that sea-level in the southern Gulf of Carpentaria was up to 2.5 m higher than present mean sea-level (PMSL) during the culmination of the post-glacial marine transgressions (ca. 6,400 years ago) and remained close to +2 m above PMSL during the mid-Holocene high-stand, before falling smoothly to the present sea-level over the last 1,000 cal. yrs BP (calibrated years Before Present) (Rhodes et al., 1980; Chappell et al., 1982; Rhodes, 1982; Sloss et al., 2012).

Reeves et al. (2013) identifies a drying trend across the Carpentaria region during the mid-Holocene (last 5,000 years), transitioning to a more variable climate regime from 3,700 to 2,000 cal. yrs BP associated with increased El Niño-Southern Oscillation (ENSO) strength and intensity (Shulmeister, 1999; Gagan et al., 2004; Prebble, et al., 2005; Donders et al., 2007). Increased variability was followed by a subsequent amelioration from 2,000 years ago to present, although there is evidence of wetter conditions in northern Australia, associated with a strong extended La Niña-like conditions from 1,500 to 1,000 years ago (Shulmeister, 1999; Markgraf and Diaz, 2000; Rein et al., 2004, Donders et al., 2007; Mann et al., 2009; Williams et al., 2010; Moss et al., 2011). An extended El Niño-like phase resulted in significantly drier conditions from 700 to 500 years ago (Goodwin et al., 2004; Goodwin and Mayewski, 2007; Williams et al., 2010; Moss et al., 2011). Williams et al. (2010) and Moss et al. (2011) have tentatively suggested that these events may have been linked to the Medieval Climatic Optimum and the Little Ice Age events, respectively, although further research is required to verify possible teleconnections. The last 500 years were characterized by highly variable climatic and hydrological regimes across Australia linked to alterations in ENSO and the Interdecadal Pacific Oscillation (IPO) (Markgraf and Diaz, 2000; Hendy et al., 2002; Macdonald and Case, 2005; Brockwell et al., 2009; Williams et al., 2010; Moss et al., 2011).

A number of studies have examined linkages between Aboriginal settlement patterns and climate change associated with ENSO variability for the late Holocene (Turney and Hobbs, 2006; Williams et al., 2010; Moss et al., 2011). In particular, Williams et al. (2010) suggested that there was a reorganization or disruption in Indigenous resource systems between 1,300 to 1,000 years ago, associated with the extended La Niña period and over the last 500 years, related to hydrological variability linked to ENSO and IPO activity. The southern Wellesley Archipelago is an ideal site to investigate linkages between human occupation patterns and alterations in ENSO intensity and strength over the last 2,000 years for various reasons.

There are indications of some form of Aboriginal use of Bentinck Island from ca. 3500 years ago, though archaeological evidence indicates that regular occupation of the archipelago only occurred within the last 2000 years (Ulm et al., 2010). A traditional lifestyle was maintained by the Kaiadilt until 1948, when they were relocated by missionaries to nearby Mornington Island in the North Wellesley Archipelago. Several freshwater swamps on Bentinck Island provide opportunities to gain insight into late Holocene environmental change and the effects of human impacts on the local vegetation; in particular, this study examines Marralda Swamp. Sedimentological, pollen and charcoal analysis explores the influence of changes in sea-level and climate on this important wetland resource over the last ca. 2,400 years, providing a crucial environmental context for understanding late Holocene human occupation of the South Wellesley Archipelago.

STUDY SITE

Bentinck Island, part of the Wellesley Archipelago, is located in the southern Gulf of Carpentaria, northern Australia (Figure 1). The Wellesley Archipelago is characterized by a tropical climate, with a marked wet summer and a dry winter, a mean annual high temperature of 30.4ºC, a mean annual low temperature of 22.1ºC and average annual rainfall of 1199 mm, with 97% of the precipitation falling during the October to April wet season (BOM, 2014a). This rainfall pattern is governed by the movement of the Inter-Tropical Convergence Zone (ITCZ), which migrates south during the austral summer bringing with it monsoonal rain and tropical cyclones (associated with extreme rainfall events and storm surges). The region is highly sensitive to ENSO variability, with significant reductions in rainfall during El Niño years when the southward movement of the ITCZ and tropical cyclone activity is much reduced, and significant increases in precipitation during La Niña years associated with the more southerly movement of the ITCZ, as well as increased cyclone activity (Nicholls, 1992). Along with the local topography, this climatic regime is a significant determinant of the local vegetation. Bentinck Island is a low-lying island, with its highest point around 24 m above PMSL. Much of it less than 5 m above PMSL and is dominated by mangrove forests, salt flats and claypans, while areas above this are occupied by savanna (mostly open eucalypt forest with a grassy understory) and spinifex grasslands. There are several areas of freshwater and estuarine mangrove swamps, with Marralda Swamp located in the southeast of the island forming the basis of this study (Figure 1).

Marralda Swamp is a freshwater swamp (Figure 2) that has formed as a series of channels in the swales of a coastal dune field 1 to 3 m above PMSL, with the dune system extending further inland (about 500 m) and reaching an elevation of 7 m above PMSL. These channels are interconnected, joining a small creek to the west and a claypan to the east. There is a three hectare area of mangroves, associated with the small creek, about 500 m to the west and there appears to be a former channel that connected the mangroves with the Marralda Swamp. A series of prograding coastal dunes separate the swamp from the modern coastline by 200 m. The dominant vegetation is a mixture of *Melaleuca* and *Pandanus* forest, with significant aquatic vegetation, particularly *Typha* and isolated mangroves. Archaeological excavations on the ridges seaward of Marralda at Murdumurdu revealed shallow shell midden deposits with AMS radiocarbon dating on marine shell for occupation returning estimates of between 320 to 330 years ago. A shell midden complex at Jarrkamindiyarrb ca.700 m to the east of

Marralda has returned a basal age of 3,483 cal. yrs BP, with the majority of archaeological material for this site complex dating to the last 1,000 years (Ulm et al., 2010).

Anthropologist/ethnographer Walter E. Roth (1901:13) visited this area in 1901, noting Kaiadilt campsites and evidence of *Pandanus* consumption, suggesting that “the Pandanus forms the stable vegetable food”. Nearly a century earlier in late 1802, Matthew Flinders (1814:146) noted that “there were some places in the sand and in the dry swamps, where the ground had been so dug up with pointed sticks that it resembled the work of a herd of swine”. Nicholas Evans (The Australian National University, pers. comm., 2014) points out that this probably describes the furrows, called *kurrngu* in Kayardild (the Kaiadilt language), resulting from the common procedure of digging up the spike-rush corms of *Eleocharis dulcis*, known in Kayardild as *damuru* and in Mornington Island Aboriginal English as *panja* (see Evans, 1992:88).

The available ethnographic records for the region suggest Kaiadilt people traditionally maintained a regular firing regime. Roth (1901) reported “a long line of fires in full blaze”. After fieldwork in 1960 Tindale (1962a:280) wrote:

“*Being situated near the drier boundary for savannah, tall grass predominates over patches of sparse deciduous woodland. While aborigines* [sic] *were present these open areas with* Themeda *grass, etc., which grew to heights of four to six feet after rain, were fired each year. In the 12 years since their departure this burning had only happened once, about May, 1959, when a party of Bentinck Islanders taken across on a brief holiday visit set fire to a large area on the south-eastern coast, thus in one area restoring a semblance to the conditions they had maintained for many centuries.”*

During a visit to Sweers Island in August 1982 Memmott (1982:11) reported that the three traditional owners accompanying him fired the entire island.

The South Wellesley Kaiadilt population was removed by missionaries in 1948 to Mornington Island in the North Wellesley Archipelago, reportedly as a direct consequence of water shortages caused primarily by a cyclonic tidal surge in February 1948 of up to 3.6 m and subsequent salinization of water sources, though Tindale (1962b:299-300) noted that high population densities, social conflict and a period of reduced rainfall in the mid-1940s were also contributing factors (see also Memmott, 1982:14). Except for rare brief visits (Tindale, 1962a, 1962b, 1963; Memmott, 1982), the South Wellesley Archipelago were effectively devoid of human presence for a 35 year period until the Kaiadilt returned to Bentinck Island to develop an outstation in 1984 at Nyinyilki (Figure 1), in the southeast corner where they have maintained a semi-annual presence ever since.

METHODS

Four cores were collected along an east-west transect using a D-section corer from Marralda Swamp (Figures 2, 3 and 4). The MARR02 core was collected in July, 2010, while the other three cores (MARR01, MARR03 and MARR04) were collected in July 2012. This paper focuses primarily on MARR02, though all four are referred to so as to identify common stratigraphic units and provide information on swamp development (Figure 4). All cores were analysed at the School of Geography, Planning and Environmental Management laboratory at The University of Queensland. The MARR02 (80cm in depth) and MARR03 (50cm in depth) cores were collected from an area with 50cm of water depth and covered by *Typha* and fringed by *Melalaeuca* and *Pandanus* trees. The MARR01 (50cm in depth) record was collected from a stand of mangroves located at the eastern edge of the swamp with very little standing water, while the

MARR04 (47cm in depth and 50cm of water depth) core was taken from the northern edge of the swamp and consisted of similar vegetation to the MARR02 /MARR03 location.

Radiocarbon dating (^{14}C) of the cores from MARR01, 02, 03 and 04 were processed at the University of Waikato Radiocarbon Dating Laboratory and the Australian Nuclear Science and Technology Organization (ANSTO) facility (Table 1). Radiocarbon ages were calibrated using OxCal 4.2.3 (Bronk Ramsey, 2009) and the IntCal13, Marine13 (Reimer et al., 2013) and the SHZ3 bomb curve extension (Hua et al., 2013) datasets, with a ΔR of -49±102 for marine samples (Ulm et al., in press). All calibrated ages are reported at the 95.4% probability distribution. The top 20cm of MARR04 was Lead-210 dated at ANSTO using alpha spectrometry following the methodology of Harrison et al. (2003). Two grams of dried sediment spiked with ^{209}Po and ^{133}Ba yield tracers was leached, releasing polonium and radium. Total ^{210}Pb is assumed to be in secular equilibrium with the ^{210}Po activity and the supported ^{210}Pb to ^{226}Ra activity. Unsupported ^{210}Pb was produced by subtracting the ^{226}Ra results from the total ^{210}Pb activity. The sedimentation rate was calculated using the Constant Rate of Supply (Appleby and Oldfield, 1978) and constant initial concentration (CIC) (Robbins and Edgington, 1975; Goldberg et al., 1977) methods.

The MARR02 sediment core was sampled for pollen and charcoal analysis at 5 cm intervals using the technique described by van der Kaars (1991) and discussed further in Moss (2013). Sodium pyrophosphate was used to disaggregate the clay sediments, which were then sieved using a 250 micron mesh to remove the sands and larger organic fragments and an 8 micron mesh to remove the clay fraction. Sodium polytungstate (specific gravity of 1.9) was then used to separate the lighter organic fraction (containing pollen and charcoal) from the heavier minerogenic fraction. Acetolysis (9:1

acetic anhydride to concentrated sulphuric acid) darkened the pollen grains and removed excess organic material. The samples were mounted in glycerol on a microscope slide and counted using a compound light microscope under 400 times magnification, with the pollen sum consisting of a minimum of 300 pollen grains or two completely counted slides. Micro charcoal counts included all black angular particles above 5 µm in diameter across three slide transects. Exotic *Lycopodium* spores were counted with charcoal particles to calculate charcoal concentrations per cubic cm (Wang et al., 1999), as well as being counted with the pollen grains for pollen concentration values per cubic cm. The pollen diagram was produced using TGView (Grimm 2004), including pollen and charcoal counts, and lithology for each core (see Figures 6). The pollen diagram is divided into zones based on the results of a stratigraphically constrained classification undertaken by CONISS (Grimm 1987, 2004) on taxa (raw counts) contained within the pollen sum.

Pollen concentrate samples (that did not undergo acetolysis), which were used for ^{14}C AMS dating were sent for analysis (in distilled water). Bulk sediment samples had rootles removed and were treated with acid and alkali to remove carbonates and humic acids, the remaining organic material was processed to graphite for dating.

RESULTS

Sedimentology and Chronology

The Marralda cores consist of three sedimentological units (Figure 4). The lowest is a fine- to medium-grained muddy sand, with large amounts of shell hash material, indicating a near-shore coastal environment deposited between ca. 2,400 to 500 years ago based on the four basal ^{14}C AMS dates. This deposit grades into the second, middle unit, which are black and very fine-grained silts that formed from around 500 years ago (based on two ^{14}C AMS dates). The uppermost sedimentological unit is an organic rich swamp deposit, forming over the last 70 to 60 years (based on ^{210}Pb dates from MARR04) (Figure 5). This is supported by two modern radiocarbon dates, at 40 and 45 cm, from the MARR02 core, as it is highly unlikely that up to 45 cm of sediment would have been deposited in three years (based on the 0 to 3 cal. yrs BP age calibration) and suggesting that these sediments would have formed over the last 50 to 60 years (based on the 53 cal. yrs BP age calibration). Differences between the length and depth of each unit across the east-west transect suggest complex swamp development and highlight the need for comprehensive studies of local areas.

Pollen and Charcoal

A total of 31 pollen taxa throughout the record are divided into five vegetation groups: arboreal taxa, herbs, pteridophytes, aquatics and mangroves. Analysis of the pollen taxa from the MARR02 core identified four zones (Figure 6), each of which is discussed in detail below.

MARR A (80 to 60cm)

The basal zone is characterized by fine to medium-grained siliciclastic sediment with abundant shell hash suggestive of a coastal environment. A radiocarbon age determination on the basal shell hash was dated to 2430 cal. yrs BP. Accordingly, contemporary sea-level at the time of deposition would have been close to +2m above PMSL to allow deposition of the near-shore, shell rich siliciclastic sediment. This interpretation is further supported by the very low pollen concentrations, with the pollen likely derived from a nearby swamp community and consisting primarily of grass, *Pandanus* and *Typha*. Mangrove values (mainly *Rhizophora*, *Exoecaria* and *Avicennia marina*) increase from 65cm, while the presence of Asteraceae (Tubuliflorae) and monolete fern spores occur at 75cm. Other low value taxa observed in this zone include *Melaleuca*, *Eucalyptus*, Casuarinaceae, *Callitris*, *Acacia*, chenopods and *Ceriops/Bruguiera*. Charcoal values are very low in this zone.

MARR B (60 to 35cm)

MARR B correlates to the mangrove muds and is dominated by mangrove pollen taxa, primarily Rhizophoraceae and *Avicennia marina*; however, other mangrove taxa, such as *Excoecaria*, *Lumnitzera*, *Nypa* and *Xylocarpus* are also present. *Pandanus* and Poaceae are an important component of the pollen sum but there is a clear decline in *Typha* abundances, with a corresponding increase in chenopod values. There is a slightly increased representation of arboreal taxa, particularly *Melalaeuca*, *Eucalyptus* and Casuarinaceae, and the largest number of pteridophyte taxa (*Lycopodium*, *Gleichenia* and monolete fern spores) in the record. A radiocarbon age determination of 491 cal. yrs BP was obtained at 55cm, and pine pollen (potentially related to European settlement in the region in the 1860 to 1870s) is observed at 50cm; this age estimate is further supported by two modern radiocarbon ages at 45 and 40cm. Pollen concentrations increase in this zone, reaching above 200,000 grains per cm^3 from 45 to 35cm, while charcoal concentrations remain very low.

MARR C (30 to 20cm)

A clear change in sedimentation from mangrove muds to organic rich estuarine/swamp clays occurs in MARR C, with the latter continuing into the MARR D zone. This sedimentary change is also reflected in the pollen record, with a clear decline in mangrove abundances, along with increase in grass and *Pandanus*, as well as an initial increase in *Typha* from 35 to 30cm, which then declines. There is also a clear shift in the dominant arboreal taxa, with *Callitris* replacing *Melaleuca*, *Eucalyptus* and

Casuarinaceae. There is a peak in monolete fern spores at 20cm and the last occurrence of Asteraceae in the record at 30cm. Pollen concentrations sharply decline and this zone observes the highest charcoal values in the record at 25 to 20cm (around one million particles per cm^3).

MARR D (20 to 0cm).

The final zone observes a sharp decline in *Pandanus* representation, with a corresponding increase in grass and *Typha* values. An increase in other aquatic taxa (particularly Cyperaceae) and mangroves is seen and Myrtaceae/Casuarinaceae replaces *Callitris* as the dominant arboreal taxa. Pollen concentrations maintain values consistent with the previous zone, except for the top sample (0cm), which has the highest pollen representation in the record. Charcoal values sharply decline (~200,000 particles per cm^3), although they are still higher than in the MARR A and B zones.

DISCUSSION

Wetland Formation and Development

This study of the Marralda Swamp complex provides insights into wetland development on Bentinck Island and the influence that late Holocene sea-level changes, prograding shorelines and cyclone activity had on the swamp formation and subsequent development. The four cores obtained from Marralda Swamp provide a ca. 2,400 year palaeoenvironmental record for the southeast coast of Bentinck Island.

Three phases of wetland development are indicated at Marralda Swamp. The first occurred between ca 2,400 to 500 years ago and reflects a coastal setting, with large amounts of shell hash and very low pollen concentrations (between 280 to 1370 grains per cm^3). Results indicate that the initial phase of the geomorphic evolution of the

Marralda Swamp reflect a near-shore beach environment linked to higher sea-levels. There is evidence from other places that sea-levels during the Holocene highstand were at least 2 m above present mean sea-level in the southern Gulf of Carpentaria (ca. 4,500 years ago) and gradually dropped to present levels from ca. 2,000 years ago (Nakada and Lambeck, 1989; Reeves et al., 2008; Sloss et al., 2012; Lewis et al., 2013). The basal unit in the Marralda record, comprising fine- to medium-grained siliciclastic sediments and a large volume of shell hash, may reflect the influence of the Holocene sea-level highstand.

With falling sea-level from ca 2,400 years ago, coastal dunes and northwest prograding beach ridge systems developed parallel to the swamp, protecting it from wave action. A similar situation was identified at Eighteen Mile Swamp on North Stradbroke Island, subtropical eastern Australia, with a prograding dune system (developed from longshore drift) providing a protected coastal estuary, that transitioned into a mangrove swamp between around 2,000 to 600 years ago and then into a freshwater wetland (due to groundwater input) around 600 to 400 years ago (Boyd, 1993; Mettam et al., 2011). It is interesting to note that, while the pollen concentrations in this zone are relatively low, they are significantly higher than what would be expected from an exposed beach setting. This finding is further supported by the range of pollen taxa present, which are derived from freshwater and mangrove swamp species. The presence of wetland taxa suggests some connection to nearby swamp environments, which may have been located at a higher elevation during the higher sea-levels of this time period.

The second phase is related to the development of a mangrove swamp around 500 years ago, which then dominated until the 1940s. This mangrove wetland would have formed in a protected environment, perhaps supporting the barrier setting described above, as mangrove forest development requires protection from wave action and suitable silt substrate deposition (Grindrod et al., 1999, 2002). Sea-level history is an important factor and the development of the mangroves could be related to falling sea-levels and/or a prograding coastal system following the Holocene sea-level highstand. The abundance of mangroves, particularly the relatively high abundances of the poorly dispersed *Avicennia marina* pollen (Crowley et al., 1994), suggests a large area of well-established mangrove forest dominating the Marralda Swamp area until the late 1940s. It may have been very similar to the mangrove forest situated to the west of the Marralda Swamp on nearby Mulla Island. A sediment core has been extracted from the latter site and has returned a similar age to the base of the mangrove phase at Marralda (ca. 500 to 400 years ago), suggesting a more extensive mangrove forest occurred across Marralda Swamp until the late 1940s.

The final phase involved the development of a freshwater swamp dominated by *Typha* and *Pandanus*. The return of modern radiocarbon ages indicates that the Marralda wetland system may have developed as a result of cyclone activity, which allowed the establishment of a barrier, blocking tidal seawater flows and allowing groundwater to freshen the site. As discussed previously, one of the key climatic factors that influence the environment of the Wellesley Archipelago are cyclones and in February 1948 an unnamed cyclone crossed directly over Bentinck Island. The Kaiadilt people described a storm surge (estimated to be approximately 3.6 m high) covering all but the highest parts of the island (Tindale, 1962a; BOM, 2014b). The storm surge covered campsites and water sources, forcing their relocation to Mornington Island in the North Wellesley Islands (Callaghan, n.d.).

Hopley (1974) examined the effects of cyclone damage on Queensland coastal regions after the impact of Cyclone Althea that affected Townsville in 1971. Large-scale damage to lagoonal *Bruguiera*/*Rhizophora* and in young mangrove stands due to sediment erosion and chenier progradation was observed, as well as mortality in *Avicennia* stands 12 months after the cyclone struck. Similarly, Nott et al. (2013) identified beach ridge development and wash-over deposits associated with Cyclones Larry (2006) and Yasi (2001) on the northeast coast of Queensland. The impact of a severe cyclone has been observed in a 8,000 year old palynological record from Lizard Island off the northeast Queensland coast by Proske and Haberle (2012), with a clear ecosystem change from a *Rhizophora*-dominated mangrove forest and open, mixed sclerophyll forest inland to a *Sonneratia* and *Bruguiera* forest that reflects enhanced estuarine conditions. The Hopley (1974), Proske and Hablerle (2012) and Nott et al. (2013) studies clearly demonstrate the impacts that severe cyclones can have on coastal systems. The records from Bentinck Island also reflect this, further demonstrating the potential for the palaeoenvironmental record to detect extreme storm events.

Environmental Context for Late Holocene Human Occupation

The Marralda Swamp record reveals dramatic environmental alterations that appear to be directly linked to the abandonment and subsequent resettlement of Bentinck Island between the late 1940s and early 1980s. As discussed previously, the 1948 cyclone resulted in profound damage to freshwater resources on the island that directly contributed to the resettlement of the Kaiadilt people on Mornington Island. Alterations in vegetation and fire history are apparent after this, with a significant increase in charcoal and arboreal taxa, particularly *Pandanus,* suggesting vegetation thickening and larger scale or greater burning. This was followed by a decline in both *Pandanus* and burning at 15 cm, most likely reflecting traditional fire management practices as the Kaiadilt people returned to the island in the early 1980s and loosely supported by the

^{210}Pb chronology from the MARR04 core.

This result firstly suggests that human abandonment and resettlement can be detected in palaeoecological records and that these methods may be useful in assessing human presence over longer time periods for island environments, which has been suggested from the archaeological record for a number of islands (e.g. Bowdler, 1995; Sim and Wallis, 2008). Secondly, it has important implications for understanding possible driving mechanisms for vegetation thickening across the northern Australian savanna. Russell-Smith et al. (2003) suggested that a major cause of vegetation thickening is the shift away from traditional Aboriginal fire management strategies across the region. The results from the Marralda record appear to support this, as well as suggesting that it is a relatively rapid process but the return of a traditional fire management regime can quickly reverse the thickening process. Further research is necessary to confirm whether this is a regional trend. Research by Moss et al. (2013) from multiple sites across North Stradbroke Island found a human palaeoecological signal depends on the wetlands local environment and setting in the landscape and that caution is needed when basing regional environmental changes on a single site.

In terms of the longer-term context for human occupation of the southern Wellesley Archipelago it appears that changes in sea-level and associated swamp development played an important role in settlement patterns. In particular, the majority of archaeological deposits located close to Marralda Swamp date to within the last 1,000 years, suggesting that the mangrove phase may have been the most conducive period for occupation at Marralda Swamp, with a relatively stable and productive estuarine environment being a focus for subsistence. Higher resolution palaeoecological analysis is required to detect if alterations in ENSO and IPO frequency and intensity impacted the Marralda Swamp environment and in turn Kaiadilt settlement patterns over the last millennia. However, it is interesting to note that the most severe impact appeared to be the 1948 cyclone event, which not only contributed to the resettlement of the Kaiadilt people but profoundly altered the Marralda Swamp (i.e. shifted to a freshwater swamp). This suggests that the Bentinck Island environment can be dramatically impacted by severe short-term events (i.e. cyclones) and was a key issue to which the Kaidalt had to adapt to with their subsistence strategies.

CONCLUSION

This study of the Marralda wetland on Bentinck Island, Gulf of Carpentaria provides insights into late Holocene wetland formation and subsequent development, particularly the influence of sea-level alterations, prograding shorelines and extreme events (in this case a severe cyclone). In addition, these wetland records provide a picture of vegetation change and alterations in fire regimes, which in turn reflect different environmental factors, i.e. changes in human settlement patterns. Further research is required to enhance the palaeoecological and archaeological picture that is emerging from Wellesley Archipelago in particular and the seasonally dry northern Australian tropics more broadly. Specifically, high-resolution analysis of the wetlands of the South Wellesley Archipelago across a range of sites will provide a broader picture of regional-scale alterations. Linking them to the extensive archaeological record found across the archipelago will significantly improve understanding of human-environment interactions for the late Holocene period, which will have direct implications for addressing contemporary issues facing northern Australia, such as vegetation thickening and sustainable fire management.

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Table

Core and Depth (cm)	Depth (cm)	Lab. Code	$\delta^{13}C$	C^{14} Age years BP	$F^{14}C$ %	Calibration Curve	Calibrated Age (95.4%) (cal. yrs BP)	Median (cal. yrs BP)
MARR01 Bulk Sediment	49-50	OZR 376	-25.1 ±0	465±35	94.37 ± 0.37	INTCAL13	606-532 (95.4%)	575
MARR02 40 Pollen Concentrate	38-40	OZO-075	-23.7 ±0.1	*Modern	105.68±0.4	SHZ3	53 (9.4%) 3-0 (86%)	53
MARR02 45 Pollen Concentrate	45-47	Wk-38216	NA	*Modern	105± 0.4	SHZ3	53 (29.5%) 2-0 (65.9%)	53
MARR02 55 Mangrove Mud	55-60	Wk-38884	NA	364±26	95.6± 0.3	INTCAL13	559-483 (52.5%) 455-376 (42.9%)	491
MARR02 80 Shell Hash	75-80	Wk-38885	2.3±0.2	2611±25	72.2± 0.2	MARINE13	2740-2167 (95.4%)	2430
MARR03 Bulk Sediment	49-50	OZR 374	-28.1 ±0.2	650 ± 30	92.24 ± 0.3	INTCAL13	732-686 (43.5%) 669-617 (51.9%)	661
MARR04 Bulk Sediment	46-47	OZR O35	-23.7 ± 0.3	1240 ± 30	93.11 ± 0.29	INTCAL13	1328-1232 (61.3%) 1225-1136 (34.1%)	1252

Table 1. AMS C^{14} Ages for the Marralda (MARR) swamp cores. Dates were undertaken at the University of Waikato Radiocarbon Dating Laboratory and the Australian Nuclear Science and Technology Organization facility. Radiocarbon ages were calibrated using OxCal 4.2.3 (Bronk Ramsey 2009) and the IntCal13 or Marine13 (Reimer et al. 2013) and the SHZ3 bomb curve extension (Hua et al. 2013) datasets, with a ΔR of -49±102 for marine samples (Ulm et al. in press). All calibrated ages are reported with a 95.4% probability distribution.

ANSTO ID	**Depth (cm)**	**Total Pb-210 (Bq/kg)**	**Supported Pb-210 (Bq/kg)**	**Unsupported Pb-210 (Bq/kg)**	**CRS model Mass Accumulation Rates (g/cm^3/year)**
P486	0 – 1	38±2	5.2±0.5	33±2	0.32±0.02
P487	2 – 3	29±1	1.7±0.2	27±1	0.33±0.02
P488	5 – 6	28±1	2.6±0.3	26±1	0.26±0.02
P489	10 – 11	14±1	2.5±0.3	11±1	0.39±0.04
P490	15 – 16	14±1	4.6±0.4	9±1	0.32±0.04
P491	20 - 21	13±1	2.5±0,2	11±1	0.15±0.02

Table 2: MARR04 Total (^{210}Po), Supported (^{226}Ra) and Unsupported (^{210}Po – ^{226}Ra) ^{210}Pb (Bq/kg) values. Mass accumulation rate (g/cm^3/year) calculated using the Constant Rate of Supply model.

Figure Legends

Figure 1. Map of the Southern Wellesley Archipelago, with the location of the Marralda Swamp on Bentinck Island. The shaded areas reflect lowland areas (less than 5 m above sea-level).

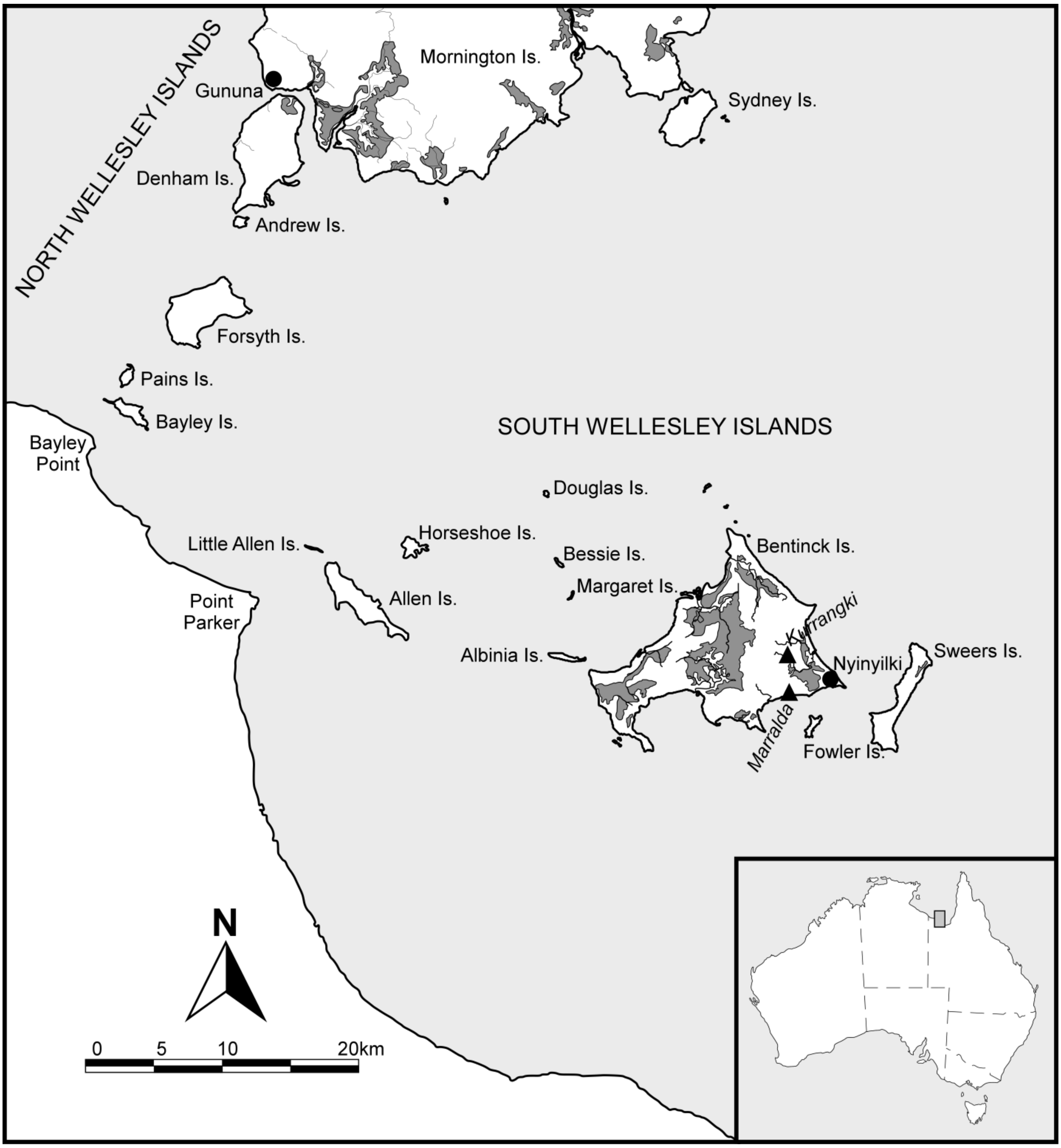
Figure 2. Map of the Marralda Swamp core sites.

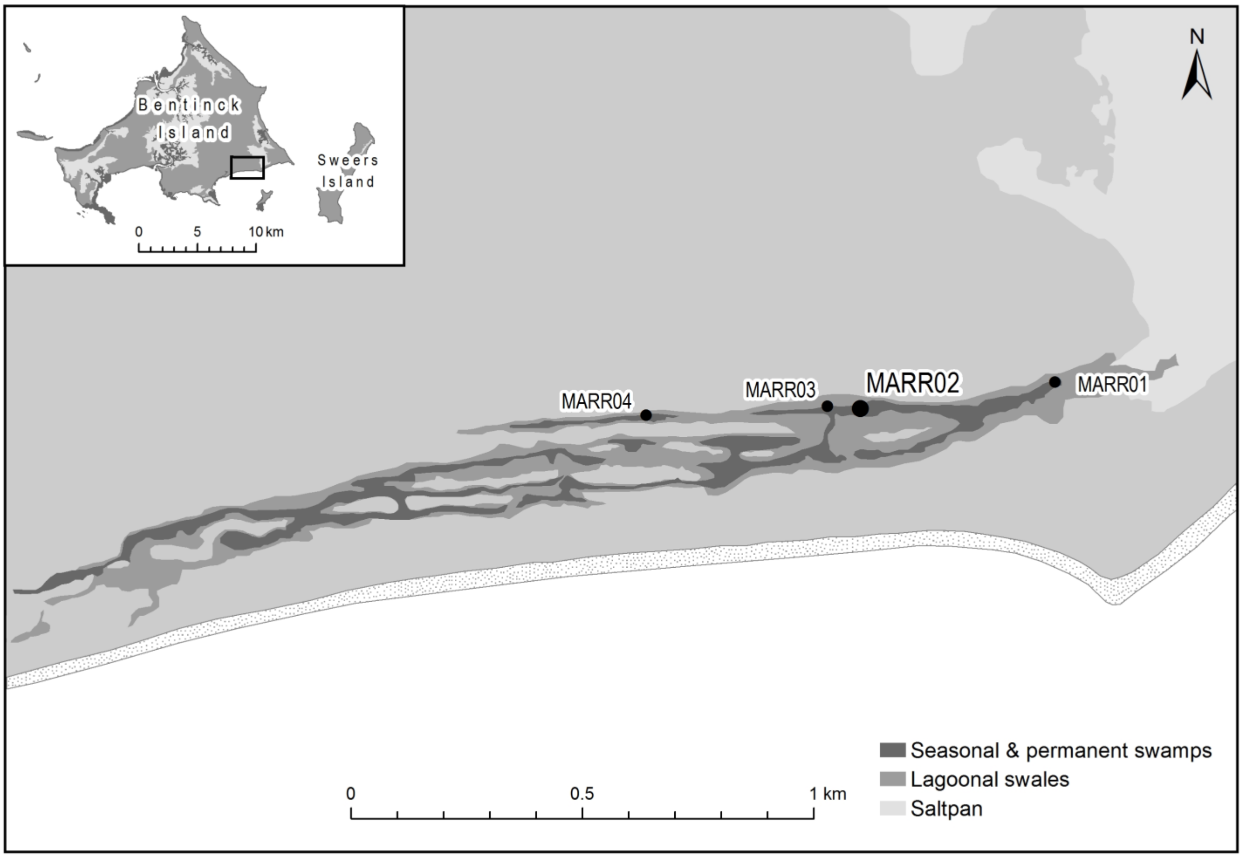
Figure 3. Photographs of the Marralda core sites. Top is the location of the MARR01; centre is the location of the MARR02 and MARR03 cores; and the bottom is the location of the MARR04 core.

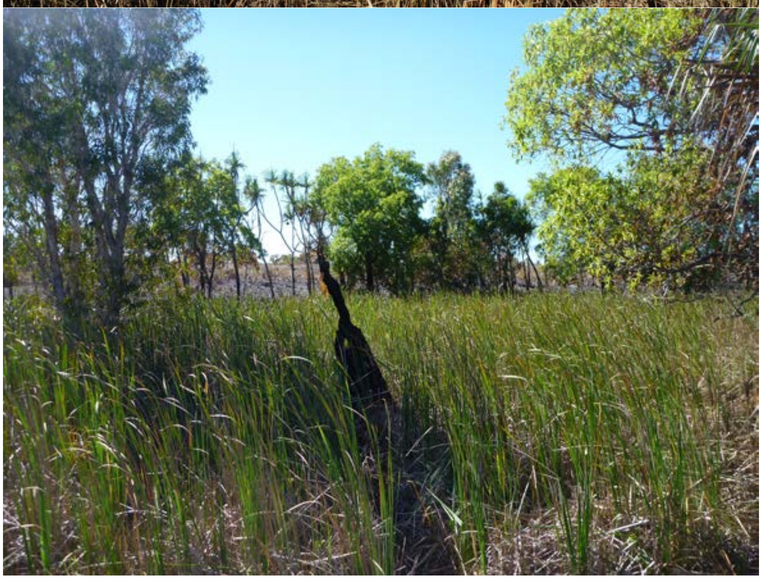
Figure 4. Sedimentological profile of the Marralda cores and ages are in cal. yrs BP.

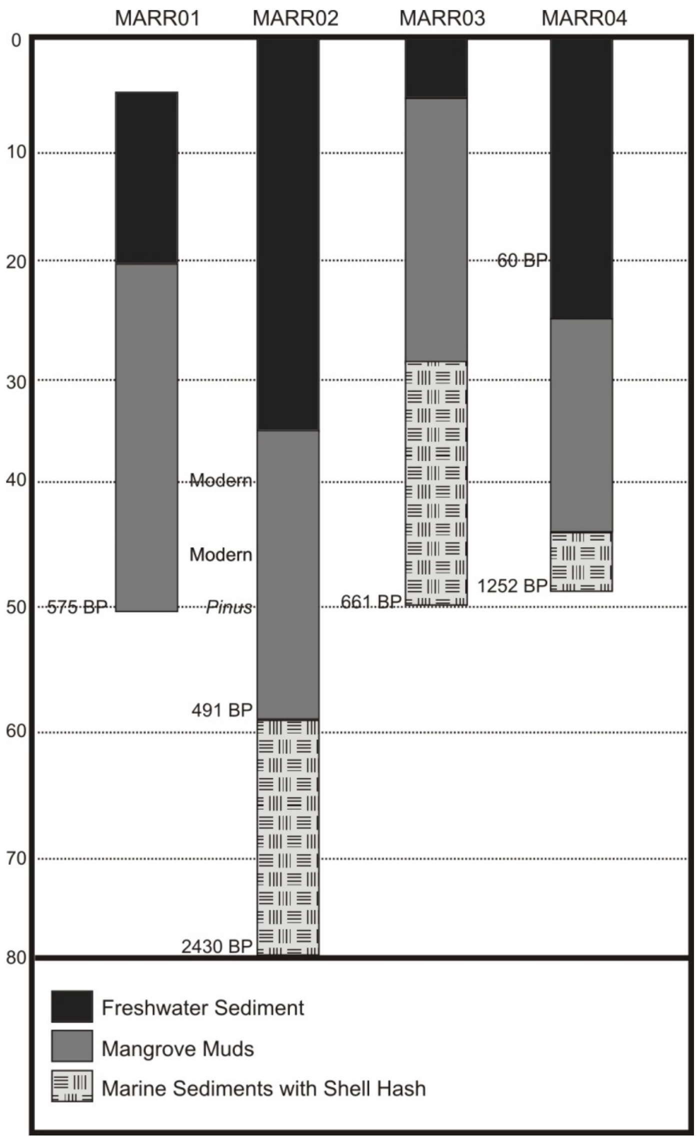
Figure 5. MARR04 ^{210}Pb dated sediment age against depth calculated with the constant initial concentration (black diamonds) and constant rate of supply (grey diamonds) method.

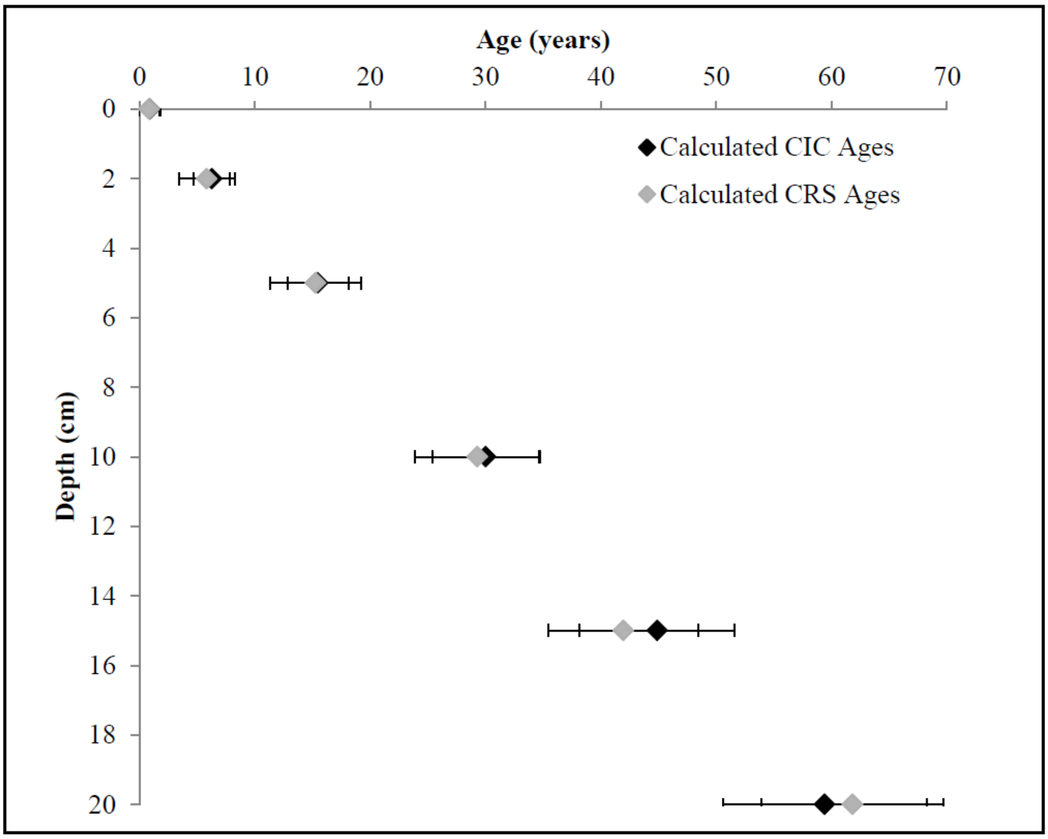
Figure 6. Pollen diagram for the MARR02 Swamp core. The + symbols reflect pollen percentages below 1.5% and the ages are in cal. yrs BP.

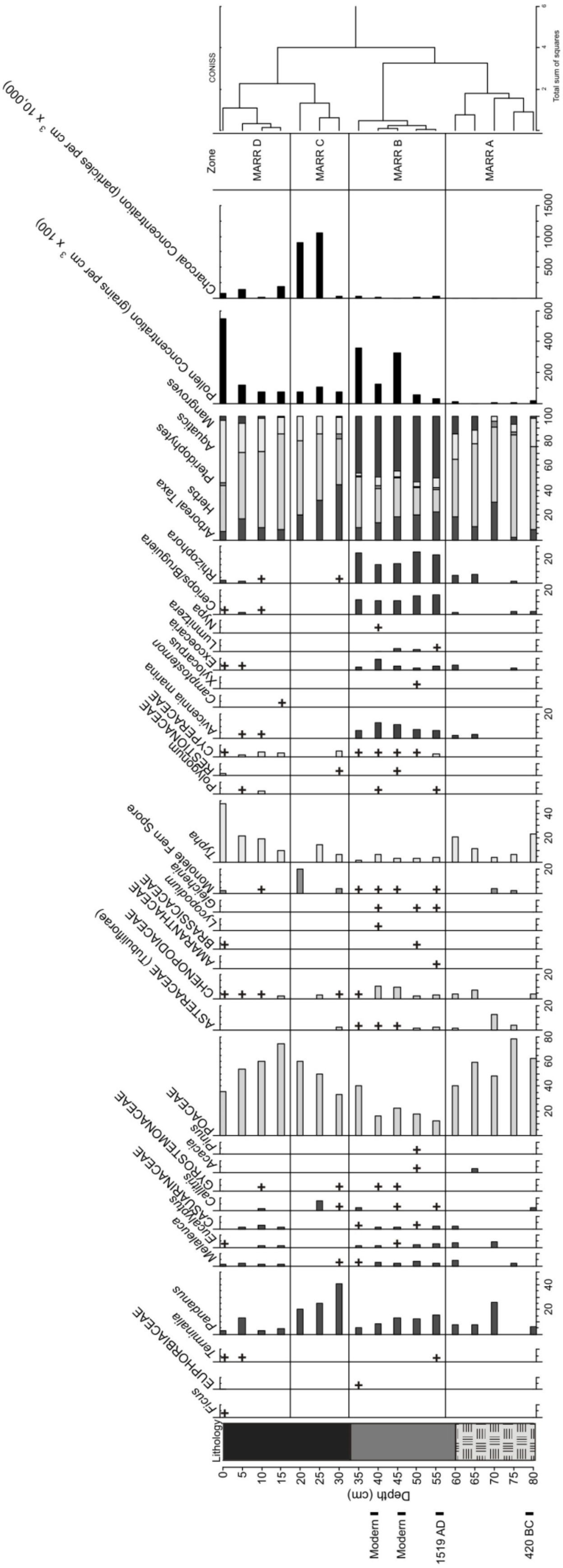

NORTH WELLESLEY ISLANDS
Mornington Is.
Gununa
Sydney Is.
Denham Is.
Andrew Is.
Forsyth Is.
Pains Is.
Bayley Is.
Bayley Point
SOUTH WELLESLEY ISLANDS
Douglas Is.
Horseshoe Is.
Little Allen Is.
Bessie Is.
Bentinck Is.
Margaret Is.
Allen Is.
Point Parker
Kurrangki
Albinia Is.
Nyinyilki
Sweers Is.
Marralda
Fowler Is.
N
0 5 10 20km


Bentinck
Island
Sweers
Island
0 5 10 km
N
MARR04
MARR03
MARR02
MARR01
Seasonal & permanent swamps
Lagoonal swales
Saltpan
0 0.5 1 km




MARR01
MARR02
MARR03
MARR04
0
10
20
30
40
50
60
70
80
60 BP
Modern
Modern
575 BP
Pinus
661 BP
1252 BP
491 BP
2430 BP
Freshwater Sediment
Mangrove Muds
Marine Sediments with Shell Hash


Age (years)
0
10
20
30
40
50
60
70
Depth (cm)
0
2
4
6
8
10
12
14
16
18
20
Calculated CIC Ages
Calculated CRS Ages


Ficus
EUPHORBIACEAE
Terminalia
Pandanus
Melaleuca
Eucalyptus
CASUARINACEAE
Callitris
GYROSTEMONACEAE
Acacia
Pinus
POACEAE
ASTERACEAE (Tubuliflorae)
CHENOPODIACEAE
AMARANTHACEAE
BRASSICACEAE
Lycopodium
Gleichenia
Monolete Fern Spore
Typha
Polygonum
RESTIONACEAE
CYPERACEAE
Avicennia marina
Camptostemon
Xylocarpus
Excoecaria
Lumnitzera
Nypa
Ceriops/Bruguiera
Rhizophora
Arboreal Taxa
Herbs
Pteridophytes
Aquatics
Mangroves
Pollen Concentration (grains per cm 3 x 100)
Charcoal Concentration (particles per cm 3 x 10,000)
Zone
MARR D
MARR C
MARR B
MARR A
CONISS
Total sum of squares
Lithology
Depth (cm)
Modern
Modern
1519 AD
420 BC