# Polynesian Plant Introductions in the Southwest Pacific: Initial Pollen Evidence from Norfolk Island

MIKE K. MACPHAIL, GEOFFREY S. HOPE AND ATHOLL ANDERSON

Department of Archaeology & Natural History, Research School of Pacific and Asian Studies,
Australian National University, Canberra ACT 0200, Australia

Macphail@coombs.anu.edu.au

geoff.hope@coombs.anu.edu.au

aja@coombs.anu.edu.au

ABSTRACT. Thick organic swamp sediments, buried under land fill on Kingston Common, preserves evidence of the Norfolk Island flora and vegetation back to the middle Holocene and probably much earlier times in the Late Quaternary. These sediments provide (1) a bench mark against which the impact of humans on the flora and vegetation of a long-isolated island can be assessed and (2) a means of determining whether particular plant genera and species are introduced or native to the island. Although sediments contemporary with Polynesian occupation about 800 years ago were destroyed by European draining and cultivation of the swamp during the early nineteenth century, the pollen data indicate that New Zealand flax (*Phormium tenax*) was introduced to Norfolk Island by Polynesians. Other putative exotics such as Ti (*Cordyline*), a bull-rush (*Typha orientalis*) and, less certain, herbs such as the sow thistle (*Sonchus oleraceus*), were part of the native flora long before the earliest recorded Polynesian settlement. Wildfires have been part of the landscape ecology of Norfolk Island since at least the middle Holocene.

Like Europeans, Polynesians have been responsible for the spread of exotic plants into the southwest Pacific. Obvious examples are food species such as bananas (*Musa paradisica*), coconuts (*Cocos nucifera*) and sweet potato (*Ipomoea batatas*). Less clear-cut examples are the New Zealand flax (*Phormium tenax*), Ti (*Cordyline*) and the sow thistle *Sonchus oleraceus*. European commensals found include dandelion (*Taraxacum officinale*) and plantain (*Plantago lanceolata, P. major*).

Norfolk Island (29°02'S 167°56'E) lies too far south for coconuts to survive (see Hoare, 1988: 18). However, when first visited by Europeans in A.D. 1774 (James Cook) and A.D. 1788 (Phillip King), large numbers of banana trees were found growing along a freshwater stream flowing from Arthur's Vale into the Kingston Swamp on the south coast (Fig. 1). New Zealand flax covered rocky outcrops and sea cliffs in the same area (references in Hoare, 1988). Hoare (1988: 19) lists *Sonchus oleraceus*, palm hearts (*Rhopalo-*

*stylis baueri*) and the fruits of the Screw Palm (*Freycinetia*) as a food plant available to Polynesian colonists. *Sonchus* was amongst the edible species collected by Cook's crew in 1774 (Hoare cited in Hicks, 1988: 165). Other suggested early introductions include one of the more common *Hibiscus* species on Norfolk Island (*H. diversifolius*), *Persicaria decipiens* (no common name) and a bull-rush (*Typha orientalis*) (Wilson, 1994).

Clearing and other forms of landscape disturbance have allowed many European exotics and some native shrubs to become invasive (Green, 1994: 2–5). Examples of the latter are the Chaff-flower (*Achyranthes aspera*) and probably the Shrubby Creeper (*Muehlenbeckia australis*). Native trees are suggested to have formed three major forest types in 1788 (Gillman and Helman cited in Green, 1994: 5). These are: (1) *Rhopalostylis baueri–Cyathea* Palm Forest lining narrower gullies and steeper moist slopes; (2) Broadleaf Hardwood Forest growing on less steep slopes and shaded areas (species suggested to have been particularly abundant (Hicks, 1991) are *Elaeodendron curtipendulum* (Maple), *Nestigis apetala* (Ironwood), *Rapanea ralstoniae* (Beech) and *Baloghia inophylla* (Bloodwood)); and (3) Gymnosperm Forest, dominated by *Araucaria heterophylla* (Norfolk Island Pine) growing on the drier and more exposed/infertile sites.

Most of these plants produce distinctive pollen grains and the presence of cultigens and commensals provides a complementary method to archaeology for detecting the presence of early human settlement on Norfolk Island. One site which preserves a long-term pollen record of the Norfolk Island flora and vegetation is Kingston Swamp (Fig. 1) where thick peats and organic silts have accumulated behind calcarenite dunes lining the foreshore of Slaughter Bay. Importantly, the swamp is located less than 0.5 km west of Emily Bay where archaeological excavation has uncovered c. 800 year old remains of a Polynesian settlement (Anderson, 1996a,b).

This study describes fossil pollen and spores recovered from the top 2.9 m of a 5 m long core (Borehole KCA) of sediments from the edge of Kingston Swamp, now buried under landfill (Anderson and Hope, 1996). Other boreholes demonstrate that the organic sedimentary infill further away from the margins is at least 7 m thick (Borehole KCB) and possibly up to 21 m thick (Borehole 197). Boreholes KCB, KCD and 197 were not analysed for this study, but contain very little material suitable for analysis. If correct, the swamp preserves a uniquely detailed record for small islands in the southwest Pacific (Macphail and Neale, 1996).

### Human settlement

Because of encircling reefs and steep volcanic terrain, human settlement of Norfolk Island has been centred around the Kingston-Arthur's Vale area on the south coast, the only extensive coastal plain and the only part of the island accessible from the sea. This area was occupied on at least three separate occasions before permanent settlement of the island began in 1856 (references in Nobbs, 1988, 1991; Wilson and McLaren, 1994; Anderson, 1996b):

1   Polynesian settlement (c. A.D. 1200). Radiocarbon dates for the Polynesian settlement at Emily Bay are clustered within 800–600 B.P. The remains of a canoe, found in A.D. 1788 (King cited in Hoare, 1988: 19) may be
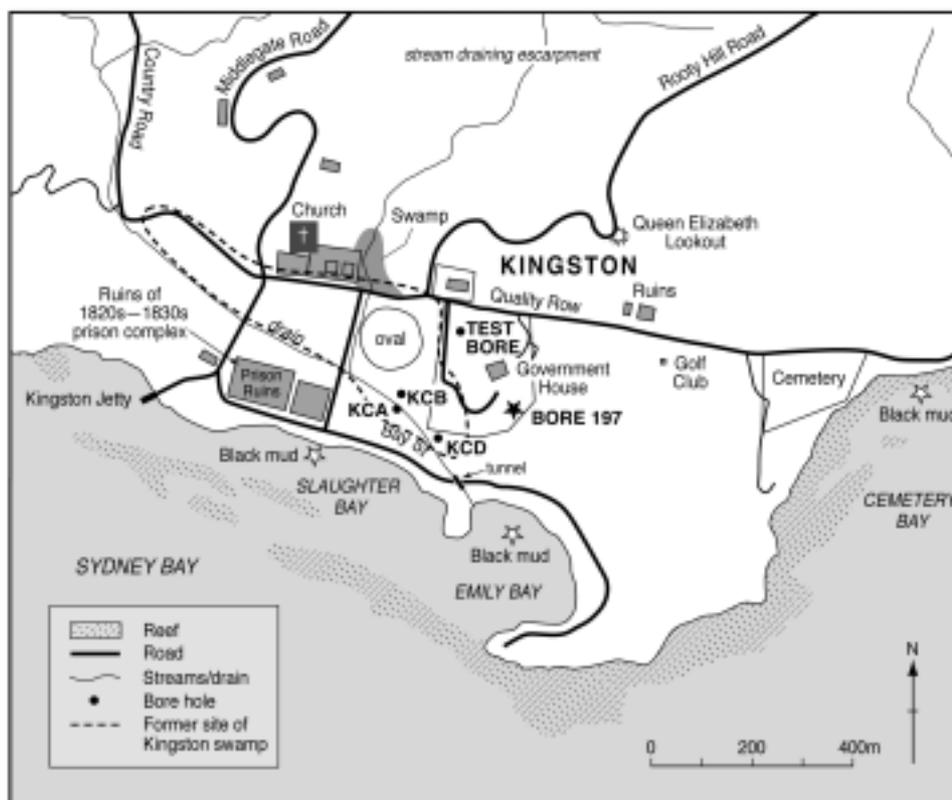


**Figure 1**. Kingston area showing location of Boreholes KCA, KCB, KCD and 197.

evidence of subsequent visits up to the eighteenth century. At the time of first European settlement in A.D. 1788, the island was covered in thick forest with dense vine thickets in the understorey. The plants growing in the Kingston Swamp were not recorded but King (cited in Hunter, 1793: 306) observed that the banana trees were interlaced with "small aquatic shrubs" and a "bear-bind" (= *Muehlenbeckia australis*?). The only naturally treeless areas were the *Phormium tenax*-covered sea cliffs. Rats, presumed to be the Polynesian species *Rattus exulans*, are listed during the first days of European settlement in 1788 as being very numerous and destructive (King cited in Hunter, 1793: 311–312; Green, 1994: 7).

2   First European settlement (A.D. 1788–1814). During the first phase of convict occupation, the native forest was cleared from about 30% of the island. Administration buildings were constructed along Quality Row at the foot of the volcanic escarpment behind Kingston Swamp and a channel was dug to regulate flooding and divert water through a tunnel excavated through the foreshore calcarenite ridge into Emily Bay. The drained swamp was used for grazing and the cultivation of crops, including vegetables and barley. Following abandonment of the settlement in A.D. 1814, the tunnel to Emily Bay became blocked, allowing the swamp to reform behind the foreshore ridges.

3   Second European settlement (A.D. 1825–1855). During the second phase of convict occupation, the top of the calcarenite ridge separating Kingston Swamp from Slaughter Bay was levelled for construction of the prison complex whilst the swamp was drained for a second time and converted into prisoners' gardens (Fig. 1). The gardened area was buried under clay landfill and reshaped as a "picturesque" landscape in the mid 1830s, and the channel straightened about A.D. 1847. The built-up section between this drain and Quality Row (now Kingston Common) has been converted to playing fields and the levelled foreshore ridge, now traversed by Bay St. (Fig. 1), is mostly covered by lawn and planted Norfolk Island Pines.

### Kingston Swamp and surrounds

Kingston Swamp occupies a deep basin formed at the junction of two Late Pleistocene carbonate sand dune fields (now lithified into calcarenite ridges), one aligned E-W and moving inland from the direction of Slaughter Bay and the other aligned NE–SW and moving inland from the direction of Cemetery Bay. Natural drainage was by percolation though the calcarenite into Emily Bay and the swamp appears to have been subject to marked seasonal lateral expansion and contraction. Drilling (Anderson and Hope, 1996; Macphail and Neale, 1996; G. Duval, pers. comm.) has demonstrated that the sedimentary infill is greater than 7 m thick and possibly up to 21 m thick away from the margins. Organic deposits of middle Holocene age outcrop below low water mark in Slaughter and Cemetery Bays. Also present in Cemetery Bay are raised reefs, one of which preserves evidence of fire in the form of partially burnt lignites sandwiched between two limestone strata (Macphail and Neale, 1996). This lignite has yet to be radiocarbon dated but is likely to be early to mid Holocene based on

radiocarbon dates of 8,310±90 B.P. (ANU-10661) for organic muds exposed below low water mark at the northern end of Cemetery Bay and 4,830±30 B.P. (ANU-10660) for black muds in the equivalent position in Slaughter Bay (Fig. 1, open star symbols).

### Lithostratigraphy and age control

Borehole KCA is located on the southeastern margin of the former swamp close to the point where the organic infill is believed to have onlapped the calcarenite ridge behind Slaughter Bay (Fig. 1). Four distinctive lithological units were intersected below a 40 cm thick layer of recent sands forming the base of the present-day lawn (depths below present-day ground level in cm). Each is separated from its neighbour(s) by unconformity surfaces representing episodes of erosion or non-deposition at the borehole site:

Unit A 40–141 cm. Grey-brown clays and silts. This unit is interpreted as landfill dumped on the swamp after c. A.D. 1835.

Unit B 141–148 cm. Yellow-white horizontally bedded carbonate sand. This unit has been variably interpreted as sands deposited by a tidal wave in A.D. 1834 (Anderson and Hope, 1996) and as a slope-wash deposit accumulating on the swamp surface during levelling of the calcarenite ridge (Macphail and Neale, 1996). The sand thins inland to c. 1 cm thick in Borehole KCB (Macphail and Neale, 1996).

Unit C 148–167 cm. Black strongly humified silty peat. This unit is interpreted to be the oxidized remnants of the upper peat layers, caused by draining and cultivation of the swamp. Organic silt between 148 and 157 cm yielded an uncorrected/conventional radiocarbon date of 1,000±150 B.P. (ANU-10090).

Unit D 167–500 cm. Interbedded peats, organic muds, and yellow-brown to dark grey clays. This unit is interpreted as being undisturbed sediments accumulating before human settlement of the island. Samples from 226–235 cm and 315–325 cm yielded conventional radiocarbon dates of 2,580±250 B.P. (ANU-10091) and 5,450±180 B.P. (ANU-10091), respectively.

Exotic pollen types such as *Plantago lanceolata*-type, and abundant Liguliflorae (*Taraxacum officinale*?) and Poaceae pollen occur at 50 cm, and a single grain of a cereal species was found at 120 cm (Table 1). These records demonstrate that the upper 80 cm of Unit A was deposited after European settlement and, by extrapolation, the whole of Unit A post-dates the mid 1830s when the former swamp was buried under landfill (see below).

The low relative abundance of woody species other than *Cyathea* indicates the interval above 50 cm represents a time when almost all native forest had been cleared from the Kingston area. The interval could be as young as the early twentieth century, based on the widespread planting of Kikuyu Grass (*Pennisetum clandestinum*) as a pasture species across the island about this time. Conversely the interval below 120 cm may represent an early phase of European clearing before A.D. 1855, or the sediment came from an area retaining some native forest species. If

**Table 1**. Kingston Common relative abundance data of commonly occurring and other selected plant types in borehole KCA. Figures in section above dashed line are %, those below the line are counts and concentrations. ([a] this species belongs to Arecaceae).

| unit / depth from surface (cm) | UNIT A 50 | 120 | 135 | UNIT B 143 | 147 | UNIT C 153 | 163 | UNIT D 175 | 185 | 195 | 205 | 210 | 225 | 235 | 255 | 285 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **PLANTS INTRODUCED BY EUROPEANS?** | | | | | | | | | | | | | | | | |
| *Brassica*-type | — | — | + | + | — | — | — | — | — | — | — | — | — | — | — | — |
| cereal Poaceae | — | + | — | — | — | — | — | — | — | — | — | — | — | — | — | — |
| Chenopodiaceae | + | + | + | + | + | — | — | — | — | — | — | — | — | — | — | — |
| Liguliflorae (*Taraxacum*?) | 15 | + | + | + | + | — | — | — | — | — | — | — | — | — | — | — |
| *Plantago lanceolata*-type | + | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — |
| **PLANTS INTRODUCED BY POLYNESIANS?** | | | | | | | | | | | | | | | | |
| *Cordyline obtecta* | — | + | + | 4 | 9 | 14 | 3 | — | — | — | — | — | — | — | + | — |
| *Hibiscus diversifolius*-type | + | + | + | + | + | + | + | — | + | + | — | — | — | + | — | + |
| Liguliflorae (*Sonchus*?) | ? | ? | ? | ? | ? | — | — | — | — | + | — | — | — | — | — | — |
| *Persicaria decipiens* | + | + | 3 | 3 | 3 | 2 | — | — | — | — | — | — | — | — | + | + |
| *Typha orientalis* | + | 32 | 25 | 32 | 20 | 6 | 3 | 3 | 11 | 5 | 6 | 6 | 2 | 6 | + | 1 |
| **LOCALLY EXTINCT? TAXA** | | | | | | | | | | | | | | | | |
| cf. *Hedyscepe canterburyana*[a] | — | — | — | + | + | — | — | — | — | — | — | — | — | — | — | — |
| *Hibiscus* sp. | — | — | + | + | 3 | 2 | + | — | + | — | — | — | — | — | — | — |
| **NATIVE TREES & SHRUBS** | | | | | | | | | | | | | | | | |
| *Achyranthes* spp. | — | — | — | — | — | — | + | 3 | 1 | + | + | 1 | 2 | 1 | 2 | + |
| *Araucaria heterophylla* | 3 | 6 | 18 | 18 | 26 | 10 | 8 | 19 | 12 | 5 | 6 | 15 | 13 | 13 | 2 | 7 |
| *Celtis paniculata* | — | — | — | — | + | 3 | — | — | + | + | — | 1 | 30 | 4 | 3 | 6 |
| *Muehlenbeckia australis* | + | 33 | 24 | 28 | 20 | 19 | 55 | 32 | 52 | 74 | 62 | 51 | 23 | 13 | 8 | 7 |
| *Nestigis apetala* | — | — | — | — | + | + | — | — | — | — | + | + | — | + | 2 | 2 |
| *Pennantia endlicheri* | — | — | — | — | + | — | — | + | + | + | + | 1 | + | + | 3 | 8 |
| *Rapanea ralstoniae* | — | — | + | — | + | + | — | + | + | — | + | — | + | — | 2 | 1 |
| *Rhopalostylis baueri* | + | + | — | + | + | — | — | + | + | — | + | — | 5 | 3 | 2 | 2 |
| **NATIVE HERBS** | | | | | | | | | | | | | | | | |
| Cyperaceae | 31 | 14 | 50 | 39 | 74 | + | + | 2 | 2 | 1 | + | + | + | 1 | 1 | 2 |
| Poaceae | 9 | + | + | — | + | — | — | + | — | + | — | — | — | — | — | — |
| **NATIVE FERNS & LIVERWORTS** | | | | | | | | | | | | | | | | |
| *Cyathea australis/brownii* | 63 | 41 | 34 | 28 | 16 | 7 | 32 | 35 | 23 | 12 | 20 | 14 | 28 | 51 | 51 | 47 |
| *Marattia salicina* | — | 7 | 4 | 3 | 3 | 3 | 2 | 8 | 7 | 4 | 9 | 12 | 18 | 11 | 17 | 11 |
| UNIDENTIFIED MONOLETE FERNS | 3 | 5 | 6 | 9 | 16 | 20 | + | 2 | 2 | 1 | 2 | 1 | 4 | 2 | 3 | 4 |
| UNIDENTIFIED TRILETE SPORES | 2 | 4 | 6 | 5 | 6 | 1 | — | — | — | — | — | — | — | — | — | — |
| dryland pollen count | 253 | 304 | 253 | 257 | 254 | 243 | 432 | 443 | 443 | 675 | 723 | 572 | 370 | 474 | 484 | 539 |
| total pollen count | 332 | 433 | 441 | 439 | 538 | 330 | 459 | 464 | 491 | 713 | 770 | 613 | 381 | 497 | 493 | 545 |
| pollen concentration ($10^3$) | 51 | 212 | 391 | 206 | 418 | 111 | 1450 | 183 | 650 | 820 | 320 | 129 | 169 | 281 | 377 | 763 |
| charcoal concentration ($10^3$) | 408 | 114 | 365 | 171 | 266 | 114 | 100 | 13 | 31 | 36 | 2 | 5 | 990 | 1783 | 525 | 1544 |

correctly interpreted, the carbonate sand unit confirms that samples above 148 cm are younger than A.D. 1824–1834.

The radiocarbon date of c. 1,000 B.P. at 148–157 cm is considered imprecise for two reasons. (1) Unit C represents the remnants of an unknown thickness of peat. (2) Older soil charcoal may have washed into the swamp during First Settlement time. Nevertheless, in combination with the sedimentary evidence, the date of c. 1,000 B.P. strongly implies that swamp sediments deposited at the KCA site during the period(s) of Polynesian occupation have been destroyed by European activities. Whether this is true in other areas of the former swamp is uncertain but a similar sequence of lithologies, including a c. 60 cm thick unit of strongly oxidized peaty silts, was intersected in Borehole KCB drilled c. 30 m to the NNE of Borehole KCA.

## Pollen analysis methods

Sixteen samples, representing all four lithological units down to a depth of 285 cm, were processed for fossil pollen, spores and other acid-resistant plant microfossils using standard techniques: addition of a known quantity of an exotic *Lycopodium* spore to each sample allowed numbers of fossil pollen, spores and charcoal particle to be estimated (see Moore *et al.*, 1991: 41–54).

Fossil extracts were mounted on glass slides and a minimum of 330 identifiable fossil pollen and spores counted for each sample using a Zeiss Photomicroscope II fitted with oil immersions objectives capable of providing magnifications of up to ×2,000. The remainder of each mount was then scanned for additional rare taxa.

The relatively small size of the Norfolk Island flora has allowed many fossil pollen and spores to be identified to species or to groups of related genera or species. Examples in the first category are *Araucaria heterophylla, Muehlenbeckia australis, Phormium tenax*, and *Rhopalostylis baueri* (Norfolk Island Palm). Examples in the latter category are *Sonchus* and *Taraxacum* species which produce Liguliflorae-type pollen, and *Plantago lanceolata* and *P. major*, which are the only known sources of *Plantago lanceolata*-type pollen on Norfolk Island.

Most ferns are a special case in that their fossil spores can only be identified to species level when the outer wall layer (perispore) is preserved intact. Fern spores which can almost always be identified to species level include *Histiopteris incisa* (Bat Wing Fern), *Marattia salicina*, (King Fern) and the three species of *Pteris* (Brakefern). The *Cyathea* count comprises spores produced by two native tree-ferns, *Cyathea australis* (Rough Tree-fern) and *C. brownii* (Norfolk Island Tree-fern).

## Results

Relative abundance data for selected commonly occurring and culturally significant plants, expressed as percentages of the total dryland pollen count, are given in Table 1. Figure 2 gives an overview of lithology, selected pollen spectra, a summary of the latter and charcoal concentration. A selection of the more distinctive fossil pollen and spore types are illustrated in Figs. 3–5, and the pollen and spore database listed in full in Appendix.

**Preservation and yield**. Apart from the fragmentation of very large pollen types such as *Hibiscus*, pollen preservation was uniformly excellent in all lithological units. Yields of fossil pollen and spores were high to very high, with concentration values ranging from $51 \times 10^3$ grains cc$^{-1}$ in the clay landfill (Unit A) to a maximum of $1,450 \times 10^3$ grains cc$^{-1}$, in what may be a lag concentrate near the base of strongly oxidized peats (Unit C). Intermediate values are recorded in the other lithologies. Charcoal fragments with a minimum dimension of 8 μm are present in all samples but concentration values vary greatly, from 2 to $1,783 \times 10^3$ particles cc$^{-1}$. Minimum and maximum values occur within Unit D, at 175–210 cm and below 220 cm depth respectively.

**Diversity**. At least 60 distinctive fossil pollen and spore types are present, of which approximately 20 can be assigned to living species and about the same number to groups of two or three related species (Appendix).

The majority of these are native taxa and include some of the more important endemic trees and shrubs in the Norfolk Island flora, e.g., *Achyranthes* (Chaff-tree/Chaffflower), *Araucaria heterophylla, Celtis paniculata* (Whitewood), *Lagunaria patersonia* (Sally Wood), *Pennantia endlicheri* (Pennantia), *Rapanea ralsoniae, Rhopalostylis baueri* and *Ungeria floribunda* (no common name). Herbs are poorly represented except for swamp plants such as the Cyperaceae (sedges) and *Typha orientalis*.

Only one confirmed cultigen pollen type was recorded—a cereal species at 120 cm within Unit A. It is possible that *Brassica*-type pollen at 135 cm and 143 cm depth represents crop species such as turnip or mustard (*Brassica* spp.).

Pollen of other plants cultivated or utilized by Polynesians, e.g., banana, sweet potato and flax, were not recorded; nor were salt-water indicators such as the cysts of marine alga (dinoflagellates) found in any sample.

Twelve pollen types could not be matched with those produced by living plants in the Norfolk Island flora. Most of these are known to be transported by wind over long distances, e.g., Casuarinaceae, Myrtaceae and *Nothofagus* (cf. Salas, 1983). Pollen types, which include aquatic species, have been carried in mud on the feet of migrating birds, e.g., Apiaceae cf. *Hydrocotyle, Lemna*-type (Duckweed) and *Triglochin*. Two types are not known to be dispersed over long distances, and therefore are more likely to be sourced from plants growing on Norfolk Island in the past. These are (1) a palm type which resembles pollen produced by a species endemic to Lord Howe Island (*Hedyscepe canterburyana*) and (2) a Malvaceae which may represent a locally extinct *Hibiscus* species.

**Dominance**. With the exception of the highest assemblage (50 cm), the same small group of native taxa dominates all microfloras, irrespective of lithology. The majority of these are produced by genera that produce and disperse pollen or spores in large numbers by water and/or wind (wellrepresented taxa). The group includes *Cyathea, Araucaria heterophylla* and Poaceae. Other commonly occurring types are more likely to come from plants which grew locally around, in or upstream of the swamp (under-represented taxa). Examples are Liguliflorae, *Marattia salicina, Muehlenbeckia australis* and *Typha orientalis*. Most herbs, shrubs and hardwood trees are severely under-represented by pollen, and low to trace pollen percentages still are reliable evidence that the source plant(s) grew locally. Examples are *Persicaria decipiens, Freycinetia, Nestigis apetala* and *Zanthoxylum pinnatum* (Box Wood).
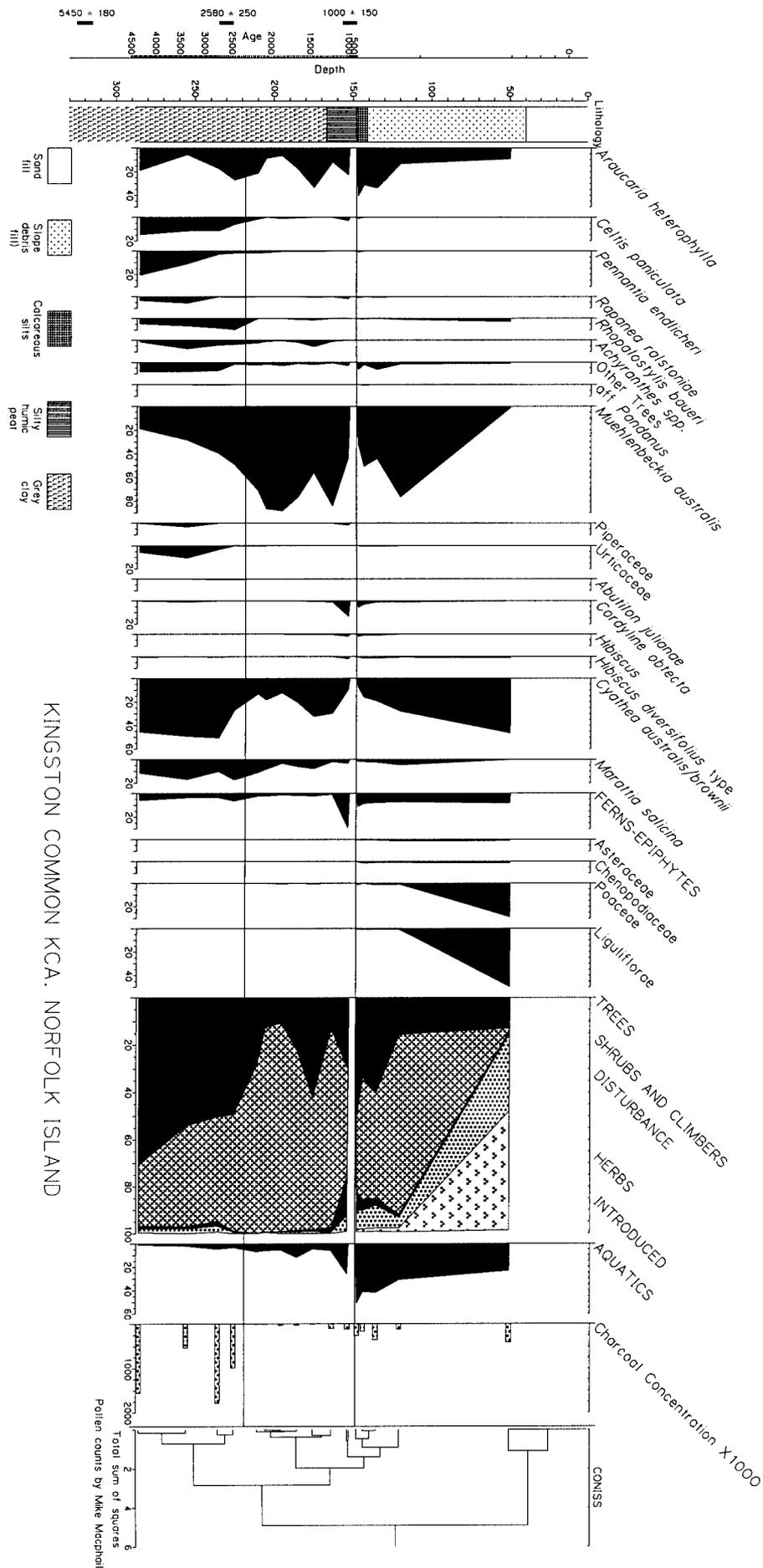
## Interpretation and vegetation history

*Unit A 40–141 cm* inferred age: after A.D. 1834

This unit is represented by three samples, at 50 cm, 120 cm and 135 cm. The microflora at 50 cm is unique in that abundant *Cyathea* and Cyperaceae are associated with high values of Liguliflorae (15%) and Poaceae (9%). Both of the latter types are likely to represent introduced species, e.g., *Taraxacum officinale* and *Pennisetum clandestinum*. *Araucaria heterophylla* percentages are low (3%) relative to values recorded at 120–135 cm. *Muehlenbeckia australis* and *Typha orientalis* pollen occur in trace numbers only.

Microfloras at 120 cm and 135 cm are dominated by Cyperaceae, *Typha orientalis, Cyathea* and *Muehlenbeckia australis*, associated with frequent (4–7%) *Marattia salicina* and other monolete and trilete fern spores. Several possible exotic pollen types are present in trace numbers, e.g., Chenopodiaceae and Liguliflorae. Charcoal particle concentration values are low relative to the maximum values in the sequence but are sufficiently high to imply that fire was used as one method to clear land.

The data indicate that the upper 10 cm of Unit A either accumulated in a sedge swamp in which the water table usually was above ground level or the clays were sourced from a similar freshwater swamp elsewhere. *Cyathea* spores are dispersed in large numbers by water and the spore count

**Figure 2.** Stratigraphy, selected pollen spectra, pollen summary and charcoal concentration for Borehole KCA at Kingston Common.

almost certainly will have come from tree-ferns growing in gullies on the escarpment behind Quality Row, or from stands growing upstream in Arthur's Vale. In either case, the data are consistent with periodic flooding of the swamp during the early to middle nineteenth century A.D.

Pollen preserved in the basal 35 cm of Unit A and within Unit B (see below) are circumstantial evidence that *Muehlenbeckia australis* and *Typha orientalis* were two of the "wild vines and aquatic shrubs" growing along streams flowing into Kingston Swamp in 1788 (King cited in Hunter, 1793: 306). Forest communities growing on the adjacent foreshore ridge included a tall tree species, *Lagunaria patersonia*, that is now widespread on the island.

### Unit B 141–147 cm inferred age: A.D. 1824–1834

The carbonate sand unit is represented by two samples, at 143 cm and 147 cm. Pollen dominance is similar to that recorded at the basal sample of Unit A (135 cm) although charcoal particle concentration values are slightly lower.

The chief distinguishing feature is that *Persicaria decipiens* and *Cordyline* pollen are frequent to common (3–9%). *Araucaria heterophylla* values (18–26%) are the highest recorded in the sequence, probably because a reduction in the local pollen influx (due to clearing or flooding of the swamp) has accentuated the representation of more distant, well-represented trees. Pollen of Arecaceae cf. *Hedyscepe canterburyana* and the possibly extinct *Hibiscus* sp. are best represented in this unit and the underlying organic silts (Unit C).

*Persicaria* is typically found in wet habitats and the inferred age of the sand is close to the date (A.D. 1835) when this herb was first collected on Norfolk Island (see Wilson, 1994: 99). The pollen type indicates that the carbonate sand was deposited on a damp surface, ie. the water table was below ground level. If the *Persicaria* pollen grains at 285 cm are *in situ* then the fossil data are against the species being an early introduction. *Cordyline* (presumed to be the endemic species *C. obtecta*) is now frequent only in Norfolk Island National Park centred around the volcanic peaks of Mt. Pitt (316 m elevation) and Mt. Bates (308 m elevation) in the northwest of the island. The pollen data are evidence that this small tree grew in the Kingston lowlands during the early nineteenth century and may have been a food resource if its roots and lower stems, like those of some other *Cordyline* species, are edible.

### Unit C 147–167 cm c. 1,000 B.P.

Unit C is represented by two samples, at 153 cm and 163 cm. The sedimentary evidence, supported by the pollen concentration data, indicates that the interval is the residue of peats accumulating on the site between c. 1,000 B.P. and A.D. 1788. Microfloras from such deposits are difficult to interpret, not least because of biases caused by preferential destruction of less robust pollen types, the condensing of widely separated strata and/or mixing of microfloras of different ages.

Marked differences in the pollen concentration values ($111 \times 10^3$ *vs* $1,450 \times 10^3$ grains cc$^{-1}$) and in the relative abundance of commonly occurring taxa such as *Muehlenbeckia australis* and fern spores indicate that the unit is a condensed sequence: (*a*) The assemblage at 153 cm is dominated by monolete fern spores (20%) and *Muehlen-*beckia australis* (19%), associated with unusually high values of *Celtis paniculata* (3%), *Cordyline obtecta* (14%) and *Persicaria decipiens* (2%). Values of *Araucaria heterophylla* (10%) and *Typha orientalis* (6%) are low relative to those recorded in Unit B. (*b*) *Muehlenbeckia australis* (55%) and *Cyathea* (32%) wholly dominate the assemblage at 163 cm. Values of *Araucaria* (8%) and *Typha orientalis* and *Cordyline obtecta* (3%) are lower than at 153 cm whilst *Persicaria decipiens* is absent. Cyperaceae pollen occurs in trace numbers only in both assemblages.

How the fossil pollen data are interpreted depends on whether *Cyathea* spores were water-transported to, or sourced from tree-ferns growing on or near, the site. If the former occurred, then the swamp was repeatedly flooded during the time represented by the sample at 163 cm. *Muehlenbeckia australis* appears to have been established on the site itself. If the latter, then the water table in Kingston Swamp was below ground level, allowing tree-ferns as well as *Muehlenbeckia australis* to colonize the damp peat surface. Circumstantial evidence that the latter hypothesis is the more likely is provided by the low value of *Typha orientalis* at 163 cm and presence of *Persicaria decipiens* at 153 cm. During the period represented by this sample (153 cm), tree-ferns and *Muehlenbeckia australis* were less common whilst *Cordyline* almost certainly was part of the woody vegetation on the adjacent calcarenite ridge.

The low representation of long distance dispersed pollen types such as *Araucaria* (8–10%) is likely to reflect the high local pollen influx. It is noted that what are interpreted as relatively dry edaphic conditions would be expected to favour the local establishment of *Phormium tenax* (nowhere recorded in the sequence) had the species been present on the island in Unit C time.

### Unit D 167–285+ cm between 2,580 and 1,000 B.P.

Unit D is represented by nine samples taken at 5–10 cm spacings between 175 and 285 cm depth. Unlike the overlying sedimentary units, there is little doubt that the microfloras predate the known settlement of Norfolk Island by humans.

All microfloras are dominated by one or more of *Cyathea, Marattia salicina, Muehlenbeckia australis* and *Araucaria heterophylla*. These are associated with low to frequent numbers of pollen of *Rhopalostylis baueri* and other palynologically under-represented trees, including some hitherto rare hardwood species, e.g., *Celtis, Nestigis*, and *Rapanea ralsoniae*. Values of *Typha orientalis* and *Muehlenbeckia australis* increase upwards within the unit whilst those of *Cyathea, Marattia salicina*, all hardwood trees and charcoal particles are most abundant below 220 cm depth. Rare pollen types include *Hibiscus diversifolius*-type at 185 cm, 195 cm, 235 cm and 285 cm, and Liguliflorae (*Sonchus*?) and the unknown *Hibiscus* sp. at 185 cm.

Since *Typha orientalis* pollen is a low (av. 4%) but persistent component of all microfloras; the data are unequivocal evidence that this species is native to Norfolk Island. Trends in its relative abundance suggest that relatively dry local conditions before c. 2,580 B.P. are behind the local establishment of hardwood trees such as *Celtis paniculata, Nestigis apetala* and *Rapanea ralstoniae*, as well as *Rhopalostylis baueri, Cyathea* and *Marattia salicina*.
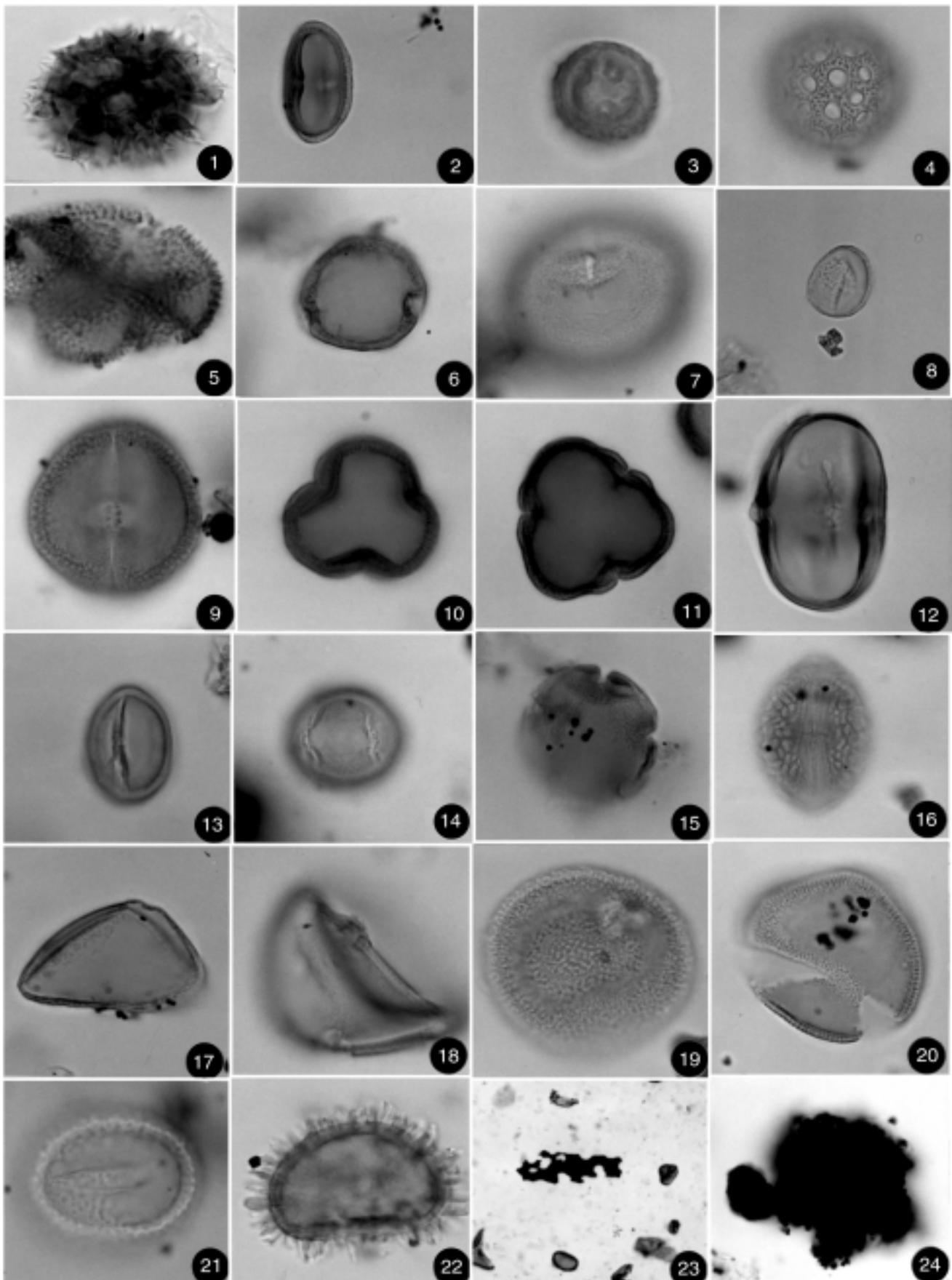
**Figure 3**. Photomicrographs taken at ×788 magnification (50 µm scale bar): 1, Liguliflorae (Asteraceae); 2, Apiaceae (*Hydrocotyle*-type); 3, *Plantago lanceolata*-type (Plantaginaceae); 4, *Achyranthes* (Amaranthaceae); 5, *Baloghia inophylla* (Euphorbiaceae); 6, *Celtis paniculata* (Ulmaceae); 7, *Coprosma baueri/pilosa* (Rubiaceae); 8, *Macropiper*-type (Piperaceae);
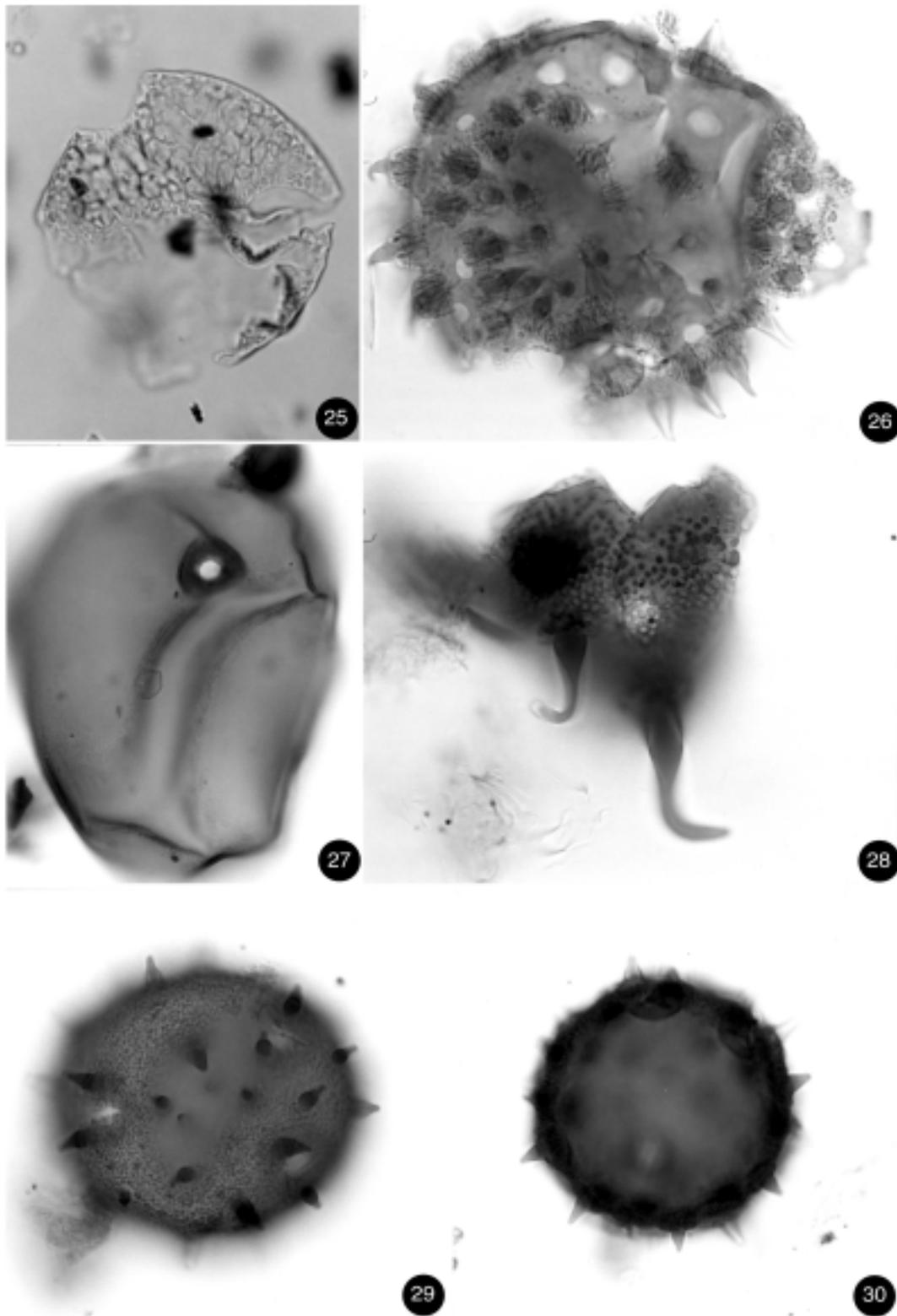
**Figure 4**. Photomicrographs taken at ×788 magnification (50 µm scale bar): 25, *Podocarpus-Prumnopitys* (Podocarpaceae); 26, unidentified *Hibiscus*-type (Malvaceae); 27, cereal (Poaceae); 28, fragment of *Hibiscus diversifolius*-type (Malvaceae); 29, *Lagunaria patersonia* (Malvaceae); 30, *Abutilon julianae* (Malvaceae). For scale bar see Fig. 5.

---

**Figure 3 (continued)**. 9, *Muehlenbeckia australis* (Polygonaceae), equatorial view; 10, *Muehlenbeckia australis* (Polygonaceae), median polar view; 11, cf. *Exoecaria agallocha* (Euphorbiaceae), median polar view; 12, *Pouteria bracteolatum* (Sapotaceae); 13, *Pennantia endlicheri* (Icacinaceae); 14, *Rapanea ralstoniae* (Myrsinaceae); 15, *Ungeria floribunda* (Sterculiaceae); 16, *Zanthoxylum pinnatum* (Rutaceae); 17, *Cordyline obtecta* (Agavaceae); 18, Poaceae (native); 19, *Typha orientalis* (Typhaceae); 20, cf. *Frankenia* (Frankeniaceae); 21, *Marattia salicina* (Marattiaceae); 22, *Hypolepis* (Dennstaedtiaceae); 23, carbonized xylem, 0.50 m depth; 24, aggregates of fine carbon particles ("soot balls"), 2.35 m depth. For scale bar see Fig. 5.
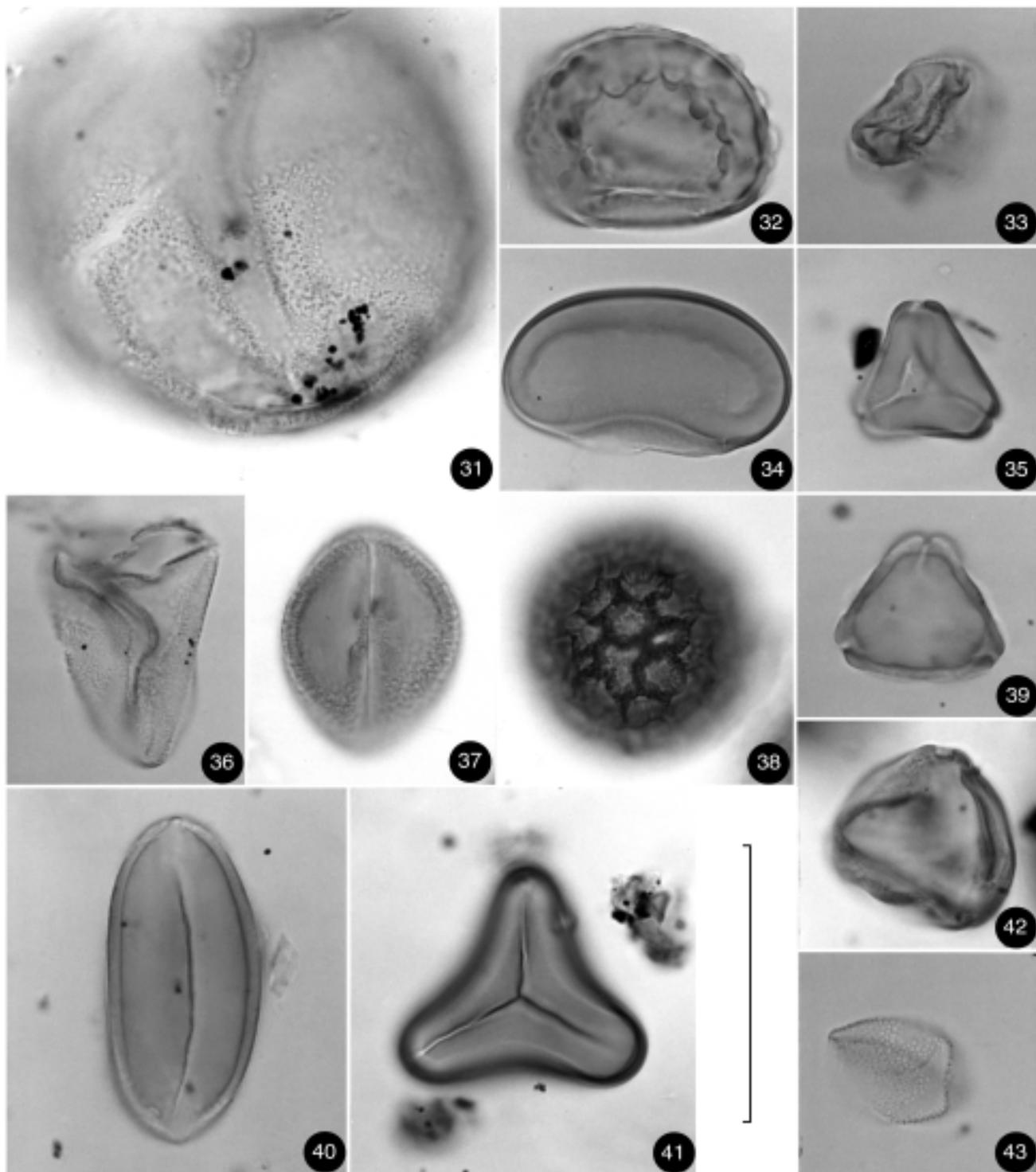
**Figure 5**. Photomicrographs taken at ×788 magnification (50 µm scale bar): 31, *Araucaria heterophylla* (Araucariaceae); 32, *Phymatosorus pustulatus* (Polypodiaceae); 33, *Nothofagus (Brassospora)* sp. (Fagaceae); 34, monolete spore cf. *Vittaria* (Vittariaceae); 35, *Metrosideros* (Myrtaceae); 36, cf. *Scirpus* (Cyperaceae); 37, *Muehlenbeckia australis* (Polygonaceae), equatorial view; 38, *Persicaria decipiens* (Polygonaceae); 39, *Eucalyptus gummifera*-type (Myrtaceae); 40, *Rhopalostylis baueri* (Arecaceae); 41, *Cyathea brownii*-type (Cyatheaceae); 42, Casuarinaceae; 43, *Triglochin* (Juncaginaceae).

*Muehlenbeckia australis* values indicate that this shrub-like creeper was uncommon at the site until after c. 2,580 B.P. (225 cm). Since charcoal particle values in the underlying sample at 235 cm are the highest in the sequence ($1,783\times10^3$ particles cc$^{-1}$) it is tempting to link the spread of *Muehlenbeckia* to one or more local wildfires as well as to increasingly wet conditions within the swamp indicated by increasing values of *Typha orientalis*. Circumstantial evidence that the expansion of *Muehlenbeckia australis* was stimulated by local disturbances is provided by maxima in the pollen curve of *Achyranthes* (presumed to be the only widespread species *A. aspera*) before c. 2,580 B.P. The apparent temporary reduction in *Araucaria heterophylla* and *Cyathea* populations almost certainly is a consequence of the increased influx of local pollen.

Charcoal particle values remain high down to the lowest sample analysed (285 cm) and seem to point to (*a*) a period characterized by relatively frequent wildfires and by inference if naturally ignited, (*b*) more strongly seasonal or drought-prone local climates. Whether the marked reduction in charcoal particle concentrations above 225 cm reflects a reduction in fuel loads near the site, a change in the hydrology of the site, and/or locally wetter climates, is unclear.

### Discussion and conclusions

Islands ecosystems in the southwest Pacific remained undisturbed by humans until some 3500–800 years ago when a sophisticated maritime culture allowed Polynesians to locate and settle the majority of basalt-cored islands and coral atolls. Lord Howe is the only known example of a sizeable habitable island for which there is no archaeological or other evidence of humans prior to its discovery by Europeans two centuries ago. Norfolk Island also was unoccupied at the time of European discovery in A.D. 1774 but there is clear archaeological evidence for one or more Polynesian settlements in the last 800 years (Anderson, 1996b). Accordingly a comparison of their palaeoecology with long-settled islands such as Vanuatu and Fiji offers a rare opportunity to unravel the impact of human activity and climatic events. An example is the question of whether marked increases in the relative abundance of charcoal particles is reliable evidence for humans or whether the fires have other, non-anthropogenic causes.

Because of the potentially unique depth of organic sediments preserved in the former Kingston Swamp and the unusually high taxonomic resolution, the Norfolk Island pollen data are an important natural archive in two related arenas of island biogeography. They provide benchmark evidence against which the impact of humans on a long-isolated island flora and vegetation can be assessed in the longer-term and provide a means of determining whether particular plants were native to the island or introduced by humans.

1  The combined charcoal and pollen data confirm that wildfires were a naturally occurring event on Norfolk Island before c. 2,580 B.P., and probably before the middle Holocene based on burnt lignites preserved *in situ* at Cemetery Bay (Macphail and Neale, 1996). The extent to which the forest vegetation observed by Cook and King had already been shaped by wildfires (natural and human-lit) is uncertain but the KCA data point to a link between fire frequency and local climatic change during the Late Holocene (cf. Macphail, 1980). It is noted that charcoal particle concentration values similar to those recorded at 225–285 cm have been cited as evidence for early human occupation on other remote oceanic islands (Kirch and Ellison, 1994: Fig. 3; challenged by Anderson, 1994, 1996b). Pollen analysis of older/deeper samples is required before the same can be inferred for Norfolk Island.

2  The same data provide unequivocal evidence that putative exotics such as Ti (*Cordyline*), the bull-rushes (*Typha orientalis*) and, less certain herbs, such as the sow thistle (*Sonchus oleraceus*) and *Persicaria decipiens*, were present on the island long before the earliest known Polynesian settlement. Because sediments contemporary with this presence have been destroyed by European activities, evidence of Polynesian cultigens other than banana has been lost—and banana is known only from historical observations, not from pollen. Nevertheless, the complete absence of *Phormium tenax* (New Zealand Flax) pollen at a site known to have been within metres of a ridge described as being covered by this plant in A.D. 1774 is difficult to explain unless *Phormium* was introduced onto Norfolk Island by Polynesians sometime after c. 1200 and before A.D. 1774. The data greatly strengthen the case that occurrences of New Zealand Flax elsewhere on small Southwest Pacific islands such as Raoul will be due to Polynesian occupation.

Until an intensive coring programme of the Kingston Common and surrounding areas has been undertaken, it is premature to conclude that European settlement has destroyed a fossil pollen and spore record of the time(s) of Polynesian settlement. Equally important to understanding the complex relationship between climate, the biogeography of small volcanic islands and human colonization will be the recovery of a continuous core through the sedimentary infill in former Kingston Swamp down to the basalt basement.

## References

Anderson, A., 1994. Palaeoenvironmental evidence of island colonization: a response. *Antiquity* 68: 845–847.

Anderson, A., 1996a. Prehistoric human colonisation of Norfolk Island. *First Interim Report to Australian Heritage Commission*, pp. 1–38. Archaeology & Natural History Publications, Research School of Pacific and Asian Studies, Australian National University.

Anderson, A.J., 1996b. Discovery of a prehistoric habitation site on Norfolk Island. *Journal of the Polynesian Society* 105: 479–486.

Anderson, A., and G.S. Hope, 1996. A reconnaissance survey of Holocene deposits of Norfolk Island. Appendix to *First Interim Report to Australian Heritage Commission*, pp. 39–45. Archaeology & Natural History Publications, Research School of Pacific and Asian Studies, Australian National University.

Green, P.S., 1994. Norfolk Island and Lord Howe Island. In *Flora of Australia; vol. 49: Oceanic Islands 1*, ed. J.G. Wilson, pp. 1–26. Canberra: Australian Government Publishing Service.

Hicks, J., 1988. The natural history of Norfolk Island. In *Norfolk Island and its First Settlement, 1788–1814*, ed. R. Nobbs, pp. 159–172. Sydney: Library of Australian History.

Hicks, J., 1991. The natural history of the island. In *Norfolk Island and its Second Settlement, 1825–1855*, ed. R. Nobbs, pp. 158–165. Sydney: Library of Australian History.

Hoare, M., 1988. The island's earliest visitors. In *Norfolk Island and its First Settlement, 1788–1814*, ed. R. Nobbs, pp. 18–22. Sydney: Library of Australian History.

Hunter, J., 1793. *An Historical Journal of the Transactions at Port Jackson and Norfolk Island*. Australiana Facsimile Editions. No. 148 (1968). Adelaide: Libraries Board of South Australia.

Kirch, P.V., and J. Ellison, 1994. Palaeoenvironmental evidence for human colonization of remote Oceanic Islands. *Antiquity* 68: 310–321.

Macphail, M.K., 1980. Natural regeneration processes in Tasmanian forests: a long-term perspective based on pollen analysis. *Search* 11: 184–190.

Macphail, M.K., and J. Neale, 1996. Kingston Swamp, Norfolk Island: a unique natural archive of SW Pacific prehistory? *Interim Report to Australian Heritage Commission*, pp. 1–12. Archaeology & Natural History Publications, Research School of Pacific and Asian Studies, Australian National University.

Moore, P.D., J.A. Webb and M.E. Collinson, 1991. *Pollen Analysis*. London: Blackwell Scientific Publications.

Nobbs, R., ed., 1988. *Norfolk Island and its First Settlement, 1788–1814*. Sydney: Library of Australian History.

Nobbs, R., ed., 1991. *Norfolk Island and its Second Settlement, 1825–1855*. Sydney: Library of Australian History.

Salas, M., 1983. Long-distance pollen transport over the southern Tasman Sea: evidence from Macquarie Island. *New Zealand Journal of Botany* 21: 285–292.

Wilson, G., and P. McLaren, 1994. Conservation study and interpretative design: the Swamp Creek and Serpentine Area. Kingston: *Report to Kingston and Arthur's Vale Historical Area management Board*.

Wilson, J.G., ed., 1994. *Flora of Australia Vol. 49: Oceanic Islands 1*. Canberra: Australian Government Publishing Service.

Full-text PDF of each one of the works in this volume are available at the following links :

Anderson and White, vol. eds, 2001, *Rec. Aust. Mus., Suppl.* 27: 1–143
http://dx.doi.org/10.3853/j.0812-7387.27.2001.1334

Anderson and White, 2001, *Rec. Aust. Mus., Suppl.* 27: 1–9
http://dx.doi.org/10.3853/j.0812-7387.27.2001.1335

Anderson et al., 2001, *Rec. Aust. Mus., Suppl.* 27: 11–32
http://dx.doi.org/10.3853/j.0812-7387.27.2001.1336

Anderson et al., 2001, *Rec. Aust. Mus., Suppl.* 27: 33–42
http://dx.doi.org/10.3853/j.0812-7387.27.2001.1337

Anderson and Green, 2001, *Rec. Aust. Mus., Suppl.* 27: 43–51
http://dx.doi.org/10.3853/j.0812-7387.27.2001.1338

Marianne et al., 2001, *Rec. Aust. Mus., Suppl.* 27: 53–66
http://dx.doi.org/10.3853/j.0812-7387.27.2001.1339

Schmidt et al., 2001, *Rec. Aust. Mus., Suppl.* 27: 67–74
http://dx.doi.org/10.3853/j.0812-7387.27.2001.1340

Smith et al., 2001, *Rec. Aust. Mus., Suppl.* 27: 75–79
http://dx.doi.org/10.3853/j.0812-7387.27.2001.1341

Matisoo-Smith et al., 2001, *Rec. Aust. Mus., Suppl.* 27: 81–84
http://dx.doi.org/10.3853/j.0812-7387.27.2001.1342

Holdaway and Anderson, 2001, *Rec. Aust. Mus., Suppl.* 27: 85–100
http://dx.doi.org/10.3853/j.0812-7387.27.2001.1343

Walter and Anderson, 2001, *Rec. Aust. Mus., Suppl.* 27: 101–108
http://dx.doi.org/10.3853/j.0812-7387.27.2001.1344

Campbell and Schmidt, 2001, *Rec. Aust. Mus., Suppl.* 27: 109–114
http://dx.doi.org/10.3853/j.0812-7387.27.2001.1345

Neuweger et al., 2001, *Rec. Aust. Mus., Suppl.* 27: 115–122
http://dx.doi.org/10.3853/j.0812-7387.27.2001.1346

Macphail et al., 2001, *Rec. Aust. Mus., Suppl.* 27: 123–134
http://dx.doi.org/10.3853/j.0812-7387.27.2001.1347

Anderson and White, 2001, *Rec. Aust. Mus., Suppl.* 27: 135–141
http://dx.doi.org/10.3853/j.0812-7387.27.2001.1348