Except where otherwise acknowledged in the text, this thesis represents the original research of the author.

JOHN GRINDROD
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Palynological investigations centred on the South Alligator River estuary, Northern Territory, are aimed at the reconstruction of vegetation histories in mangrove, saltmarsh and freshwater wetland environments. Interpretation of fossil pollen assemblages is facilitated by the study of modern pollen production and dispersal, through the analysis of pollen trap and surface sediment samples from selected sites along the South Alligator, West Alligator and Adelaide Rivers. The results provide a basis for a model of pollen transfer across the South Alligator coastal plain, and elucidate the pollination behaviour and pollen dispersal of mangrove and saltmarsh plants, many not previously studied in this regard.

Pollen analysis of 4 sediment cores from the prograded coastal plain provides details of vegetation changes, which accompanied changes in sea level and geomorphological settings from approximately 6800 radiocarbon years B.P. to present, on transgressive and regressive shores. The results suggest that the change from non-mangrove to mangrove vegetation on the transgressive shore was abrupt, and did not feature a succession of neatly zoned mangrove communities or the development of saltmarsh. In contrast, vegetation successions on the regressive shore followed predictable sequences, involving mangrove, saltmarsh and freshwater swamp community types, with variations according to specific geomorphological settings local to the core sites. Together, the results of all coastal plain cores provide a detailed account of vegetational and environmental changes through phases of mangrove invasion, estuarine infill and coastal plains development.
Two cores collected on the river floodplain adjacent to the mid-tidal reaches of the South Alligator River provide records of vegetation change in specific settings within the developing estuary. Pollen analysis of core HC 5 is aimed at investigating species presence and vegetational successions on the inside bend of a meander loop of the former, sinuous river channel, for comparison with modern pollen data from potentially analogous settings on the Adelaide River. Difficulties with detailed reconstructions in this instance, relate to poor pollen representation of key mangrove taxa. The pollen record from core HC 9 covers the period from approximately 6000 radiocarbon years B.P. to present and traces vegetation changes from mangrove to freshwater swamp communities.

Pollen assemblages older than 5500 radiocarbon years B.P. throughout the estuary provide evidence of the floristic composition of the mid Holocene extensive mangrove community identified by Woodroffe et al. (1985c, 1986). No substantial difference is indicated between the former extensive mangrove and the lesser mangrove communities of the region today, in terms of floristic composition or the relative abundances of species. A comparison of conceptual models of pollen transfer in fringing and extensive mangroves is made, based on pollen concentrations in sediments, and mangrove to non-mangrove pollen ratios.

The record of relative sea level changes is discussed. Pollen analysis confirms mangrove origins for many dated organic samples used by Woodroffe et al. (1987) as a basis for sea level reconstruction. Stratigraphic evidence indicates that sediment compaction may have affected the height of data points, bringing sea level data for the South Alligator River in line with records from elsewhere in northern and eastern Australia. Palynological evidence for palaeotidal heights,
cited by Woodroffe et al. (1986) may be similarly affected by compactional processes.

The pollen record from the South Alligator River estuary provides no clear indication of climatic changes from 6800 radiocarbon years B.P. to present. The former existence of extensive mangrove in the river estuary, and the more recent development of saltmarsh communities at the coastal fringe, may be related to geomorphological adjustments to sea level change and stabilisation, and do not require climatic explanation.
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Mangrove ecosystems have come under increasingly intense scientific scrutiny over the last few decades for a few key reasons. Firstly, ecological studies based mainly in North America and the Caribbean demonstrated the economic importance of mangroves to coastal developments and nearshore industries, particularly fishing. This precipitated an abrupt change of attitude towards mangrove environments, which had for centuries been regarded as wastelands by the general populace and, to some extent, the scientific community as well. Secondly, the potential scientific rewards from studies concerning unusual ecological, botanical, zoological and geomorphological aspects of mangrove systems have gained recognition in their own right. Thirdly, in the face of rapid land-use development world-wide, the growing interest in mangroves has to some extent gone hand in hand with a more general concern to better understand natural environments, with a view to their continued conservation.

The coast of mainland Australia provides habitats for extensive and varied mangrove communities, particularly in the more humid, tropical regions. Although considerable effort has been made in the study of present day mangrove environments, there has been little concerted effort to provide detailed vegetation histories centred on this community type. This is despite the fact that macrofossil evidence indicates that mangroves were far more widespread in parts of northern Australia during the mid-Holocene than they are today, and flourished perhaps in response to favourable climatic conditions (Jennings, 1975), or to broadscale sedimentary re-adjustments to relative sea level rise.
(Woodroffe et al., 1985c, 1986). Large scale changes in the extent and luxuriance of mangroves in northern Australia must have had a profound effect on the character of the coastline, the ecology of related wetland communities and the life economies of coastal Aborigines who utilised mangrove and mangrove-related resources. The need to obtain detailed historical information regarding mangrove vegetation, particularly through the application of palynological techniques, has long been recognised for the potential wealth of ecological information which may be derived (Flenley, 1979). Until recently, however, such studies have rarely been attempted due to problems inherent in the detailed interpretation of littoral zone stratigraphies.

The subject of this thesis is the detailed study of mangrove distributions and their changes during the Holocene along a geomorphically active coast and within a developing estuary, South Alligator River, Northern Territory. The major technique employed is pollen analysis of littoral zone sediments. By necessity, the study is linked closely to the relative sea level history of the area.

The primary aims of the study are:

1. The reconstruction of a vegetation history of transgressive and regressive phases of the South Alligator River coastal plain.
2. The reconstruction of vegetation histories for selected sites in the upper tidal reaches of the South Alligator River estuary, with particular emphasis on the development of specific habitat types.
3. The investigation of floristic composition of extensive mid-Holocene mangrove communities, identified by Woodroffe et al. (1985c, 1986), which filled the South Alligator River estuary.
4. The refinement of sea level and tidal range reconstructions.
The study forms part of the broader Northern Rivers Project, headed by Dr John Chappell, and supported jointly through the Department of Biogeography and Geomorphology and the North Australia Research Unit, both of the Research School of Pacific Studies, Australian National University.

MANGROVE VEGETATION

GENERAL

The term "mangrove" applies to woody plant communities and individual plant species of those communities inhabiting coastal environments subject to tidal inundation by salt or brackish water. Mangroves are distinct from saltmarsh communities, which constitute another common near-coastal halophytic vegetation type associated with high soil salinities and characterised by succulent herbaceous species, particularly of the Chenopodiaceae and Bataceae.

The world distribution of mangroves is described by many authors (e.g. Walsh, 1974; Chapman, 1970, 1975, 1977). In general mangroves are characteristic of tropical and subtropical coasts where they attain their greatest floristic diversity and luxuriance, although at least 2 species, Avicennia marina and Aegiceras corniculatum, extend well into temperate latitudes (Jones, 1971; Macnas, 1968).

At the broadest scale the distribution of mangroves falls into 2 geographically distinct groups: the "old world" mangroves of the Indo-west Pacific region, and the "new world" mangroves of the American continents and western Africa. The greater floristic diversity exhibited by communities of the former group, has prompted some authors to suggest that early evolution of the mangrove vegetation complex
occurred along old world shorelines (Chapman, 1975, 1977). Although the 2 groups have no species in common they are floristically related in that they share 2 important mangrove genera, *Rhizophora* and *Avicennia*. Other mangrove genera are restricted to one or other of the major world groups.

In structural terms mangroves are diverse, ranging from tall closed-forests more than 30 metres high with a canopy cover of 70 to 100 percent, to low open-forests and woodlands of around 5 metres height and 30 to 70 percent canopy cover, and low open-scrub and shrubland less than 2 metres tall with only 10 to 30 percent canopy cover (Saenger, et al., 1977). In general, particularly where tree canopies are dense, mangrove communities contain only 1 canopy stratum. Ground cover layers are also generally absent where tidal inundation is frequent. The mangrove fern *Acrostichum* may provide a ground layer beneath mangrove trees where tidal inundation is less frequent. In humid areas mangrove communities protected from salt spray also play host to a variety of epiphytic ferns and orchids (Jones 1971).

In floristic terms mangrove communities are dominated by a few plant families, notably the Rhizophoraceae, Avicenniaceae and Sonneratiaceae, and have relatively low species diversity compared with terrestrial plant communities of low latitudes.

**Mangrove Ecology and Physical Settings**

Mangroves occupy those areas of coast where certain environmental factors combine to provide a suitable habitat. Walsh (1974) outlined 5 prerequisites for the development of extensive mangrove communities, including tropical temperatures, suitable alluvial substrate, saltwater, large tidal range and protection from strong waves. Subsequently
Chapman (1975) suggested that ocean currents and gentle shore profiles also play an important role in this regard, while Macnae (1967) emphasised the importance of a humid climate for mangrove luxuriance.

Temperature

Extensive mangroves are confined to areas which have average cold season temperatures not below 20°C, and where the seasonal range does not exceed 5°C (Walsh, 1974). However, mangrove communities of low species diversity exist well outside these ranges (Chapman, 1975; Macnae, 1968). Saenger and Moverley (1985) gauge threshold and optimal mean temperatures for mangrove growth by leafing rate measurements taken in the field, and conclude that temperature exerts a controlling influence on mangrove distributions where other factors, such as rainfall, are not critical. Hence the southern limits of a number of mangrove taxa on Australia's east coast are thought to be dictated by temperature, while on the semi-arid west coast low humidity is probably the critical factor.

Substrate

Optimum conditions for mangrove development occur in estuaries and on deltaic coasts which receive abundant fine-grained terrigenous sediments. This point is emphasised by the generalised environmental settings suggested by Thom (1982, 1984), described later in this chapter. Well developed communities occur on sediments of various origins such as those derived from volcanic parent material (Chapman, 1975) and quartzitic and granitic substrata (Walsh, 1974), while less well developed communities may also occupy sand cay beaches, beachrock platforms (Stoddart, 1980) and coralline limestones (Fosberg, 1975).
Protection from strong waves and currents

Strong wave and tidal currents may restrict mangrove development through erosion of the substrate and inhibition of seedling establishment. Mangroves therefore attain greatest development in protected areas such as in the lee of islands and reefs, and in bays, estuaries and lagoons (Macnae, 1968).

Saltwater

Although many mangrove species are tolerant of high soil water salinities, they are not necessarily obligate halophytes, as indicated by a number of recordings of common mangrove taxa which are persistent under freshwater conditions (Chapman, 1975; Saenger et al., 1977). Bunt et al. (1982) indicate that at least some Australian mangrove species reach optimal growth in salinities somewhat lower than seawater. Conversely, hypersaline conditions, such as those which prevail in high-tide mudflats common along arid or seasonally dry coasts, inhibit mangrove development.

More recently Ball and Pidsley (in press) describe the effect of salinity variations on seedling establishment and growth for 16 mangrove species from north Australia. In all species growth was enhanced by the presence of salt, with maximum growth occurring in less than 50 percent seawater salinity. The results suggest that some species would not grow to maturity in freshwater; Bruguiera parviflora, Ceriops decandra, Ceriops tagal var. australis and Sonneratia alba being tentatively identified as obligate halophytes.
Shore profile and tidal range

The larger the tidal range the greater is the horizontal extent of suitable mangrove habitat, although this factor is obviously also related to the steepness of the intertidal ramp. It has also been suggested that tides play an important role in regulating species zonation within mangroves, either through the selection of types with exacting physiological preference to depth and duration of inundation (Chapman, 1975), or through the sorting by water depth of differently sized mangrove propagules (Rabinowitz, 1978). Deep tidal penetration within estuaries and river systems is also a factor facilitating the "inland" establishment of mangrove vegetation (Walsh, 1974).

Chapman (1975) points out that gentle shore gradients are necessary for the establishment of broad mangrove communities, because they provide a wide intertidal zone suitable for mangrove growth, and are conducive to sedimentary accretion. Coasts of steep gradient at best support only narrow, fringing mangrove communities (Chapman, 1975).

Ocean currents

Ocean currents play an obvious role in the dispersal of floating mangrove propagules, but their indirect effect on the development of communities at sites where mangroves are already established is largely unknown. Chapman (1975) observed that the southern extents of mangroves along the west coasts of Africa, South America and Australia coincide with cold water upwelling from northward flowing ocean currents, and suggests that water temperature is a factor which limits mangrove distribution. In southeastern Australia, however, where cold surface waters circulate from the Southern Ocean (Shannon et al., 1973) mangroves occur beyond their west coast southern limit, suggesting that
factors other than water temperature must be involved. Saenger and Moverly (1985) conclude that mean air temperatures have a critical influence in this regard (see above). It is possible that the predominantly northward circulation on the African, South American and Australian west coasts has restricted the southward migration of mangroves.

Humidity and rainfall

Although mangroves inhabit tropical coasts in arid regions, they reach their greatest species diversity and structural complexity along humid coasts. This was formerly suggested to be the case for Australian mangroves by Macnae (1968). More recently Bunt et al. (1982) have demonstrated from data collected through extensive field observation along the east coast of Queensland that species diversity in mangroves corresponds closely to degree and reliability of rainfall, and to freshwater discharge from rivers.

Geomorphological settings and mangrove habitat

The criteria outlined above have been described by many mangrove ecologists as a basis of defining ecological parameters within which mangroves grow. Such descriptions overlook long-term temporal considerations important to mangrove habitat evolution and hence to our understanding of mangrove distributions themselves. More recently, Thom (1982, 1984) described aspects of mangrove ecology from a geomorphological perspective, portraying mangrove habitats in the context of the dynamic evolution of coastal landforms. At the broadest scale, Thom emphasises the importance of geophysical, geomorphic and biotic components of any coastal environment in which mangroves grow. In particular the first two components determine the character of
physical settings and plant distributions over a wide range of spatial and temporal scales.

Geophysical factors determine the regional geographical make-up of the coastal locality. Important regionally variable factors contributing to the geophysical component are underlying geology, sea level history, and climatic and tidal regimes. Geomorphological features are essentially a product of the combined influence of geophysical factors. For instance, the nature and quantity of sediments delivered to the coast by rivers are largely attributable to regional geological and climatic factors. The distribution and redistribution of coastal sediments through time is also influenced by former and present relative sea levels and tidal regimes. At a smaller scale, factors such as land surface elevation, drainage, sediment stability and nutrient availability within a particular landform create environmental gradients which may be clearly reflected in plant distributions and zonation (Thom, 1982).

From a consideration of the major physical components of the coastal environment, Thom (1982) illustrates 5 generalised settings for mangrove colonisation (Figure 1.1). The settings are for coasts dominated by terrigenous sedimentation, and thus exclude biogenic carbonate systems such as reefs and carbonate banks. The settings do not constitute a comprehensive list of environment types for mangrove habitat, but illustrate basic sets of process variables which influence mangrove establishment, growth and regeneration. Common to each is freshwater and sediment input to the coast from rivers. Variations in tidal range, wave energy and geological constraints result in variations between estuarine plan forms and hence the distribution of sedimentary environments suitable for mangrove colonisation. It is implicit that these environments are subject to change according to continued coastal landform evolution.
Figure 1.1 Five generalised environmental settings for mangrove (shaded), described by Thom (1982, 1984).
ZONATION WITHIN MANGROVES AND THE CONCEPT OF SUCCESSION

Many authors have described species zonation within mangrove communities of both old and new world coastlines (for example Watson, 1928; Davis, 1940; Macnae, 1967, 1968; Walsh, 1974; Lear and Turner, 1977). The pattern of zonation within mangrove communities runs parallel to the coast with successive zones comprised of a different mangrove species or mixtures of species. The transition from one zone to the next often is abrupt and accompanied by a change in vegetation structure, such as in the height or density of the canopy layer. Given a particular suite of mangrove species, zonation will generally conform to a predictable sequence across the intertidal zone.

A number of schemes based on physical environmental factors and plant taxon distributions within mangroves have been proposed to aid the description of mangrove zonation. For example, Watson (1928) categorised mangrove zones according to frequency of tidal inundation, while de Haan (1931) suggested a model based predominantly on soil water salinities. More recently the description of zones have simply followed plant genus dominance. Two of the better known examples of zonation models representing Indo-Pacific (Macnae, 1968) and Atlantic (Davis, 1940) mangrove communities are compared in Figure 1.2. As each is based on floristic criteria alone, the degree to which they are comparable is restricted by the number of plant taxa common to each group. The greater species diversity in mangroves of the West Pacific is reflected in a greater complexity of zonation as indicated by the model proposed by Macnae. Similarities between the 2 occur in that species of Rhizophora generally form a zone (or zones) close to the mean tide level. Avicennia on Atlantic shores commonly occupies a zone immediately landward of this. Although on west Pacific shores Avicennia
TROPICAL FOREST
climax association

CONOCARPUS
transition associates

mature mangrove forest associates

AVICENNIA
salt-marsh associates

mature
RHIZOPHORA
consocies

pioneer
RHIZOPHORA
family

marine aquatic associates

Figure 1.2a Mangrove zonation on tropical American shores (summarised after Davis, 1940).

THE LANDWARD FRINGE
ZONE OF CERIOPS THICKETS
ZONE OF BRUGUIERA FORESTS
ZONE OF RHIZOPHORA FORESTS
THE SEAWARD AVICENNIA ZONE
THE SONNERATIA ZONE

Figure 1.2b Mangrove zonation for Indo-Pacific coasts as described by Macnae (1968).
may form a zone seaward of the *Rhizophora* belt, it is also a common component of landward mangrove communities (Macae, 1968; Lear and Turner, 1977).

The work by Davis (1940) made popular the concept that zones in mangrove vegetation represent stages in a succession through time, which begins with the most seaward associations representing the forerunners in an invasion of new ground which leads through seral stages to the eventual establishment of a true terrestrial, non-halophytic vegetation type. Hence, in the Davis model, terms such as "pioneer *Rhizophora*" for the most seaward and "climax associations" for the most landward vegetation types are used. The successional process is contingent upon the general seaward migration of the respective vegetation zones and hence the coastline itself. Further, it is often implied that this process is autogenic; that is, through enhancement of sedimentation and consolidation in intertidal environments the mangroves orchestrate to a significant degree the progradation and establishment of shorelines (Davis, 1940; Flenley, 1979). A challenge in the more recent literature to this idea has been voiced mainly through the results of geomorphic and sediment-based studies. Scholl (1968, 685) has claimed, "too much importance has been placed on the ability of mangrove trees to bring about coastal progradation by sediment entrapment", and that "mangrove swamp and forest advance seaward only where sedimentary processes have prepared shallow-water areas suitable for the establishment of new mangrove growth". Similar views are expressed by Thom (1967) who describes a number of mangrove habitats on a deltaic coast in Mexico, and concludes that seral changes within mangrove vegetation are of short-term significance, and that the longer-term trends in mangrove and coastal sediment distributions can only be explained in the context of the dynamics of physiographic processes (Thom, 1967).
The relative effectiveness of mangroves as geomorphic agents in coastal environments has therefore been of considerable debate, with extreme opposing views holding that mangrove systems have a significant "land-building" function on the one hand, and that they behave purely as "passengers" which opportunistically colonise suitable sedimentary habitats as they become available, on the other.

MANGROVE VEGETATION IN AUSTRALIA

The distribution of Australian mangroves is described in detail by Galloway (1982). Mangrove communities inhabit coastal sites in all mainland states. Their greatest structural development, species complexity and areal extent occurs in humid, tropical areas where as many as 45 species are recorded (Bunt et al., 1982). The number of species and extent of communities decreases towards higher latitudes on both western and eastern Australian coasts, so that south of Batemans Bay on the New South Wales coast, for example, mangrove communities are mono-specific (Avicennia marina).

In structural terms the progression in mangrove vegetation from low to high latitudes begins with closed forests of 10 to 30 metres tall in the tropical region, grading through low closed forest from 5 to 10 metres tall in subtropical areas and low open forest or low woodland in temperate regions (Saenger et al., 1977). These descriptions relate to optimal mangrove development of the respective regions, and within-region variation due to vagaries of local habitat conditions may be considerable. For example, where rainfall is locally depressed along north eastern tropical shores, stunted mangrove communities, rather than the optimal closed forest types, predominate (Saenger et al., 1977).
Australian mangroves show close floristic affinities with their counterparts in the Indo-west Pacific region (Macnae, 1968) and as such are species-diverse and contain few endemics. Table 1.1 provides a mangrove species list for Australia compiled by Bunt et al. (1982) from extensive field observations along the eastern Queensland coast from Rockhampton (latitude 23°S) to Cape York (latitude 11°S). The list includes all mangrove species previously recorded for Australia by such authors as Jones (1971), Saenger et al. (1977) and Lear and Turner (1977), as well as a number of new recordings which serve to strengthen the floristic ties of the Australian mangrove group with that of the Papua New Guinea region (Bunt et al., 1982). With the exceptions of the ground fern Acrostichum speciosum and the palm Nypa fructicans, all species listed are dicotyledonous trees or shrubs.

The mangrove flora also has a floristic affinity with rainforest vegetation. The single most important mangrove family is the Rhizophoraceae which contains at least 1 rainforest genus (Carallia) and contributes at least 12 species from 3 genera to the mangrove flora. Other important mangrove families, which include 1 mangrove genus and 1 to 3 mangrove species, and which are also well represented in tropical rainforest include Arecaceae, Bombacaceae, Caesalpiniaceae, Combretaceae, Euphorbiaceae, Meliaceae, Myrsinaceae, Myrtaceae, Rubiaceae and Sterculiaceae (Jones, 1971). Some of these families, particularly the Myrtaceae and to a lesser extent Euphorbiaceae, are also well represented in sclerophyll vegetation communities throughout Australia.
<table>
<thead>
<tr>
<th>Family</th>
<th>Genus and Species</th>
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<tbody>
<tr>
<td>ACANTHACEAE</td>
<td><em>Acanthus ilicifolius</em> L. (including <em>A. ebracteatus</em> Vahl.)</td>
</tr>
<tr>
<td>ARECACEAE</td>
<td><em>Nypa fruticans</em> Wurumb</td>
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<tr>
<td>AVICENNIACEAE</td>
<td><em>Avicennia</em> sp.</td>
</tr>
<tr>
<td>BIGNONIACEAE</td>
<td><em>Dolichandrone spathacea</em> (L.f.) K.Sch.</td>
</tr>
<tr>
<td>BOMBACACEAE</td>
<td><em>Camptostemon schultzii</em> Mast.</td>
</tr>
<tr>
<td>CAESALPINEACEAE</td>
<td><em>Cynometra ramiflora</em> L.</td>
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<tr>
<td></td>
<td><em>Cynometra ramiflora</em> var <em>bijuga</em> (Spanoghe) Benth</td>
</tr>
<tr>
<td>COMBRETACEAE</td>
<td><em>Lumnitzera littorea</em> (Jack) Voight</td>
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<tr>
<td></td>
<td><em>Lumnitzera racemosa</em> Willd</td>
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<td></td>
<td><em>Lumnitzera rosea</em> (Gaud.) Presl.</td>
</tr>
<tr>
<td>EBENACEAE</td>
<td><em>Diospyros ferrea</em> var <em>geminata</em> (R.Br.) Bakh</td>
</tr>
<tr>
<td>EUPHORBIACEAE</td>
<td><em>Excoecaria agallocha</em> L.</td>
</tr>
<tr>
<td>LECHYTHIDACEAE</td>
<td><em>Barringtonia racemosa</em> (L.) Spreng.</td>
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<tr>
<td></td>
<td><em>Barringtonia acutangula</em> (L) Gaertn.</td>
</tr>
<tr>
<td>LYTHRACEAE</td>
<td><em>Pemphis acidula</em> J.R. &amp; G. Forst</td>
</tr>
<tr>
<td>MELIACEAE</td>
<td><em>Xylocarpus granatum</em> Koenig</td>
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<td></td>
<td><em>Xylocarpus australasicus</em> Ridl.</td>
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<tr>
<td></td>
<td><em>Xylocarpus moluccensis</em> (Lam.) Roem.</td>
</tr>
<tr>
<td>MYRSINACEAE</td>
<td><em>Aegiceras corniculatum</em> (L.) Blanco.</td>
</tr>
<tr>
<td>MYRTACEAE</td>
<td><em>Osbornia octodonta</em> F. Muell.</td>
</tr>
<tr>
<td>POLYPODIACEAE</td>
<td><em>Acrostichum speciosum</em> Wild</td>
</tr>
<tr>
<td>PLUMBAGINACEAE</td>
<td><em>Aegialitis annulata</em> R. Br.</td>
</tr>
<tr>
<td>Family</td>
<td>Species</td>
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<td>-----------------</td>
<td>-------------------------------------------------------------------------</td>
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<tr>
<td>RHIZOPHORACEAE</td>
<td>Bruguiera cylindrica (L.) Bl.</td>
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<tr>
<td></td>
<td>Bruguiera exaristata Ding Hou</td>
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<td></td>
<td>Bruguiera gymnorrhiza (L.) Lam.</td>
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<tr>
<td></td>
<td>Bruguiera parviflora (Roxb.) Wight &amp; Arn. ex Griff</td>
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<tr>
<td></td>
<td>Bruguiera sexangula (Lour.) Poir.</td>
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<tr>
<td></td>
<td>(Daintree River form)</td>
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<tr>
<td></td>
<td>Bruguiera sexangula (Lour.) Poir.</td>
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<tr>
<td></td>
<td>(Jacky Jacky Creek form)</td>
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<tr>
<td></td>
<td>Ceriops decandra (Roxb.) Ding Hou</td>
</tr>
<tr>
<td></td>
<td>Ceriops tagal var. australis C.T. White</td>
</tr>
<tr>
<td></td>
<td>Ceriops tagal var. tagal (Perr.) C.B. Rob.</td>
</tr>
<tr>
<td></td>
<td>Rhizophora apiculata Bl.</td>
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<tr>
<td></td>
<td>Rhizophora lamarckii Montr.</td>
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<td></td>
<td>Rhizophora mucronata Lam.</td>
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<td></td>
<td>Rhizophora stylosa Griff.</td>
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<tr>
<td>RUBIACEAE</td>
<td>Scyphiphora hydrophyllacea Gaertn.</td>
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<tr>
<td>SONNERATIACEAE</td>
<td>Sonneratia alba Sm. (petalous form)</td>
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<td></td>
<td>Sonneratia alba Sm. (semipetalous form)</td>
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<tr>
<td></td>
<td>Sonneratia alba Sm. (apetalous form)</td>
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<td></td>
<td>Sonneratia caseolaris (L.) Engl.</td>
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<td></td>
<td>(Claudie River form)</td>
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<td></td>
<td>Sonneratia caseolaris (L.) Engl.</td>
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<td></td>
<td>(Johnstone River form)</td>
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<td></td>
<td>Sonneratia caseolaris (L.) Engl.</td>
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<td></td>
<td>(Tully River form)</td>
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<td></td>
<td>Sonneratia caseolaris (L.) Engl.</td>
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<tr>
<td></td>
<td>(Olive River form)</td>
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<tr>
<td></td>
<td>Sonneratia caseolaris (L.) Engl.</td>
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<tr>
<td></td>
<td>(McIvor River form)</td>
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<tr>
<td>STERCULIACEAE</td>
<td>Heritiera littoralis Ait.</td>
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</table>
Evidence for former extensive mangroves has been described for a number of localities in northern Australia; for instance, in Western Australia at the Fitzroy River (Jennings, 1975), the Ord River (Thom et al., 1975) and King Sound (Semeniuk, 1980, 1982), and in the Northern Territory at the Daly and South Alligator rivers (Hope et al., 1985; Woodroffe et al. (1985c, 1986). Radiocarbon dates indicate the presence of the former extensive mangroves between 7500 and 5500 years Before Present (B.P.) (Jennings, 1975; Thom et al., 1975; Woodroffe et al., 1985c, 1986). Mangroves of this period in the South Alligator estuary alone are estimated to have covered about 80000 hectares, or 8 to 10 percent of the present area of mangrove in tropical Australia. Jennings infers a wetter than present mid-Holocene climate for the Fitzroy River area, based on the greater extent of mangroves, and on high mangrove vigour deduced from fossil tree stump diameters exceeding the dimensions of trees living in the area today. In contrast, Thom et al. (1975) and Woodroffe et al. (1985c, 1986) do not invoke climatic explanations for the former extensive mangroves, and emphasise instead, changes in geomorphological settings related to relative sea level rise and stabilisation.

MANGROVE PALYNOLGY

Studies of Pollen Morphology

Muller (1969, 1978) describes the pollen types of 5 species and 2 interspecific hybrids of Sonneratia, which indicate genetic relationships with the Lythraceae. Results of this work combined with a summary of reliable macrofossil evidence lead to a critical evaluation of the early fossil record of this genus. Muller and Caratini (1977)
describe the pollen of 6 species and 2 hybrid populations of Rhizophora, and contribute a useful review of the known geological history of the pollen type. A number of other sources describe the pollen morphologies of particular mangrove taxa, for example, Muller (1964) - Nypa, Sonneratia, Avicennia, Rhizophora; Erdtman (1966) - Avicennia, Bruguiera, Ceriops, Nypa, Pemphis, Rhizophora, Sonneratia; Assemien (1969) - Rhizophora; and Ludlow-Weichers and Alvarado (1983) - Rhizophoraceae. These studies are important for the reliable recognition of fossil mangrove pollen amongst other similar forms, and contribute to the study of taxonomic affinities between plant groups.

Pollen Preservation in Intertidal Sediments

Along many tropical mangrove shores the intertidal zone can be conveniently divided into 3 main sedimentary units: low-tide muds and sands, mangrove sediments and high-tide muds. Descriptions of sedimentary processes within the latter 2 units, insofar as they affect palynological considerations, are given below.

Mangrove sediments

Although mangroves occupy a variety of substrates they are most common and luxuriant on fine-grained sediments. These provide an environment suited to the entrapment and preservation of pollen grains. Under conditions where clay-size particles accumulate, suspended pollen grains also settle readily. Fine mangrove muds tend to remain saturated during exposure at low tide, and where sedimentation proceeds at a reasonable rate they quickly become anoxic and acidic with depth (Semeniuk et al., 1978). Pollen grains preserve well under these conditions (Faegri, 1970). In contrast, coarser sediments such as sand tend to drain easily and entrapped pollen grains are likely to degrade
rapidly through abrasion within a relatively mobile inorganic matrix (Faegri, 1970), and through oxidation during phases of wetting and drying.

Although fine-grained, littoral zone sediments have the capacity to preserve pollen well, some aspects of sedimentation within mangroves reduce the fidelity of the fossil pollen record. Mangroves occupy open systems where sediments may be redistributed by tidal currents and storm waves. Semeniuk et al. (1978) provide an illustration of biotic interaction in a mangrove sediment, which can be regarded as a living soil (Figure 1.3). A variety of biological agents, including nektonic, terrestrial and resident fauna can disturb the mangrove sediment. A vertical section through a productive mangrove soil commonly contains living and dead roots and other plant remains such as mangrove leaves and twigs. Active burrows occur, inhabited by animals including clams, worms, crabs and fish, together with filled traces of disused burrows. The burrowing organisms mix sediments to a depth of at least 30 centimetres and destroy fine detail in the stratigraphic record.

High-tide muds

On many tropical shores high-tide mudflats occur immediately landward of the mangrove fringe, often grading imperceptibly into supra-tidal mudflats. Examples of this sedimentary environment are described by Fosberg (1961), Rhodes (1980) and Chappell and Grindrod (1984). High-tide mudflats lie near to the upper limits of normal high tides, and are sub-aerially exposed for long periods. They may be bare, or covered by low, succulent saltmarsh plants of the Chenopodiaceae, although other families commonly represented include Aizoaceae, Bataceae, Convolvulaceae, Frankeniaceae, Goodeniaceae, Malvaceae,
Figure 1.3 Generalised illustration of a mangrove environment and soil (after Semeniuk et al., 1978). Nektonic, terrestrial and resident fauna cause vertical mixing of sediments to at least 30 centimetres.
Plumbaginaceae, Poaceae, Primulaceae and Scrophulariaceae (Specht, 1981). In humid areas the flats remain damp throughout the year and have a continuous vegetation cover. Under these conditions the sediment surface may steadily accrete, providing a substrate suited to pollen preservation in a continuous stratigraphic sequence.

In seasonally arid environments sedimentary processes on the high-tide flats may be less simple. Rhodes (1980) describes sedimentation on high-tide mudflats in northern Australia (Figure 1.4), in an area subjected to a monsoon climate with heavy summer rains and prolonged, dry winters. Vegetation on the flats is sparse due to high soil water salinities resulting from occasional tidal flooding and excessive evaporation during the dry season. Unlike mangrove sediments, the high-tide muds experience little bioturbation but are exposed to wind which deflates the surface during the dry season, reworking sediments deposited during wet season flooding. By alternation of wet season deposition and dry season deflation the mudflat surface is maintained at a constant elevation even though the adjacent coastline may be prograding (Rhodes, 1980). Pollen preservation is likely to be poor in these sediments due to oxidation and mechanical damage. Pollen records from this facies cannot be interpreted in terms of continuous vegetation histories due to seasonal deflation. However, the vegetation on the high-tide mudflats, though sometimes sparse, is often floristically distinctive, and this has led to the confident recognition of this zone through pollen analysis (Grindrod, 1985).

Studies of Mangrove Pollen Rain and Deposition

A handful of modern pollen studies in mangrove settings provide invaluable information about production, dispersal and deposition of pollen from mangrove plants. Spackman et al. (1966) describe pollen
A summary of the processes of sedimentation and deflation on high-tide mudflats in seasonally arid environments (after Rhodes, 1980).
assemblages from surface sediment samples collected throughout the Everglades–mangrove complex on the Gulf coast of Florida. The results demonstrate that the relative abundances of 3 common pollen types (Rhizophora, Avicennia and Chenopodiaceae) reflect the present zonation of plant species, and provide a useful index of depositional environment and proximity to the mangrove coast. In particular, strong representation of Rhizophora pollen indicates coastal, saline environments; strong representation of Avicennia indicates back mangrove, brackish environments; and strong representation of Chenopodiaceae indicates landward, freshwater swamp conditions. The modern pollen assemblages also provide a basis for convincing interpretations of core sequences described below.

From extensive sampling of coastal and offshore sediments in the Orinoco Delta region of Venezuela, Muller (1959) describes the pollen distributions of Rhizophora mangle and Avicennia nitida. From the recorded distributions of parent plants, aspects of the pollen production and dispersal are inferred. Avicennia pollen has a localised distribution around the parent source, due to low pollen production and the heavy structure of the grain which probably renders it unsuited to wind and water dispersal. In contrast, Rhizophora pollen is widely distributed both landward and seaward of the parent source, indicating prolific pollen production and efficient wind and perhaps water-borne dispersal. Such information is crucial to interpretation of fossil pollen assemblages for the palaeoecological information they contain, and for recognition of former sedimentary environments. The value of Muller's work is demonstrated by its application in other fossil pollen studies (e.g. see Flenley, 1979).
Caratini et al. (1973) describe the relationship between the modern distribution of pollen preserved in surface sediments and the vegetation of a mangrove environment at Pichavaram in southeastern India. The results demonstrate that pollen assemblages do not directly represent the extant vegetation due to the over-representation of Rhizophora and Sonneratia, and the under-representation of Avicennia. Other less common mangrove taxa, including Lumnitzera and Acanthus, maintain pollen representations equal to the abundance of parent plants, while Aegiceras is not represented in the pollen flora. Allochthonous pollen types from upland sources are also well represented within the mangrove sediments. Caratini et al. (1977) briefly mention similar findings in a preliminary report of surface sediment analyses of 4 other mangrove sites in India.

Grindrod and Rhodes (1984) describe the palynology of mangrove environments at Missionary Bay in northeastern Queensland. Although as many as 27 mangrove species are recorded within the Bay, mangrove communities are largely dominated by Rhizophora, Ceriops and Bruguiera, while other common mangrove trees include Avicennia, Xylocarpus, Lumnitzera and Excoecaria. Terrestrial vegetation nearby includes fresh to brackish swamp forests which form just above the level of highest tides, coastal dune communities, and dense wet sclerophyll and tropical rainforests on mountain slopes.

Pollen analysis of modern sediment samples from a range of vegetation types in and around Missionary Bay indicate that, at least in broad terms, surface pollen assemblages reflect the vegetation surrounding the sites of deposition. Samples collected landward of the mangrove swamp, and at the mangrove/dune scrub boundary have low to moderate mangrove pollen components dominated by Rhizophora. In these
samples sclerophyll pollen from upland sources is well represented. Samples from within the mangrove communities are dominated by either Rhizophora or Ceriops/Bruguiera pollen, while other mangrove taxa - Avicennia, Aegiceras, Lumnitzera and Osbornia are recorded at low frequencies (Grindrod and Rhodes, 1984). The surface samples are used in the interpretation of 17 fossil sediment samples analysed for their pollen content to provide a basis for relative sea level reconstruction, described below.

Grindrod (1985) provides a study of modern pollen rain and deposition across a mangrove-fringed chenier plain at Princess Charlotte Bay in northeastern Queensland, based on pollen trap and surface sample analysis. The results provide the basis of a model for pollen transfer across the chenier plain. Components within the pollen rain derive from local, extra-local, regional and long distance sources, with the latter 2 categories achieving ubiquitous and relatively even dispersal. Important locally deposited pollen types in the intertidal and supra-tidal sediments are Rhizophora, Ceriops/Bruguiera, Avicennia and Chenopodiaceae. The results show that the abundance of these pollen types relative to regional and long distance components clearly defines environments of deposition, be they within the zoned mangrove fringe or on the saltmarsh flats.

Studies of Fossil Mangrove Pollen

Pre-Holocene records

The fossil record of mangrove pollen types includes many geologically old (pre-Quaternary) occurrences which document to some extent the early evolution and distribution of this vegetation type. The literature which describes this record is reviewed adequately.
elsewhere (Müller, 1964; Fosberg, 1975; Müller and Caratini, 1977).

Although the most detailed Quaternary fossil pollen sequences containing evidence of former mangrove communities are of Holocene age, 2 longer records have been produced for tropical South American localities. Wijmstra (1969) describes the pollen sequence from Alliance Well in Surinam, which represents the period from the late Tertiary to present, while Van der Hammen (1974) records a sequence from a site near Georgetown, Guyana, representing the period from late Pleistocene to present. Both sequences indicate the alternation of Rhizophora and Avicennia with non-mangrove trees and grasses, which occurred in conjunction with relative sea level changes at the respective core sites. The records do not provide fine detail in vegetation successions due to gaps in the Alliance Well core, and generally coarse sampling intervals. They are valuable, however, because they give some indication of the ecological roles of the 2 mangrove taxa recorded, and indicate that mangrove pollen sequences from both transgressive and regressive shores may be preserved intact for long periods.

Holocene records

Detailed, problem-oriented palynological studies of Holocene mangroves have been undertaken at widely dispersed localities throughout the world. These are aimed at the reconstruction of vegetation histories for transgressive and regressive coastlines and tidal river-estuarine environments, and the analysis of sea level and climatic changes.
Vegetation histories from transgressive shores

Pollen sequences from 2 cores described by Spackman et al. (1966) detail vegetation successions which occurred in conjunction with the recent marine transgression relative to the Florida coast. The deepest core samples contain high concentrations of Chenopodiaceae and open marsh pollen types, and low concentrations of Rhizophora and Avicennia. These are analogous to pollen assemblages from modern freshwater marshes, which presently exist at least 30 kilometres inland from the core sites. A subsequent sharp increase in Rhizophora pollen and decrease in freshwater swamp indicators in both cores indicates a transition to mangrove environments, as rising sea level inundated the site. Rhizophora remains the dominant pollen type through upper sections of both cores though Avicennia is also well represented in some levels. Similarity between pollen assemblages from surface sediments (described above) and core samples, supports the authors' interpretation that the core sequences represent vegetation successions consistent with the 3 major vegetation zones which comprise the present coastal swamp complex. The study by Spackman et al. (1966) was one of the earliest attempts at environmental reconstruction based on pollen analysis of cores collected expressly from mangrove environments.

Vegetation histories from regressive shores

Anderson and Muller (1975) investigate the Holocene evolution of a raised peat bog near Marudi in Sarawak. Their detailed pollen sequence suggests a number of transitions through freshwater swamp associations which succeeded a mangrove community represented by the pollen of Rhizophora, Avicennia, Sonneratia, Oncosperma and Nypa, and spores of the mangrove fern Acrostichum, during a period of rapid shoreline progradation. Due to the relatively strong representation of Oncosperma
and *Nypa* the mangrove unit is taken to represent a low salinity, or backswamp zone of mangrove, subject only to occasional tidal inundation. This interpretation is supported by the presence of *Acrostichum* spores. It is unfortunate that the core ends at the top of the mangrove facies, as deeper boring may have revealed details of early mangrove successions at the site.

Grindrod (1985) reconstructs the history of mangrove and saltmarsh vegetation on a prograded chenier plain at Princess Charlotte Bay in northeastern Queensland. The seaward margin of the plain is fringed by zoned mangrove forests, in which *Rhizophora*, *Bruguiera*, *Ceriops* and *Avicennia* are the most important genera. Behind the mangroves are extensive high-tide to supra-tidal mudflats which are either barren or covered by sparse saltmarsh communities. Four chenier ridges running roughly parallel to the modern coast, traverse the plain for most of its length. These are formed of coarse shell debris moved onshore by storm waves, and mark former shorelines. Stratigraphic analysis indicates that mangroves have maintained continuous occupation of the prograding shoreline through the plain's evolution.

Comparison of pollen sequences from 2 cores collected at geomorphologically contrasting locations provides detailed information regarding mangrove and saltmarsh successions which vary in response to major geomorphic events in the chenier plain's evolution. In particular, the records show that vegetation successions on the smoothly prograding coast follow a predictable sequence consistent with modern plant zonations, but that they may vary dramatically with the imposition of storm-built chenier ridges. The sequences provide the most detailed records so far of species changes in mangrove and saltmarsh communities in geomorphically active environments.
Vishnu-Mittre and Guzder (1973) describe modern plant zonation and the pollen stratigraphy of a mangrove site near Bombay. Although observed pollen occurrences are described briefly the account is of limited value as there is no absolute chronological control on the sequence, and insufficient pollen was extracted from the organically impoverished sediments to justify a pollen diagram.

Caratini et al (1977) describe preliminary pollen analyses of 4 mangrove sites in India. The fossil strata contain a relatively diverse mangrove flora, including Excoecaria, Sonneratia, Aegiceras, Dalbergia, Rhizophora and Avicennia. The first 4 of these taxa have rarely been recorded as important mangrove elements in fossil pollen from other sites. However, due to coarse sampling intervals and a lack of radiocarbon ages, no detailed inference regarding changes within the mangrove communities can be made.

Vegetation histories from lowland swamps and estuaries

A detailed study of the vegetational history of the Isthmus of Panama by Bartlett and Barghoorn (1973) provides concurrent records of former mangrove occupations on tropical American shores. Four pollen diagrams based on a number of cores collected in the Gatun Basin record vegetation changes from mangrove to freshwater lowland swamp communities. The mangrove pollen and spore types recorded are Rhizophora, Avicennia and Acrostichum. Terrestrial plants represented include herbaceous swamp taxa and a diverse array of tropical rainforest trees and ferns.

Core samples containing a high frequency of Rhizophora pollen (sometimes greater than 60 percent of the total pollen recorded) are interpreted by these authors as mangrove in origin. Pollen types
accompanying strong Rhizophora values are primarily from Urticales and rainforest trees, while freshwater swamp taxa are sparse or absent. In some samples further evidence of marine depositional environments includes the presence of histrichosphaerids and oyster shell. The authors also invoke the presence of large pollen types of non-mangrove plants, including Symphonia, Mendoncia, Quararibea, Ochroma and Malvaceae as further evidence of near-shore, marine depositional environments (Bartlett and Barghoorn, 1973).

Pollen of the mangrove tree, Avicennia, is recorded at low frequencies, and only in samples where Rhizophora counts are high. This may reflect the poor dispersal of this pollen type, as reported by Muller (1959). Spores of the mangrove fern, Acrostichum, are generally recorded in conjunction with the other mangrove types, but are also present in samples dominated by terrestrial taxa and lacking other mangroves. This accords with the ecology of Acrostichum which, in Panama, includes two species. Acrostichum aureum is characteristically found in mangrove swamps where tidal inundation is frequent, while A. danaeifolium is most common at the inland limit of tidal influence, where salinities are subdued and mangrove trees are absent. Peaks in Acrostichum values generally accompany a decline in Rhizophora, representing the transition from saline tidal swamp towards fresher conditions. This transition may be short-lived, with Rhizophora again increasing in frequency through successive levels, or lead to the permanent establishment of non-mangrove vegetation around the core site. The results of pollen and radiocarbon analyses of these cores also provide the data points for a time-depth plot of Holocene and older sea levels relative to the Isthmus of Panama (described later in this chapter).
Two palynological studies of cores collected from the South Alligator River estuary have provided details of the history of mangrove vegetation in that region. Hope, et al. (1985) and Russell-Smith (1985) describe pollen sequences from backhoe trenches dug to a depth of 4 metres at Ki'na Swamp. This site lies above tidal influence on the river floodplain adjacent to the tidal river channel, approximately 70 kilometres from the sea. The extensive river floodplains support both ephemeral and persistent freshwater swamps dominated by grasses and sedges. The coastline adjacent to the river mouth is fringed by mangrove forests, in which Rhizophora, Sonneratia, Camptostemon, Avicennia, Bruguiera, Ceriops, Lumnitzera and Excoecaria are common. The pollen record demonstrates that the site was formerly occupied by diverse mangrove vegetation. The mangrove pollen types recorded are Rhizophora, Avicennia, Bruguiera/Ceriops type, Sonneratia, Lumnitzera, Cynometra, Xylocarpus, Excoecaria, Osbornia, Aegiceras and Acanthus. Below 1.6 metres depth the sequence is dominated by Rhizophora pollen and suggests well formed mangrove forests established prior to 6,200 radiocarbon years B.P. Between 1.6 and 1.2 metres depth mangrove pollen decreases relative to other taxon groups. Within the mangrove component there is a change in dominance from Rhizophora to Avicennia, which suggests a transition to a higher intertidal environment. Low pollen values at 1 metre are thought to indicate hypersaline conditions unsuitable for plant growth although, in view of the lack of pollen evidence for a succession to saltmarsh plants, this interpretation may be questioned. If a salt mudflat did develop following the decline of mangroves, the sequence is analogous to those described by Grindrod (1985) for Princess Charlotte Bay. Between 0.4 and 0.7 metres depth the freshwater swamp component dominates the pollen spectra, indicating the establishment of swamplands free of marine incursion. In the upper
levels of the sequence mangrove pollen types, especially Rhizophora, again become important. There is no Rhizophora community currently close to the site. The presence of this pollen is attributed to either occasional saltwater incursions in recent times, or reworked material from older mangrove sediments of the area (Hope et al., 1984).

Similar pollen sequences are described by Chappell and Grindrod (1984), and Woodroffe et al. (1985c, 1986) from core SAH 40 and core SAH 67, collected in mid to upper sections of the South Alligator River floodplain adjacent to the tidal river. Core SAH 40 (also described as SA 40 by Woodroffe et al., 1985c) provides the most detailed pollen record. Vegetation surrounding the site is predominantly of grasses and sedges, and is seasonally flooded by fresh water. The pollen sequence extends from approximately 8 m to 0.8 metres depth. Above this level the core consists of black clays of the modern floodplain. The core is divided into 6 zones. Zone 1 (below 8 metres depth) is made up of estuarine sediments, which have a low pollen content. In zone 2 (8 to 3 metres depth) Rhizophoraceae pollen is strongly represented, suggesting mangrove forests which, according to radiocarbon dates, were established prior to 6,700 years B.P. This pattern is consistent with the record from Ki'na Swamp described earlier. Through zones 3 to 6 (3 to 0.8 metres depth) there is a general decline of Rhizophoraceae pollen, with subsequent short-lived increases in 2 other mangrove taxa, first Sonneratia and then Avicennia. In the upper levels of the sequence pollen of floodplain plants (Poaceae and Cyperaceae) becomes dominant.

Pollen changes in the Ki'na Swamp, SAH 40 and SAH 67 sequences provide detailed information regarding local vegetation histories of the respective core sites, which relate to changes of sea level and geomorphological settings in the drowned, infilling South Alligator
River valley. They are discussed more fully in Chapter 7, together with new palynological evidence for vegetation change in this region.

Climatic reconstructions

Van Campo (1986) describes 2 marine pollen sequences from cores collected near latitudes 15 and 10 degrees north in the Arabian Sea, approximately 150 kilometres from the west coast of India. Absolute stratigraphic ages for both sequences are resolved by comparison of the oxygen isotope content of specific planktonic foraminifera within the cores, with similar, well-established records elsewhere. Both sequences cover the period from the Last Glacial Maximum (L.G.M.) of 18,000 years ago to present. There is good between-core correlation for the relative representation of certain pollen groups, particularly the mangrove group which includes *Avicennia*, *Rhizophoraceae* and *Sonneratia*. The author reconstructs 3 major climatic phases based on the relative representation of mangrove pollen. The interpretation relies on the assertion that high mangrove pollen content in the cores represents extensive mangrove vegetation resulting from a more humid climate than present, and consequent high freshwater discharge from coastal rivers. Major features of the pollen sequence and interpretation are: i) poor representation of mangrove pollen around 18,000 years ago reflects poorly developed mangrove communities and relatively arid conditions in western India; ii) strong representation of mangrove pollen (as high as 40 to 80 percent of the pollen sum) centred around 11,000 years ago, reflects luxuriant mangroves and humid conditions; and iii) a steady decline in mangrove pollen from 11,000 years ago to present indicates the gradual onset of drier conditions thought, in particular, to relate to a weakening of summer monsoonal activity.
Although the results seem to provide useful information regarding fluctuations in mangrove vegetation which indirectly provide evidence of climatic change, uncertainties in the interpretation relate to both geomorphological and palynological variables discussed as points 1 and 2 below.

1. The assertion that phases of luxuriant mangrove growth reflect a change towards humid climatic conditions is questionable because mangrove communities may show dramatic response to geomorphological changes. Woodroffe et al. (1986) conclude that the existence of extensive mangrove between 7,000 and 5,500 radiocarbon years ago in northern Australia can be explained by coastal geomorphological adjustments to sea level rise and stabilisation, and that freshwater hydrological changes need not be invoked. Even though the period of extensive mangrove growth recorded by Van Campo for the west Indian coast occurred prior to the final stabilisation of sea level following the Holocene transgression, it may represent a change in geomorphological conditions related to a temporary slowing or halting of sea level rise sufficient to promote the establishment of broad mangrove communities.

2. During the period from 11,000 years ago to present the coastline migrated many tens of kilometres away from the core sites. The steady decline in both absolute and percentage representation of mangrove pollen during this period may be partly or wholly attributable to the increasing distance between pollen source and site of deposition. In percentage terms the well represented terrestrial pollen types such as Cyperaceae, Gramineae (Poaceae) and Chenopodiaceae, may not be expected to decline as markedly as these derive from a far greater source region than mangrove.
**Mangroves as sea level indicators**

A number of workers have invoked mangrove stratigraphic horizons as indicators of former relative land/sea levels (eg. Spackman et al., 1966; Bartlett and Barghoorn, 1973; Belperio, 1979; Woodroffe, 1981; Grindrod and Rhodes, 1984; Woodroffe et al., 1987). Mangrove sediments are useful in this regard as they maintain in modern environments a predictable relationship to mean tide level, and often include a macrofossil component suitable for radiocarbon dating which provides the necessary chronological control. The sea level reconstructions have generally been based on sediments interpreted as mangrove by their macrofossil content alone (eg. Belperio, 1979; Woodroffe, 1981). A problem with this approach is that mangrove roots may penetrate non-mangrove sediments such as low-tide muds or freshwater swamp organic facies, and so render them indistinguishable at the macrofossil level. A few studies have used pollen horizons in mangrove and related near-shore swamp sediments to provide datum points for former sea levels.

Bartlett and Barghoorn (1973) reconstruct Holocene and older relative sea levels for the Isthmus of Panama. Their time-depth plot is based on radiocarbon determinations for 15 sediment samples from palynologically defined depositional environments. The authors interpret the data as indicating a rapid early Holocene sea level rise of approximately 36 metres between 11,000 and 7,300 years B.P., followed by a more moderate and somewhat variable rate of rise towards modern sea level which was not attained before 1,000 years B.P. Although the early to mid Holocene section of this record is consistent with many other studies from the northern hemisphere, all samples which date younger than 6,500 years B.P. suggest lower relative sea levels than are
reported for the Florida coast (Scholl et al., 1969) and for Bermuda (Neumann, 1972).

When referring to their sea level curve Bartlett and Barghoorn do not describe in detail the environments of deposition responsible for each dated sample. However, cross referencing to their table of radiocarbon dates and then to the pollen diagrams provides this information for all but 1 of the points in the time-depth plot. This reveals that only 2 samples are from mangrove environments; that is, where Rhizophora values exceed 40 percent of the pollen sum. Four other samples appear to represent environments close to the level of high tide, as they are near the mangrove to freshwater swamp transitions in the cores, have low Rhizophora counts (0-10%), and in most cases contain Acrostichum spores. The remaining 8 samples are from freshwater swamp sediments containing no evidence of mangrove in their pollen content, and deriving from levels in the cores many metres above mangrove sediments. In the modern setting, these different depositional environments bear defineable but different relationships to mean sea level. The authors argue convincingly that Rhizophora pollen is a good sea level indicator, especially in areas of low tidal amplitude such as Panama. The high-tide facies also provide useful height reference data, having formed a predictable distance above the level of mean tide. Freshwater swamp samples, which provide all but 1 of the points younger than 5,000 years in the time-depth curve, are not such precise sea level indicators. Prior to its artificial flooding in 1914, the Gatun Basin contained extensive freshwater swamps which apparently did not form more than about 8 metres above mean sea level (Bartlett and Barghoorn, 1973). The trace of mean sea level drawn on the time-depth plot above high tide samples and through freshwater swamp samples is therefore inappropriate, and should pass below all points younger than 6,500 radiocarbon years.
B.P. The trace of mean sea level below the freshwater swamp samples cannot be precisely fixed, but given the ecology of modern environments in this locality may be within 8 metres. Interpretation of the data in this way places the mid to late Holocene sea level evidence from Panama even lower relative to other sea level studies than is indicated by the authors, and requires a rapid rise of 4 to 5 metres in the last 1,000 years to reach present height. The differences between these data and results of the Florida and Bermuda studies mentioned earlier, cannot be attributed to local tectonic or isostatic effects, as in each case the authors play down the importance of these effects for their respective locales. However, it is possible that compaction of the deep, highly organic sediments in the Gatun Basin has significantly reduced the height of dated sedimentary horizons, particularly in upper stratigraphic units (Bartlett and Barghoorn, 1973).

Grindrod and Rhodes (1984) reconstruct early to mid Holocene sea levels for Missionary Bay, north Queensland, based on radiocarbon analysis of 19 organic sediment samples. Environments of deposition for 17 samples are determined by pollen analysis. Of these, 15 are from *Rhizophora* mangrove, 1 is from non-*Rhizophora* mangrove, and 1 is from fresh/brackish swamp. The vertical ranges in modern environments at Missionary Bay for these vegetation types provide vertical error terms for each of the samples on the time-depth plot. Fresh/brackish swamp and non-*Rhizophora* mangrove have the narrowest vertical ranges of the environments identified, and provide the most useful sea level indicators. *Rhizophora* mangrove has a relatively broad vertical range and permits a less precise sea level estimate. The 2 samples not analysed for pollen are inferred to be of mangrove origin by their macrofossil content alone. These carry the largest vertical error.
The data from Missionary Bay suggest a rapid rise in sea level from greater than 15 metres below present some 8,500 radiocarbon years B.P. to within 1.2 metres below present by about 7,000 radiocarbon years B.P. This is in keeping with other sea level reconstructions for eastern Australia by Thom and Roy (1983), based on a variety of primary data types, and Belperio (1979), based on dated mangrove sediments. The considerable scatter in the sea level data from Missionary Bay is probably due to problems inherent in radiocarbon dating of mangrove environments, as outlined elsewhere (Woodroffe, 1981; Grindrod and Rhodes, 1984). This is indicated by radiocarbon age inconsistencies for samples collected within the modern mangrove swamp. Significant height reduction in these sediments through compaction is unlikely as the transgressive organic units directly overly consolidated basal strata.
The Alligator rivers region lies approximately 200 kilometres east of Darwin in the Northern Territory, and drains northward to the southeastern shores of Van Diemen Gulf (Figure 2.1). The region encompasses the catchments of the South Alligator and East Alligator rivers, and the relatively minor West Alligator River. The headwaters of the 2 larger streams flow from the valleys and deep ravines of the rugged sandstone uplands of the Arnhem Land Plateau. To the north and west the river valleys incise an extensive, rolling plain which dips gently northward towards the Gulf. Broad alluvial and deltaic-estuarine plains flank the river courses in the mid to lower reaches of major valleys. Due to a maximum tidal amplitude exceeding 6 metres at the coast and relatively low coastal relief, the South Alligator River is tidal for 100 kilometres upstream from the sea.

Climate

General accounts of the climate of northern Australia and the Darwin region are provided by Southern (1966) and Nix and Kalma (1972), while more specific descriptions of the climate of the Adelaide–Alligator area and the Alligator rivers region are given by McAlpine (1969, 1976). The far north of the Northern Territory experiences a tropical, monsoon climate with dry, relatively cool winters, and hot, rainy summers.
Figure 2.1 The South Alligator River in its geographical context.
Regional Climatic Controls

Atmospheric systems of major regional influence are the subtropical high pressure belt and the Intertropical Convergence Zone (I.T.C.Z.). Seasonal latitudinal migration of these components largely dictates weather patterns across northern Australia. The anticyclonic cells of the subtropical high pressure belt track west to east at roughly 29 to 32 degrees south in winter, and 37 to 38 degrees south in summer. The southeasterly trade winds stem from their northern flanks to converge in the I.T.C.Z. with similarly derived northeasterly trade winds from north of the equator (Nix and Kalma, 1972).

Under the influence of the anticyclonic systems winter weather is typically stable with mean monthly temperatures ranging from 24 to 30 degrees centigrade (McAlpine, 1976), and winds from the east and southeast predominating. In summer, when the high pressure belt is displaced southward, the predominance of moist, unstable, equatorial and tropical maritime air associated with perturbation belts of the I.T.C.Z. brings higher temperatures and heavy rains to much of northern Australia. During this period tropical cyclones are a further, albeit erratic, source of precipitation. Although they follow no common path, cyclones influencing the Darwin region typically originate over the Timor Sea and move in an easterly or northeasterly direction to deliver torrential rains and high seas to coastal Northern Territory (Hopley and Harvey, 1979). Brunt and Hogan (1956) have shown the following frequency of cyclones in the north Australia region over a ten year period: December 0-1, January 2-3, February 1-3, March 1-3, April 0-1.
Rainfall

Five major rain-producing systems for the Darwin region, recognised by Southern (1966), are shown in Figure 2.2. These determine the character and seasonality of both organised rainfall, typified by cyclonic weather and widespread convection, and non-organised rainfall resulting from mesoscale and seemingly random convection.

The annual rainfall distribution for northern Australia west of the Gulf of Carpentaria is summarised in Figure 2.3. The attenuation of rainfall to the south and east of Darwin reflects the importance of moisture laden air from the northwestern sector during the summer months. Mean monthly rainfall data for 4 climatic stations surrounding the South Alligator River are summarised in Figure 2.4. Striking features of the rainfall regime for the area are said to be high annual and monthly reliability, strong seasonality, and relatively little variation in either amount or seasonality from place to place (McAlpine, 1976). Although the relatively short term climatic records provided by stations at Humpty Doo, El Sherana and Mudginberri make the placement of annual isohyets in Figure 2.4 somewhat arbitrary, the data indicate that rainfall in the South Alligator River catchment ranges from less than 1270 mm in inland areas to greater than 1400 mm at the coast. The seasonality of rainfall is clearly illustrated in the monthly histograms. The almost rainless dry season extends from June to September, while heavy rains fall during November to March. Periods of transition occur in May and September-October.
Figure 2.2  Seasonal occurrence of five rain-producing systems for the far north of the Northern Territory (after Southern, 1966).
Figure 2.3 Annual rainfall distribution across northern Australia (from Wells, 1983).

Figure 2.4 Histograms of mean monthly rainfall (from January to December) at 4 climatic stations, and mean annual isohyets in the Alligator Rivers Region (after McAlpine 1969 and 1976).
Wind

Wind roses showing the percentage occurrence of wind direction for summer and winter periods at Darwin airport, Jabiru airport and Oenpelli are provided in Figure 2.5. Values are averages based on 0900 and 1500 hours readings for each station. During the wet season westerlies and northwesterlies predominate at Darwin, although winds from all other sectors remain relatively important. At Jabiru and Oenpelli the westerly influence is less pronounced, with a relatively even spread of wind from most sectors. During the dry season the influence of the southeast trades is very clear at the 2 eastern stations with predominant winds from the northeast, east and southeast. The dry season trend is similar at Darwin, although winds from the northwest and north remain common.

Physiography and Drainage of the South Alligator River Catchment

The total catchment of the South Alligator River covers approximately 12,500 square kilometres (Figure 2.6). In its upper reaches the river drains the escarpment and plateau country to the south of El Sherana, some 150 kilometres from the coast. Here the terrain is rugged, featuring numerous waterfalls and deep ravines containing little or no alluvium. Major tributaries to the South Alligator River from the Plateau are Barramundie, Jim Jim and Nourlangie creeks. Below the escarpment the streams follow incised, gravelly channels in well drained, undulating terrain. In its middle reaches, between 90 and 100 kilometres from the coast, the main river channel is braided and flanked by numerous sandy levees. Extensive freshwater swamps and wetlands fill the valley floor. During summer floods these are connected by a continuous sheet of water which recedes through the dry winter to reveal a system of discontinuous swamps and deep water holes.
Figure 2.5 Percentage occurrence of wind direction during wet and dry seasons for three stations in the Darwin-Alligator Rivers Region. Based on combined 0900 and 1500 hours readings. Total years of observation: 32 at Darwin airport, 9 at Jabiru airport and 29 at Oenpelli (Bureau Meteorology data, 1987).
Figure 2.6 Physiography and drainage of the South Alligator River catchment (after Woodroffe et al., 1985).
The lower reaches of the River are tidal along a single, meandering channel. Tides penetrate at least 100 river kilometres inland from Van Diemen Gulf, to a point well upstream of the outfall of Nourlangie Creek. Broad river floodplains supporting extensive freshwater swamps, and estuarine clay pans extend from the river banks. Freshwater input to the main channel from tributaries north of Nourlangie Creek is negligible.

Relief within the catchment is relatively subdued, with maximum altitude on the escarpment approaching 450 metres above Australian Height Datum (A.H.D.), while the undulating country to the north and northwest does not rise more than 250 metres above A.H.D. The estuarine plains and river floodplains lie in the altitudinal range from 2.5 to 3.5 metres above A.H.D. (Woodroffe et al., 1985a).

**Geology of the South Alligator River Catchment**

The South Alligator River catchment drains a single tectonic depression, called the South Alligator Trough, a pre-Tertiary structural feature associated with the larger and older Pine Creek Geosyncline (Williams, 1969a). Figure 2.7 provides a summarised geological map of the area surrounding the mid to lower reaches of the South Alligator River valley, after Needham and O'Donnell (1983). Archaean basement rocks lie in a low, discontinuous ridge running north/south along the eastern edge of the river catchment. Proterozoic rocks include sediments intruded by granite and dolerite in the west and northeast, and sandstones with interbedded volcanics of the Arnhem Land Plateau to the south and east. Minor occurrences of Mesozoic sedimentary rocks lie to the east and adjacent to the outfall of the East Alligator River. Deeply weathered surfaces and various unconsolidated sedimentary features of the Tertiary and Quaternary overlie deeper strata in
Figure 2.7  Geology of the lower South Alligator River area. Most of the area marked Quaternary has a cover of Holocene sediments. (after Needham and O'Donnell, 1983; and Woodroffe et al., 1986).
intervening areas (Needham and O'Donnell, 1983; Woodroffe et al., 1986).

A detailed account of the early geological history of the area, from the Lower Proterozoic to the Lower Cretaceous, is provided by Williams (1969a), while Galloway (1976) describes major events through the period covering the Cretaceous to Quaternary. The brief description of the geological history of the area given here concentrates on events since the mid-Tertiary as these are particularly relevant to the shaping of the present landscape.

During the second half of the Tertiary era, prolonged erosion reshaped the older weathered land surfaces of the Cretaceous into what is termed the "younger weathered land surface" (Galloway, 1976). Over an extended period of weathering a lateritic cover developed wherever there was sufficient iron in parent rocks. The resultant surface, termed the Koolpinyah surface (Story, 1969), is extensively preserved today on the rolling plains to the north and west of the Arnhem Land Escarpment. This period also saw the steady retreat of the Arnhem Land Escarpment to reveal the gently undulating surface of underlying strata, which is now only moderately weathered, and littered with sandy and gravelly detritus.

On the Arnhem Land Plateau broad valleys incised the upper Proterozoic sandstones and conglomerates of the Kombolgie formation. Most of these valleys are still followed by the major rivers of the area, although the South Alligator River subsequently captured the upper catchment of Fisher Creek which had previously fed into the Katherine River (Galloway, 1976).
A renewed period of erosion in the Late Tertiary resulted in further incision of the Arnhem Land Plateau and further scarp retreat. Following lines of weakness in the Lower Proterozoic rocks, streams in the headwaters of the South Alligator River cut rapidly southward across the Plateau. The lower valleys of the larger rivers incised the "younger weathered surface" to depths well below present sea level, indicating that the sea was relatively lower then than now (Galloway, 1976).

Evidence of several phases of Quaternary alluviation is common throughout the area. On the rolling coastal plains older Quaternary deposits include extensive sand sheets and levee tracts derived from the Kombolgie sandstones of the Plateau, and gravel beds of lateritic and vein quartz material derived from Lower Proterozoic rocks and interbedded Kombolgie volcanics (Galloway, 1976). Younger Quaternary deposits consist of 2 distinct sets of alluvium which are widespread across lowland areas and along major stream courses. The higher set lies 5 to 10 metres above the low water level of rivers, and is apparently not presently accumulating. The lower set is subject to inundation by very high tides and wet season overbank flooding, and is still actively developing (Galloway, 1976). The age and stratigraphy of this lower alluvial set are of prime interest to the present study, and are described in detail in Chapter 4.

Vegetation

The vegetation within and adjacent to the South Alligator River catchment is described in various detail by a number of authors (e.g. Christian and Stewart, 1953; Specht, 1958; Story 1969 and 1976, Taylor and Dunlop, 1985; Woodroffe et al, 1986). Each of these works
is by necessity a simplification of the vegetation of a diverse area and
various inconsistencies exist between them, in part due to the
descriptive techniques employed. In this chapter the mapping and
description of non-halophytic vegetation based on both structural and
floristic characteristics follow most closely the work by Story
(1969, 1976). Descriptions of halophytic communities (saltmarsh and
mangrove) are primarily based on field observation and surveys.

Interrelated aspects of topography, soils and drainage, summarised
in Figure 2.8, determine the broadscale distribution of major plant
communities in the area. A further important environmental factor is
fire. All areas upslope from littoral environments which carry a
sufficient fuel load, are subject to frequent, if irregular, dry season
burning, through fires purposefully lit as a land management practice
and those naturally started by lightning. There is evidence that within
eucalypt communities, tall, open forests are the least often burnt,
probably because this community often includes a relatively sparse
ground cover of grasses unlikely to support a continuous hot fire, and
tree canopies are discontinuous and high above ground (Story, 1976). It
is likely that the present burning regime favours the maintenance and
spread of eucalypt communities at the expense of the less fire-tolerant
rainforest-related communities (Story, 1976).

Descriptions of major halophytic and non-halophytic vegetation
community types are given below. The distribution of these around the
South Alligator River is summarised in Figure 2.9.
Figure 2.8 Generalised relationships between topography, soils and drainage, and the distribution of some major plant community types from lateritic uplands to the tidal fringe (after Aldrick, 1976; and Woodroffe et al., 1986).
Mangrove

Saltmarsh and bare salt mudflat

Sedgelands and grasslands on coastal plains and river floodplains

Herbaceous freshwater swamp

Paperbark forest

Tall open forest, woodland, stunted woodland and scrub

Tall open forest, paperbark forest, grassland and savannah

Grassland on alluvial soils and savannah

Figure 2.9  Major vegetation communities in the South Alligator River Region (modified after Story, 1969; Woodroffe et al., 1986.)
Non-halophytic vegetation communities

Tall open forest

Tall open forest (Plate 2.1) is widespread throughout the region, and displays considerable floristic consistency, particularly in canopy tree taxa. The forest is common on the flat to gently undulating plains north of the Arnhem Land Escarpment, and rarely occurs on steeper, drier slopes. Tall open forest is found on a range of soil types, such as those derived from deeply weathered laterite, fresh quartz sandstone and deep, well drained sand sheets on the Koolpinyah land surface. The predominantly evergreen forest canopy varies from 12 to 18 metres tall, while visibility through the trunk space ranges from 30 to 200 metres. The dominant canopy trees are *Eucalyptus miniata* and *E. tetrodonta* which occur in varying proportions and generally account for at least 50 percent of all tall trees present. The next most widespread and common tree is *Erythrophleum chlorostachys*, while *Eucalyptus bleeseri*, *E. clavigera* and *E. terminalis* occur sporadically. Other tall trees are rare and almost invariably occur with some local variation in habitat (Story, 1969). Subcanopy trees throughout the forest are common and include a variety of species of *Acacia*, *Bossiaea phylloclada*, *Buchanania obovata*, *Cochlospermum gillivraei*, *Gardenia megasperma*, *Grevillea pteridifolia*, *Maytenus cunninghamii*, *Petalostigma quadriloculare*, *Planchonia careya*, *Terminalia ferdinandiana* and *Xanthostemon paradoxus*. The small palm *Livistona humilis* and the palm-like tree *Pandanus spiralis* are also common in particular areas. *Cycas media*, 1 to 2 metres tall, also grows abundantly in restricted patches within tall open forest in the northeastern sector of the South Alligator River catchment. Elsewhere lower shrub strata are generally absent except at sites of copious seedling recruitment by the dominant canopy species.
Plate 2.1 Tall open forest dominated by *Eucalyptus miniata* and *E. tetrodonta.*

Plate 2.2 Woodland with *Erythrophleum chlorostachys*, *Eucalyptus miniata*, *Eucalyptus tetrodonta* and *Livistona humilus.*
The ground layer in tall open forest is dominated by grasses, which are floristically variable relative to the woody plant component. Annual grasses are prominent during the summer rainy season, forming dense stands to 1.5 metres tall, to become dried and brown by mid to late winter. The major contributing species is *Sorghum intrans*, while other important annual grasses include *Eragrostis japonica*, *Eriachne ciliata*, *Pheidochloa gracilis*, *Schizachyrium obliqueberbe*, *Setaria apiculata* and *Thaumastochloa major* (Story, 1976).

Perennial grasses are less common than annuals, providing about 25 percent of the total ground cover. These include many mid height to tall species, some of which retain their greeness, at least in leaf bases, through the dry season. The common perennials include *Allopteris semiliata*, *Chrysopogon fallax*, *C. latifolius*, *C. pallidus*, *Coelorachis rottboellioides*, *Eriachne triseta*, *Heteropogon triticeus* and *Sorghum plumosum*.

Other herbaceous species are not prominent, but include numerous sedges of the genus *Fimbristylis* and dicotyledons including *Bonamia pannosa*, *Borreria spp*, *Gomphrena canescens*, *Pachynema junceum*, *P. complanatum* and *Striga curviflora*.

**Woodland**

Within the South Alligator River region woodland (Plate 2.2) has close floristic affinities with tall open forest, so that the distinction between the two, though convenient for descriptive purposes, may be somewhat arbitrary. However, the major points of difference are:

1. Canopy trees in woodland are not as tall and are more widely spaced than in tall open forest;
2. *Eucalyptus miniata* and *E. tetrodonta*, although common, do not
co-dominate the canopy strata in woodland as they do in tall open forest;

3. Non-eucalypt trees and shrubs are slightly more numerous in woodland than in tall open forest (Story, 1969).

The canopy of woodland is dominated by eucalypt trees from 6 to 12 metres tall. Visibility through the trunk space is generally greater than 200 metres, but varies according to denseness of shrub strata. Common evergreen eucalypts include *E. bleeseri*, *E. miniata*, *E. patellaris*, *E. pheonicea*, *E. tectifica*, *E. terminalis* and *E. tetrodonta*, while deciduous eucalypts include *E. alba*, *E. clavigera*, *E. confertiflora*, *E. dichromophloia*, *E. ferruginea*, *E. foelscheana*, *E. grandiflora*, *E. latifolia* and *E. papuana*. Although a few of the latter group are invariably deciduous, most become so in response to low soil water availability exacerbated by harsh dry seasons and shallow soils (Story, 1969).

Small non-eucalypt trees and shrubs are abundant in woodland and, with the probable exception of *Cycas media*, include those species listed for tall open forest. Ground cover consists of a fairly uniform spread of short, mid-height and tall grasses, with perennials equally or more strongly represented than annuals.

Story (1969) recognises three subdivisions of woodland based on floristic and structural criteria. The first is a *Eucalyptus miniata*-dominated community in which *E. tetrodonta* is rare or absent. In the second, non-eucalypt trees and shrubs are dominant, *E. tetrodonta* is common and *E. miniata* is rare. The third consists of a low woodland characterised by a mixture of deciduous eucalypts and few non-eucalypt trees and shrubs. Although extreme examples of these subdivisions are distinctive, boundaries between them are generally vague within broad, integrade communities (Story, 1969).
Stunted woodland

Stunted woodland occurs on shallow, rocky hillslope soils and has restricted distribution within the South Alligator River catchment. It is characterised by crooked and dwarfed, deciduous eucalypt trees ranging from 3 to 6 metres tall. *Erythrophleum chlorostachys* and *Xanthostemon paradoxus* are also common, while *Cycas media*, *Grevillea pteridifolia*, *Livistona humilis* and *Pandanus spiralis* are notably absent. The shrub layer is sparse apart from occasional clumps of *Calytrix achaeta*, but includes all taxa listed for woodland. The ground cover of grasses is very sparse, with prominent species including *Plectrachne pungens* and *Themeda australis* (Story, 1969).

Scrub

Areas of scrub, termed margin woodland by Taylor and Dunlop (1985), including mixed scrub, *Pandanus* scrub and leguminous-myrtaceous scrub, occur sporadically on moister footslopes and seepage zones of the lateritic uplands, often fringing permanent freshwater swamps of the riverine and coastal plains. Mixed scrub is characterised by densely packed non-eucalypt trees and shrubs. The canopy rarely exceeds 8 metres in height, and visibility is generally less than 60 metres. Characteristic canopy species include *Acacia aulacocarpa*, *Calytrix achaeta*, *Grevillea pteridifolia*, *Melaleuca nervosa*, *Pandanus spiralis* and *Lophostemon lactifluus* while less common trees include *Banksia dentata*, *Eucalyptus polycarpa*, *Grevillea heliosperma*, *Petalostigma pubescens* and *Syzygium suborbiculare*. *M. nervosa* and *G. pteridifolia* sometimes establish as dominant shrubs over relatively restricted areas.
Common species in the floristically rich ground cover include the grasses Chrysopogon fallax, Ectrosia leporina, Paspalum scrobiculatum, Schizachyrium obliqueberbe and Themeda australis, and other small herbaceous taxa including numerous species of Cyperaceae and Restionaceae, Drosera petiolaris, Mitrasacme elata, M. indica, Stylidium floodii and Utricularia fulva (Story 1969, 1976).

Pandanus scrub (Plate 2.3) merges with mixed scrub, and is dominated by Pandanus spiralis, occasionally to the exclusion of other trees. The ground is littered with fallen, dry leaves. A few introduced species such as the herbaceous weed Hyptis sauveolens and the twiner Passiflora foetida are common among a ground cover otherwise consisting of short sedges (Cyperaceae) and annual grasses. Where present, subordinate tree species include Alstonia actinophylla, Eucalyptus papuana, Ficus opposita, F. scobina, Parinari nonda and Syzygium suborbiculare (Story 1969, 1976).

Leguminous-myrtaceous scrub occurs in small patches on gravelly, lateritic soils. This low-growing community ranges from 1 to 3 metres in height, and is characterised by Acacia spp., Bossiaea phylloclada, Calytrix acheata and Verticordia cunninghamii. The sparse ground cover contains a variety of annual grasses common also in Pandanus scrub, and perennial grasses such as Eriachne ciliata, E. triseta and Plectrachne pungens.

Paperbark forest

Paperbark forest (Plate 2.4) occurs most extensively in ephemeral and permanent freshwater swamps adjacent to the South Alligator River where the drainage of tributary valleys is impeded by river levee and floodplain development. Sites of this nature, which also accommodate
Plate 2.3  
*Pandanus* scrub dominated by *Pandanus spiralis*.

Plate 2.4  
Paperbark forest with *Melaleuca* spp.
herbaceous freshwater swamp communities, are termed "backwater swamps" by Woodroffe et al. (1986).

The tree species characteristic of paperbark forest are *Melaleuca cajuputi*, *M. leucadendra* and *M. viridiflora*. Of these *M. leucadendra* is the most common, forming open to dense stands to 20 metres tall. In areas subject to long periods of inundation the canopy strata is exclusively *Melaleuca*, with individual trees displaying copious, short, adventitious roots about their lower trunks. Shrub layers are generally absent except for occasional thickets of the tall, annual *Sesbania cannabina*. The scrambling vines *Ipomoea aquatica* and *Merremia gemella* festoon fallen trees. The lower herbaceous strata varies in luxuriance and floristic makeup depending on water depth, average duration of seasonal inundation, and the amount of shading imposed by the tree canopy. The annual aquatic grasses *Isachne pulchella* and *Panicum mindanaense*, and perennial grasses *Paspalum scrobiculatum* and *Pseudoraphis spinescens* are common. These intermingle at varying frequencies with a variety of aquatic plants common to the herbaceous freshwater swamp flora.

Under drier conditions at swamp margins the paperbark trees lack adventitious roots, and mix with other tree species, notably *Barringtonia acutangula*, *Eucalyptus alba* and *E. papuana*. Here the ground cover is dominated by short sedges and perennial grasses including *Eriachne triseta*, *Fimbristylis pauciflora*, *Paspalum scrobiculatum* and *Pseudoraphis spinescens*.

Paperbark forest also occurs in a mixed form fringing upstream sections of the South Alligator River. Here the common species of *Melaleuca* intermingle with other trees such as *Barringtonia acutangula*, *Eucalyptus papuana*, *Ficus opposita*, *Pandanus aquaticus*, *Parinari nonda* and *Syzygium suborbiculare* (Story, 1969).
Herbaceous freshwater swamp

Herbaceous freshwater swamps (Plate 2.5) grade into paperbark forest, but contain no woody plant taxa. They display greater floristic diversity than the seasonally flooded sedgelands and grasslands of the estuarine and coastal plains (described below), often with a profusion of non-graminoid aquatic taxa. Where water depths exceed 0.5 metres or so throughout the year the swamps are luxuriant with characteristic water lilies, including *Nelumbo nucifera*, *Nymphaea gigantea*, *Nymphoides hydrochoroides* and *N. indica*; perennial sedges including *Eleocharis dulcis*, *E. sphacelata* and *Fimbristylis pauciflora*, and aquatic grasses, particularly *Oryza meridionalis* and those listed for paperbark forest. Other common herbaceous swamp taxa include *Caldesia oligococca*, *Commelina lanceolata*, *Cyperus javanicus*, *C. procerus*, *Fuirena ciliaris*, *Hygrochloa aquatica*, *Hygrophila salicifolia*, *Hymenachne amplexicaulis*, *Ipomoea aquatica*, *Limnophila indica*, *Ludwigia adscendens*, *Monochoria cyanea*, *Polygonum attenuatum*, *Phyla nodiflora*, *Schoenoplectus dissachanthus*, *Sporobolus virginicus*, *Utricularia exoleta* and *Vallisneria spiralis*.

Pteridophytes, such as the primitive fern-ally *Isoetes coromandelina*, the tiny floating fern *Azolla pinnata*, and the rooted aquatic fern *Marsilea mutica* occur on damp ground and in shallow water at the swamp edge. The small annual fern *Ceratopteris thalictroides* has sporadic distribution throughout ephemeral swamps.
Plate 2.5  Herbaceous freshwater swamp with *Eleocharis dulcis*, *Nymphaea gigantea* and *Nymphoides indica*.

Plate 2.6  Saltmarsh communities dominated by *Tecticornia australasica*. Narrow, bright green band at rear of mangrove forest is *Batis argillicola*.
Savannah

Savannah is an open vegetation type characterised by widely spaced, small or moderate sized trees and a ground cover of grasses. It is distinct from woodland in that the trees are more widely separated, permitting visibility to 400 metres or more, and where these two communities abut, their boundaries are generally clear (Story, 1969). Savannah is extensive on alluvial soils in the upper reaches of the South Alligator River valley and the Nourlangie Creek valley. Trees are predominantly eucalypts, with E. papuana and E. polycarpa the most frequent co-dominants. Other common species include E. alba, E. apodophylla, E. clavigera and E. latifolia. The tree stratum typically comprises a mix of species, with monotypic stands neither common or extensive (Story, 1969). The commonest non-eucalypt trees include Banksia dentata, Grevillea pteridifolia, Livistona humilis, Melaleuca nervosa, M. symphocarpa, Pandanus spiralis and Xanthostemon paradoxus. Acervate pockets of P. spiralis and M. symphocarpa also occur, but these are infrequent and do not detract from the characteristic open, grassy appearance of savannah as a whole (Story, 1969). Banksia, Grevillea and Melaleuca are prominent on ill-drained soils.

Grass-dominated communities which constitute the ground cover in savannah are floristically distinct from grass communities beneath tall open forest and woodland. Although they include a variety of short, mid-height and tall species, the mid-height perennials Eriachne burkittii and Themeda australis are clearly dominant. Other common ground cover species include those listed for grasslands on alluvial soils, described below.
Grassland on alluvial soils

Grassland communities on the extensive alluvial tracts of the mid to upper South Alligator River valley grade into savannah, and differ from it only in that they lack trees. *Eriachne burkittii* and *Themeda australis* occur over extensive areas in almost pure communities, which alternate in accordance with subtle changes in soil drainage. Other common grasses occur most profusely around water holes and on stream verges. Characteristic species are the annuals *Panicum effusum*, *P. delictatum*, *P. trachyrachis* and *Pseudopogonantherum contortum*, and the tall perennials *Sclerandrium truncatiglume* and *Sorghum plumosum*. Numerous short sedges, particularly of the genus *Fimbristylis* are also frequent throughout the grassland communities.

Grassland of the sandstone uplands

Grassland communities of the sandstone uplands (not mapped in Figure 2.9) are floristically distinct from those associated with savannah on alluvial soils and within the South Alligator River catchment are restricted to upstream localities in the south and east. The characteristic plant is the perennial grass *Plectrachne pungens* (spinifex), which forms large dense clumps dotted across an otherwise rocky land surface, with occasional small mixed communities of less prominent graminoids such as short Cyperaceae, *Eriachne burkittii*, *Micraira subulifolia*, *Schizachyrium obliqueberbe* and *Sorghum intrans* (Story, 1969).

Sedgeland and grassland of estuarine and coastal plains

Sedge and grass-dominated communities cover the seasonally flooded plains adjacent to the coast and river estuaries. The major community types are described by Taylor and Dunlop (1985) as *Eleocharis* swamp,
Oryza swamp and Fimbristylis sedgeland. These communities are distributed across the plains according to variations in elevation and drainage from site to site. In places they grade into herbaceous freshwater swamp and paperbark forest described earlier.

The higher areas of floodplain are dominated by a relatively diverse sedgeland community in which Fimbristylis tristachya is the characteristic plant, and the low, creeping perennials Ludwigia perennis and Merremia gemella are prominent components. Other common species include the sedges Fimbristylis dichotoma, F. littoralis and Fuirena ciliaris and grasses Elytrophorus spicatus, Imperata cylindrica, Isachne pulchella and Paspalum scrobiculatum. Non-graminoid plants include Bacopa floribunda, Hygrophila salicifolia, Ipomoea aquatica, I. coptica, Malachra faciata, Monochorea cyanea and Phyllanthus urinaria. The tall annual shrub Sesbania cannabina, the deciduous perennial shrub Clerodendrum inerme and the small deciduous tree Cathormion umbellatum occur sporadically either singly or in small groups throughout the drier sedgeland communities. The exotic annual weeds Cassia obtusifolia and C. occidentalis are widespread and often occur in dense stands to more than one metre tall.

In ill-drained depressions, such as infilling palaeo-river channels, the perennial sedges Eleocharis dulcis and E. sphacelata form an even, dense cover to approximately 0.5 metres tall, almost to the exclusion of other plants. This community is the least diverse of any in the area; the few other species recorded being Ludwigia adscendens, Maidenia rubra, Najas tenuifolia, Nymphaea violacea, Oryza meridionalis and Utricularia muelleri (Taylor and Dunlop, 1985).
Swampy habitats towards the upland margins of the estuarine plains are characterised by the annual, aquatic grass *Oryza meridionalis* in another species-poor community which includes the annual grasses *Hygrochloa aquatica* and *Pseudoraphis spinescens*, the perennial sedges *Cyperus javanicus*, *C. procerus*, *Eleocharis dulcis* and *E. sphacelata*, and non-graminoide plants such as *Aeschynomene indica*, *Ceratopteris thalictroides*, *Limnophila indica*, *Ludwigia adscendens*, *Maidenia rubra* and *Monochorea cyanea* (Taylor and Dunlop, 1985).

Halophytic communities

Saltmarsh

Saltmarsh communities (Plate 2.6) occur on high-tide and supra-tidal saline mudflats landward of the mangroves, where they frequently form a distinct, narrow, shore-parallel vegetation zone. At its most luxuriant this community type forms a near-continuous cover of low, spreading shrubs to about 1 metre tall, but more commonly occurs as a sparse to very sparse low shrubland about 0.5 metres tall. Species diversity in the saltmarshes of the South Alligator River region is very low; prominent taxa include the chenopods *Halosarcia indica*, *Suaeda arbusculoides* and *Tecticornia australasica*, all of which are succulent, perennial shrubs. *Batis argillicola*, though not universally present, is common and often forms a narrow, bright green, monotypic vegetation band in contrast to the blue-green and red chenopods. Seedlings and occasional stunted shrubs of woody mangrove plants such as *Aegialitis annulata* and *Avicennia marina* may also be dotted throughout the saltmarsh community. Towards their seaward extent saltmarsh plants may merge with, and provide an understorey to, mangrove communities. To the landward, high ground water salinity associated with dry season desiccation often dictates that extensive areas of saline mudflat are
devoid of vegetation. However, where salinities are locally moderated by, for example, prolonged freshwater seepage from nearby uplands, a few non-succulent plants merge with the salt marsh taxa. These commonly include partially salt-tolerant species of Cyperaceae, and the grasses Diplachne fusca and Sporobolus virginicus.

Mangrove

Mangrove communities fringe open muddy coasts and extend more than 100 kilometres upstream along the major rivers feeding into Van Diemen Gulf. When compared with true terrestrial vegetation communities, the mangroves are floristically poor, with 24 species now recorded for the shores and estuaries around Van Diemen Gulf, including Melville Island (Wells, 1982; Woodroffe et al., 1986), and 20 species within the South Alligator River estuary. The mangrove communities are structurally diverse, ranging from tall, closed forests to low, open shrublands, depending on their age, prevailing environmental conditions and species present. Broad communities of the open coast (Plate 2.7) display segregation of species into distinct vegetation zones in sequences which, though often predictable, may vary from site to site. Boundaries between adjoining zones are usually very sharp.

Typically, Sonneratia alba and Camptostemon schultzii form a tall, open forest in a zone 70 to 100 metres wide, which extends approximately to mean sea level at its seaward limit (Plate 2.8). Behind this is a zone of tall, dense forest dominated by Rhizophora stylosa, in which other species are infrequent (Plate 2.9). Behind the Rhizophora forest, landward mangrove communities typically form mixed shrublands dominated by Ceriops tagal and Avicennia marina with less frequent shrubs of Excoecaria agallocha, Lumnitzera racemosa and Osbornia octodonta. Aegialitis annulata often forms a very low, shrubby ground layer.
Plate 2.7  Looking east from the South Alligator River mouth. Zoned mangrove forest is approximately 300 metres wide. Saltmarsh communities and bare salt mudflats extend landward.

Plate 2.8  Seaward mangrove communities of the open coast dominated by *Sonneratia alba* and *Camptostemon schultzii*. 


Plate 2.9  
Rhizophora stylosa forest.

Plate 2.10  
Avicennia marina woodland adjacent to the South Alligator River, 30 km from the river mouth. Ground cover is Sporobolus virginicus.
In contrast to the open muddy coasts of Van Diemen Gulf, broad and neatly zoned mangroves are uncommon in upstream sections of the South Alligator River estuary, with much of the riverbank supporting only narrow, discontinuous communities or scattered trees and shrubs (Plate 2.10). The width and character of these communities in relation to geomorphological settings are described by Woodroffe et al. (1986), and are summarised in Figure 2.10. Twenty mangrove species are recorded for the South Alligator River estuary. Certain of these, including Aegialitis annulata, Aegiceras corniculatum, Avicennia marina, Camptostemon schultzii, Ceriops tagal and Excoecaria agallocha are common the full length of the estuary, while Bruguiera gymnorrhiza, Osbornia octodonta, Rhizophora apiculata and Sonneratia alba are restricted to the seaward end of the estuary, and Derris uliginosa, Lumnitzera racemosa and Sonneratia lanceolata prefer upstream locations.

It can be seen in Figure 2.9 that mangrove communities fringing the West Alligator River are extensive in comparison to those of the South Alligator River. Clear zonations within these communities are maintained in upstream locations, though zonation sequences vary from that of the open coast due to species preferences for upstream or downstream locations, variations in geomorphological settings, and the topographic height of the river floodplain. Broad and diverse mangrove communities also fringe the estuarine funnel and sinuous meandering section of the Adelaide River (see Figure 2.1 for location). Relatively low salinity environments adjacent to the mid tidal reaches of this river support communities typified by species such as Acanthus ebracteatus, A. ilicifolius, Acrostichum speciosum, Avicennia marina, Dyospyros ferrea and Xylocarpus australasica, which are either rare or absent from the South and West Alligator rivers. Fuller descriptions of mangrove zonations at the open coast adjacent to the South Alligator
Figure 2.10 Distribution of mangroves along the South Alligator River, after Woodroffe et al. 1986, with additional information from M. Ball (pers.comm) and field observation.
River mouth, and at various upstream locations in the West Alligator and Adelaide rivers are provided in chapter 5 in conjunction with surface pollen analyses from littoral zone sediments.
CHAPTER 3

FIELD AND LABORATORY METHODS AND POLLEN IDENTIFICATIONS

Study and Core Site Selection Criteria

Jacobson and Bradshaw (1981) maintain that the judicious selection of field sites for palaeoenvironmental studies is a prerequisite if palaeoecologists are to address specific research problems, other than primary descriptions of past vegetation. Although this has philosophical merit, Head (1984) points out that in practice logistical factors, particularly accessibility and ease of sample collection, may also have a profound influence in this regard.

To reiterate the research aims outlined in Chapter 1, this project set out to provide a site-specific study of the Holocene history of northern Australian mangroves through periods of transgressive and regressive development in coastal and estuarine environments. Closely related to this is the study of relative sea level change, and its effect on local environments. The South Alligator River region was selected as a desirable study site because:

1. The area contains a broad suite of tropical mangrove environments and species, and diverse coastal freshwater swamps in a variety of geomorphological settings which have not previously been palynologically investigated; and

2. At the time the project began the South Alligator River was the subject of a detailed geomorphological study within the joint A.N.U./N.A.R.U. Northern Rivers Project, which could provide logistic support and supporting field data.
Core Site Selection

Initially the South Alligator River coastal plain was selected for coring because the morphostratigraphy of the area suggested a relatively uncomplicated geomorphological history of steady progradation since the mid Holocene, and because it supported clearly zoned, well-developed mangrove forest along its seaward margin. A transect of exploratory auger probes subsequently demonstrated good potential for a detailed palynological record of the transgressive and regressive history of littoral zone vegetation at the site, and ample organic material for radiocarbon dating.

Two upstream core sites were selected to provide examples of vegetation changes in different geomorphological settings through the evolution of the river estuary. Core HC 9 was collected close to the valley edge, in the lower reaches of a well developed backwater swamp. It was expected that a pollen sequence from this site would provide a detailed history of vegetation successions with the transition from a tidal environment to a freshwater swamp. Core HC 5 was collected from the inside bend of a former meander loop of the South Alligator River, manifest at the surface as an oxbow lake now remote from the main river channel and surrounded by river floodplain. Pollen analysis of this core was expected to provide details of riverside mangrove species, species zonations and vegetation successions at a time when the river's plan form, channel morphology and presumably mangrove habitat was different than it is today.
Surface Sample and Pollen Trap Site Selection

Surface samples from 6 transects through mangrove and other near coastal environments of the South Alligator River coastal plain, West Alligator River and Adelaide River were analysed to provide modern pollen signatures for comparison with the fossil records. Pollen traps were also placed across the South Alligator River coastal plain to gauge atmospheric pollen distribution. Each of the sites chosen for modern pollen studies contain particular mangrove species, species assemblages and/or vegetation sequences for which pollen dispersal data were considered useful to interpretation of the fossil pollen record. The detailed description of each transect and relevant pollen analytical results are provided in Chapter 5.

Collection of Samples

Auger probes and sediment cores

Preliminary stratigraphic investigation of a number of sites in the South Alligator River basin was done by auger probe. This and subsequent continuous coring of the coastal plain was accomplished with the University of New South Wales' truck mounted Mole Pioneer drilling rig. Continuous cores were collected by a piston corer attachment using split, 75 centimetre lengths of 50 millimetre diameter P.V.C. tubing as a core tube liner. Core samples retained in their liners were labelled and plastic-wrapped in the field, to eventually be opened and sampled in the laboratory. The drilling rig sampled sedimentary environments accessible to the truck with relative ease. Though core recovery was generally excellent, most samples were compacted during the coring procedure. Cores collected in this manner and analysed for pollen include SAH 29, SAH 30 and SAH 31.
Numerous sediment cores were also collected from the coastal plain and upstream sections of the South Alligator River by a hand coring technique. The procedure involved hammering a continuous length of 80 millimetre diameter class 12 P.V.C. core tube through the sediment, and subsequent extraction by a hand operated winch attached to a 3 or 4 metre tall aluminium tripod. To minimise sediment compression a core tube piston fixed in position at the sediment surface by a line to the tripod head was used to maintain negative pressure inside the core tube as it was driven into the sediments. The sediment-filled core tubes were capped upon retrieval and remained sealed until cores were sampled in the laboratory. The hand coring technique allowed for relatively easy collection of continuous cores up to 4 metres long, and it is likely that longer cores could be retrieved if required. A major problem with the technique was the shattering of core tubes during the "hammering in" procedure, even though they were protected by a neatly fitted steel anvil. In sediments which afford only moderate resistance this problem can be avoided by prudent use of the hammer. For stiffer sediments, heavier gauge P.V.C. tubing (class 15 or class 18) could be used. Advantages of this technique are that the equipment is hand-portable, and the 80 millimetre diameter cores generally provide ample material for pollen and radiocarbon analysis. Cores collected by the hand coring technique and analysed for pollen include HC 4, HC 5 and HC 9.

Surface sample collection and pollen traps

Surface sediment samples for pollen analysis were collected by hand into plastic vials. Generally about 10 cubic centimetres of material was collected; and only the upper 0.5 centimetres of sediment was sampled. Samples were stored in absolute ethanol immediately following collection.
Pollen traps of the Oldfield design (Flenley, 1973), were used to collect airborne pollen grains at selected sites. The traps were protected by standard mesh insect wire, and attached by tie-wire to trees in mangrove environments, and on wooden stakes 2 to 3 metres above ground level in non-mangrove environments. Major difficulties with the pollen trapping program occurred through loss of trap or sample through storm damage or interference by birds and feral buffalo.

Chemical Preparation of Samples for Pollen Analysis

The laboratory preparation for pollen analysis of a range of sediment types from subtidal, lower intertidal, mangrove, upper intertidal, freshwater swamp and floodplain environments dictates the use of relatively complicated and rigorous chemical procedures. In particular, sediments tend to be low in organic content, with inorganic matrices ranging from clay to medium sands. Some also contain considerable quantities of calcium carbonate, generally in the form of whole or fragmented marine shells. The major pollen extraction procedure used in this study (procedure I) for the preparation of sediment and pollen trap samples relies on chemical separation of pollen from extraneous organic and inorganic material, and broadly follows techniques described by Erdtman (1969), Faegri and Iversen (1966) and Gray (1965). A second procedure (procedure 2) relies heavily on physical means for the separation of organic and inorganic components within sediment samples. This procedure was followed for the preparation of some core samples from which pollen extraction proved difficult by chemical procedures alone.
Regardless of the extraction procedure followed, estimations of pollen concentrations in sediments rely on accurate dry weight and volumetric measurement of samples, and rigorous steps are taken to avoid loss of sample during preparation through spillage, chemical degradation or adherence to glassware. All sediment samples for pollen analysis are oven dried at 40°C for 24 hours prior to laboratory preparation.

Procedure 1

Between successive stages of the procedure, where a change in liquid matrix is required, the sample is centrifuged at 2,000 r.p.m. for 3 minutes, and the supernatant decanted. Mixing of samples in the test tube is achieved on a vortex rotary mixing machine. All procedures involving acids are conducted in a fume cupboard.

An accurately weighed sample of dry sediment is washed in distilled water. To remove calcium carbonate, the sample is mixed in 10 percent hydrochloric acid until bubbling ceases. Samples containing large amounts of marine shell may require several acid changes.

The sample is then hydrolysed in hot, 2 percent sodium hydroxide solution for 5 minutes and washed through a 200 micron terylene cloth sieve, and the coarser fraction discarded.

The sample is then washed in distilled water and mixed in 40 percent analytical grade hydrofluoric acid and left to stand for either 1 hour in a boiling water bath or 24 hours cold. This is generally sufficient to remove the fine silicates. The sample is washed again in distilled water and then mixed in 10 percent hydrochloric acid and left to stand in a boiling water bath for 10 minutes to remove residual fluorides.
The sample is then treated in cold, dilute Schulze solution. In concentrated form Schulze solution provides a powerful (and potentially explosive) oxidant commonly used for the maceration of carbonaceous sedimentary rocks, especially coals (Gray, 1965). In dilute form the solution is useful for the solubilisation of phenolic detritus in sediments, and has been applied in this study for the removal of organic materials which may be resistant to acetolysis. Due to the bleaching effect of the chloric acid evolved, it is convenient to apply this treatment prior to acetolysis to obviate the need for staining the pollen grains at some later stage.

The Schulze solution is prepared by dissolving approximately 1 gram per sample of potassium chlorate crystals in 25 percent nitric acid. The volume of acid is not critical, and the dissolution of crystals may be facilitated by stirring and gentle warming of the mixture over a hot plate.

The sample is left to stand for 1 hour in cold Schulze solution, and then for 10 minutes in 5 percent ammonium hydroxide solution.

The sample is then washed in distilled water and twice in glacial acetic acid in preparation for acetolysis which removes further extraneous plant material through the hydrolysis of polysaccharides to form water-soluble products. The sample is heated for 10 minutes in a 9:1 mix of acetic anhydride and concentrated sulphuric acid. The sample is then washed twice in glacial acetic acid and 4 times in distilled water to bring it to neutrality.

The sample is then dehydrated by washing twice in absolute ethanol, mixed in tertiary butyl alcohol (T.B.A.), and transferred to a glass storage vial.
Procedure 2

This procedure was developed by Dr. Robyn Clark of the Water Resources Division of the C.S.I.R.O. The removal of the inorganic fraction of sediment samples is primarily achieved by heavy liquid separation. Chemical treatments are kept to a minimum so that chemical damage to pollen grains is unlikely. The procedure is generally time efficient (relative to procedure 1), and recommended for samples which are poor in pollen and rich in fine-grained, inorganic material. In this study the procedure was used in the treatment of all samples from core HC 9. These samples provided inadequate pollen for analysis when preparations followed procedure 1. Preparations following procedure 2 were carried out in the laboratories of the Water Resources Division of the C.S.I.R.O. at Black Mountain, Canberra, with the kind consent of Robyn Clark.

Except where otherwise specified, when a change in liquid matrix is required, the sample is centrifuged at 2,000 r.p.m. for at least 3 minutes, and the supernatant decanted.

An accurately weighed sample of dry sediment is macerated in 10 percent potassium hydroxide in 0.1 molar sodium polyphosphate (calgon). The sample is again mixed in the potassium hydroxide/calgon solution and placed in a boiling water bath for 10 minutes. The sample is then filtered through a 200 micron terylene cloth mesh and the coarse fraction discarded. The sample is then mixed in 10 percent hydrochloric acid and left to stand until bubbling ceases.

The sample is vigorously mixed in zinc bromide solution with a specific gravity of 2.2 and centrifuged at 1500 r.p.m. for 15 minutes, and the supernatant (with suspended organic fraction) decanted onto a 5
micron acetate membrane filter. This step is repeated twice; filtration is vacuum assisted and changes of filter paper may be necessary. At completion of this stage the heavier (inorganic) fraction of sediment at the bottom of the test tube, and the finer sieved fraction are discarded. The filter paper which should now contain only organic material is dissolved in acetone.

The sample is then mixed in 40 percent hydrofluoric acid and left to stand in a boiling water bath for 10 minutes, to remove fine silicates which may have survived the heavy liquid separation procedure. The sample is then mixed in 10 percent hydrochloric acid and again placed in a boiling water bath for 10 minutes to remove fluoride residues.

The sample is washed twice in glacial acetic acid, and then mixed in acetalolysis mixture (9:1 acetic anhydride and concentrated sulphuric acid), and left to stand in the boiling water bath for 10 minutes.

The sample is washed in glacial acetic acid, and then in acetone and transferred to a storage vial, prior to placement onto microscope slides.

**Placement of samples onto microscope slides**

The sample in storage vial, following either of the procedures outlined above, is centrifuged and the supernatant decanted. A measured volume of silicon oil is then added; the amount varying according to the volume of sample retained. The sample and oil are mixed thoroughly and left to stand in the open vial on a hot plate to ensure the remaining T.B.A. or acetone is evaporated. A measured volume of the sample, generally 20 microlitres, is placed onto a microscope slide and
sealed beneath a cover slip with paraffin wax. This preparation ensures long-term preservation of the sample in a form which can be readily examined under the microscope.

**Pollen concentration determinations in sediment samples**

The quantitative sampling procedures described above provide a means by which estimations of pollen concentrations per gram dry sediment can be made. The estimations are based on the total of all pollen grains and pteridophyte spores recorded, using the formula:

\[ P(c) = \frac{P(n) \times T(p) \times v}{V(s) \times T(n)} \]

where, 
- \( P(c) \) = number of pollen grains per gram of dry sediment
- \( P(n) \) = number of pollen grains counted
- \( T(p) \) = number of transects possible on slide(s)
- \( T(n) \) = number of transects counted
- \( V \) = volume of silicon oil in prepared sample
- \( V(s) \) = volume of sample on microscope slide(s).

**Pollen influx determinations for pollen trap samples**

Rates of pollen influx (\( P_i \)) for pollen trap samples, are expressed as the number of pollen grains (including pteridophyte spores) deposited per centimetre squared of trap area per year, and are calculated by the following formula,

\[ P_i = \frac{(T_p \times P_n \times V / T_n \times V_s \times C)}{M} \]

where, 
- \( P_n \) = number of pollen grains counted
- \( T_p \) = number of transects possible on slide(s)
- \( T_n \) = number of transects counted
- \( V \) = volume of silicon oil in prepared sample
Vs = volume of preparation on slide

C = area of pollen trap aperture

M = fraction of one year that the traps were set.

**Organic fraction determinations**

Estimations of the organic content of surface sediment and core samples followed the loss on ignition technique which is widely used in soil and sediment analysis (Allen, 1974). The samples are left in a drying cabinet at a constant 110°C for 24 hours. A measured weight of dry sample is then ignited in a muffle furnace at 550°C for 2 hours. The difference between the dry weight measurement and the weight of residue after ignition is taken as the weight of the organic fraction of dry sediment.

Due to the relatively small amount of material available from cores, and space available in the muffle furnace, only small sediment samples (generally about 2 grams dry weight) were used for the organic fraction determinations. Consequently, large organic fragments, which are common in mangrove muds, were avoided during sampling, so that organic determinations relate to the organic content of the fine-grained sedimentary matrix. If large samples, containing organic macrofossil remains could be processed using the same technique, higher values for the organic fraction might be recorded for some facies types. There are no organic fraction determinations for samples from core HC 9, because many of the samples apparently exploded at high temperature in the muffle furnace, causing exchange of material between samples contained in open crucibles, and thereby destroying the results.
Pollen Counting and Identifications

Pollen counting was conducted on a Zeiss (Oberkochen) photomicroscope and an Olympus BH2 microscope at X256 and X250 magnification respectively, with higher magnification (up to x1600 oil immersion) for identification of small or problematic grains. Transects across the slide were placed at regular intervals such that the fields of view of consecutive runs did not meet. Where possible counts continued until a pollen sum of 150 angiosperm and gymnosperm pollen grains was achieved. Pollen identifications were aided by the use of the reference slide and photographic collections held at the Department of Biogeography and Geomorphology, Australian National University. Additional reference material of mangrove pollen was collected from various field locations in the study area, from the Northern Territory Conservation Commission Herbarium in Darwin, and the C.S.I.R.O. Herbarium at Black Mountain in Canberra. Pollen was also collected from more than 100 non-mangrove species in the study area for addition to the reference collection. Ecological descriptions of all plants represented in modern and fossil pollen assemblages are provided in Appendix 1.

In all cases identifications are made to at least family or genus level. The suffix "undetermined" appears in conjunction with the family titles Myrtaceae and Leguminosae, to denote pollen of these taxa that cannot be confidently assigned generic status. For some categories the term "type" is affixed to the generic or species name (e.g. Eucalyptus tetrodonta type) to describe a pollen morphological type which conforms to that of the designated taxon, but which may include pollen from other morphologically similar groups.
The degree of confident identification of all common pollen types encountered in this study is high, with unidentified grains usually less than 5 percent of the pollen sum. This is partly due to the low diversity of pollen floras in littoral zone environments, and because only 1 of the mangrove families recorded in the study area contains more than 1 mangrove genus so that, at the genus level at least, most of the mangrove pollen types encountered are morphologically dissimilar. Further, the predominant mangrove families are not strongly represented in the local or regional non-halophytic vegetation, so that their pollen floras are distinct from those of neighbouring landward communities. On humid coasts, where mangroves abut rainforest at their landward margin, this distinctiveness may be less pronounced as many mangrove families have clear rainforest affinities. A few important pollen groups encountered in this study do, however, present problems of identification, particularly at genus and species level, and these are discussed briefly below. Photographs of common and important pollen types encountered in this study are provided in Plates 3.1 to 3.3.

The family Rhizophoraceae contributes the greatest number of genera and species to the mangrove flora. Detailed descriptions of the pollen morphology of the family are given by Erdtman (1966) and Ludlow-Wiechers and Alvarado (1983), and of the genus Rhizophora by Muller and Caratini (1977). The separation of Rhizophora pollen from that of the related genera Ceriops and Bruguiera is straightforward, based on grain size and morphology. The separation of Rhizophora pollen types to species level is more difficult however.

The detailed morphological study of 6 species and 1 hybrid of Rhizophora, including all Australian types, led Muller and Caratini (1977) to comment that "it is extremely difficult to find characters
PLATE 3.1

1a-c **Rhizophora** 3-colporate, often zonorate or nearly zonorate; subprolate, 18-25 microns long; psilate to faintly reticulate.
   a & b, equatorial view; c, polar view.

2a-d **Ceriops/Bruguiera** 3-colporate, laalongate pore; prolate to spheroidal, 12-16 microns long; psilate to faintly reticulate.
   a, polar view; b & c, equatorial view; d, oblique equatorial view.

3a-c **Avicennia** 3-colporate, pores round; oblate spheroidal, 25-35 microns long; thick exine wall, distinctive reticulate sculpturing.
   a, polar view; b, equatorial view; c, polar view, mid-focus.

4a-b **Excoecaria** 3-colporate; oblate spheroidal, 30-36 microns diameter; finely reticulate.
   a, oblique equatorial view, b, polar view.

5a **Sonneratia** 3-aperturate, pores round; often subprolate, sometimes bulging at the pores, tapering to the poles, 30-50 microns long; verrucate with strongest patterning in broad equatorial belt.
   a, oblique polar view.

6a-c **Lumnitzera** Heterocolporate (6 colpi, 3 pores); subolate, spheroidal, 26-30 microns diameter; distinctly reticulate with strong polar sculpturing.
   a, polar view, mid-focus; b & c, oblique equatorial view.

7a-c **Xylocarpus** 4-colporate (brevicolporate), nexine thickened at pores; subolate, 27-32 microns diameter; pattern indistinct.
   a, polar view, mid-focus; b, polar view; c, equatorial view.
PLATE 3.2

1a-b Acanthus
3-colpate; prolate to elongate, 38-60 microns long; reticulate, retipilate. a & b, equatorial view.

2a-b Aegiceras
3-colporate, lalongate pore; subprolate to prolate, 15-20 microns long; psilate to faintly reticulate. a, equatorial view, mid-focus; b, oblique equatorial view.

3a-c Camptostemon
4-aperturate, thickened pore edges; spheroidal to suboblate, 40-48 microns diameter; spinate with thickened spinule bases. a, polar view, mid-focus; b, oblique equatorial view; c, oblique polar view.

4a-b Batis
3-colporate (colporoidate); subprolate to prolate, with distinct exine thickenings midway between colpi, generally at equator; 20-26 microns long; pattern indistinct. a, equatorial view; b, equatorial mid-focus.

5a-b Chenopodiaceae
Periporate, pores round; spheroidal, 22-30 microns diameter; pattern indistinct to faintly reticulate.

6a-b Eucalyptus tetrodonta type
3-porate, parasyncolpate; isopolar, triangular, straight-sided, 19-26 microns maximum width; faintly reticulate, polar island patterned. a, polar view, mid-focus; b, polar view.

7a-b Eucalyptus nesophila type
3-porate, parasyncolpate, thickened pores; isopolar, oblate, 18-25 microns maximum diameter; reticulate, indistinct pattern on polar island. a, polar view; b, oblique equatorial view.

8a-b Gonocarpus type
4-6 aperturate (stephanoporate) lalongate pores; oblate to oblate-spheroidal, 28-32 microns diameter; pattern indistinct. a, oblique equatorial view; b, oblique equatorial view, mid-focus.

9a Casuarina
3-porate, pores round or slightly lalongate; suboblate, 25-40 microns maximum diameter; pattern indistinct. a, oblique polar view.
PLATE 3.3

1a-b Poaceae

1-porate, thickened pore anulus; spheroidal to ovoid, 25-35 microns diameter; psilate to faintly reticulate.
a, deformed grain; b, entire grain.

2a Cyperaceae

One or more ulcerate, generally 1 ulcerate pore at thickest end and 3 lateral pores; elongate (tapering) to ovoid, 25-38 microns long; L0 pattern (Erdtman 1966).
a, lateral view.

3a-b Restionaceae/
Centrolepidaceae

1-aperturate, pore large with irregular outline; spheroidal to ovate, 28-36 microns diameter; exine appears perforate due to numerous lumini (scrobiculate).

4a Pandanus

1-aperturate, pore more or less round, often indistinct; spheroidal to ovoid, 13-17 microns diameter; spinate, spinules generally about 1.5 microns long.

5a-b Typha

1-aperturate (ulcerate); ovoid to spheroidal, 13-17 microns diameter; reticulate.

6a-b Aeschynomene

3-colporate, lalongate pore; prolate to spheroidal, 14-19 microns long; pattern indistinct or faintly reticulate.
a, equatorial view; b, oblique polar view.

7a-b Selaginella

Two spore types:
a, large spore: trilete, radiosymmetric and heteropolar; 27-48 microns diameter; rugulate, often with ridges running parallel to equator.

b, small spore: trilete, radiosymmetric and heteropolar; 27-40 microns diameter, psilate.
which unequivocally permit the recognition of species of Rhizophora on their pollen. Especially at the light microscopical level the differences between the species are slight and mostly quantitative with considerable overlapping" (p376). However, with the combined use of light and electron microscopy (S.E.M. and T.E.M.) these authors conclude that "on the basis of a limited number of diagnostic criteria three groups could be distinguished" (p386). The groups suggested are (1), R. mucronata, R. stylosa; (2), R. apiculata, R. lamarckii, R. mangle; and (3), R. racemosa.

Initial examination in Australia of Rhizophora pollen collected at Hinchinbrook Island in north Queensland suggested that the pollen of R. stylosa and R. apiculata could be separated on size and morphological criteria under the light microscope. More recent examination of a large selection of reference material from elsewhere in Queensland and in the Northern Territory, has revealed sufficient overlap in the pollen morphologies of the 2 species to make their confident separation untenable (Grindrod, 1983). In pollen diagrams of the present study, Rhizophora pollen is represented at genus level only.

Pollen grains of Bruguiera and Ceriops are not readily distinguishable from each other under the light microscope, as there are no morphological groups strictly representative of either genus, or of any 1 species. Micro-patterning revealed under X1600 oil immersion magnification and originally thought to be confined to species of Ceriops, has also been observed in Bruguiera parviflora. In the present study all pollen grains of this type are recorded in the single category Ceriops/Bruguiera.
Muller (1969) provides a detailed study of the pollen morphology of 5 species and 2 interspecific hybrids of *Sonneratia*, based on samples collected throughout the Pacific region, including the eastern coast of Queensland, and Darwin Harbour in the Northern Territory. The study indicates morphologic differences between the pollen of *Sonneratia alba* and *S. lanceolata* (syn. caseolaris), but demonstrates considerable intra-specific variability for these taxa. The geographical distribution of pollen morphological subtypes is not random, and factors thought to effect variability include plant growing conditions such as soil type and climate, the age of the parent tree and genophytic variation. It was also shown that certain pollen subtypes of *S. alba* share striking morphological similarities with certain subtypes of *S. lanceolata*. The results therefore suggest that site specific studies of the pollen morphologies of these 2 species is appropriate if their respective pollen types are to be confidently separated. Because of time constraints and a difficulty in collecting *Sonneratia alba* pollen from field sites before pollen counting began, such a study was considered beyond the means of the present project. Although *Sonneratia* grains were separated into size categories in the raw pollen counts, the pollen type is categorized at genus level only on the pollen diagrams.

Other mangrove pollen types recorded in the pollen counts can be confidently identified to genus level. These include *Acanthus*, *Aegiceras*, *Avicennia*, *Camptostemon*, *Excoecaria*, *Lumnitzera* and *Xylocarpus*.

Chenopodiaceae pollen is identified to family level only, as the common chenopod genera in the area, *Halosarcia*, *Suaeda* and *Tecticornia* were found to be inseparable by their pollen morphologies. Chenopodiaceae pollen is distinguishable from similar periporate
Amaranthaceae and Caryophyllaceae pollen types presently produced within the study area, by differences in pattern, grain size and/or the ratio of grain size to aperture size.

**Batis argillicola** is the sole representative in the study area of the monogeneric family Bataceae. *Batis* pollen shares some morphological similarities with pollen types of the Gyrostemonaceae, but is distinctive due to pronounced local exine thickenings usually spaced equatorially and midway between the colpi.

Morphological descriptions of many Myrtaceae pollen types from the southwest Pacific region are given by Pike (1955), while Dodson (1974) discusses the identification of types within the group from sites in southwestern Australia. In the present study only 2 Myrtaceae pollen types are sufficiently distinctive and similar to reference material to be identified beyond family level. These are *Eucalyptus tetrodonta* type and *Eucalyptus nesophila* type. *E. tetrodonta* is a common forest tree throughout the far north of the Northern Territory. *E. nesophila* is not recorded in the study area, but occurs nearby at Coburg Peninsula and on Bathurst and Melville Islands. The pollen of this species bears close morphological similarity to that of *E. spathulata*, a marlock species from southwestern Western Australia. Other Myrtaceae pollen grains are lumped into the general category "Myrtaceae (undetermined)."

**Gonocarpus** pollen is not distinguishable from pollen of a number of *Haloragis* species recorded in the Northern Territory. It is generally distinguishable from *Myriophyllum* pollen by elongate rather than rounded pores, although there may be some morphological overlap between these types as well. The *Gonocarpus* type pollen encountered in pollen counts is thought, almost certainly, to derive from *G. leptothecus*, which is the only dryland species of the Haloragaceae recorded in the South Alligator River area.
Identification of the Aeschynomene pollen type relies on 1 sample held in the pollen reference collection in the Department of Biogeography and Geomorphology at the Australian National University. Aeschynomene indica is a small annual shrub which apparently grows through the wet season (see Appendix 1), and is relatively common in floodplain communities of the Alligator rivers region (Taylor and Dunlop, 1985). Unfortunately reference pollen for this species from the study area has not been collected, as the plant was not recorded in vegetation surveys, and no pollen was available from the Conservation Commission of the Northern Territory Herbarium. Pollen of A. indica collected from the semi-arid environments near the Finke River, Northern Territory (Biogeography and Geomorphology reference number 129-128-1a) bears little resemblance to pollen grains encountered in the present study. However, reference pollen of A. indica collected from coastal environments in the Morobe District of Papua New Guinea (Biogeography and Geomorphology reference number 129-128-1), although variable in size and shape, is sufficiently similar to pollen grains in sediment samples from the study area to permit confident identification of this pollen type to genus level. The morphological differences between the 2 reference pollen samples presumably reflects genotypic differences between distinct populations of the species in contrasting environments.

Other commonly recorded pollen types in this study include Poaceae, Cyperaceae, Restionaceae/Centrolepidaceae, Typha, Pandanus, Casuarina and Callitris. These are well known from many palynological studies Australia-wide, and provide few problems of identification when well preserved.
Pteridophyte spores are generally poorly represented in the pollen counts, but are occasionally important. *Selaginella uliginosa* produces distinctive, trilete spores. The plant is not common in the Alligator rivers region, but dense, localised populations occur in coastal swamps on Melville Island at the western end of Van Diemen Gulf. The species produces 2 distinct spore types, which presumably represent the female megaspore and the male microspore. The larger spore is the most common in pollen counts, approximately 40 microns across the proximal face, with a prominent trilete scar and rugulate patterning. Some spores also display ridging which runs roughly parallel to the equator. The smaller spore measures 20 to 25 microns across the proximal face, and is psilate with the exosporium intact. The trilete scar is often indistinct or apparently absent under normal magnification. Where *Selaginella* is well represented in pollen counts both spore types invariably occur, and both are present on the reference slide for *S. uliginosa* in the Biogeography and Geomorphology reference pollen collection (number 401-2-2). In all pollen counts, the spore types were recorded separately, but their scores are combined in a single curve on the pollen diagrams.

Other distinctive pteridophyte spores recorded include *Ceratopteris*, *Lygodium* and Polypodiaceae. These and undifferentiated pteridophyte spores appear infrequently in the pollen counts.
INTRODUCTION

The geomorphological description of the South Alligator River and adjacent plains given in this chapter follows closely the detailed work by Woodroffe et al. (1986), with emphasis on the coastal and tidally influenced reaches of the river estuary. General landform and environmental descriptions for this area are also provided in the C.S.I.R.O. Land Research Series by Williams et al. (1969) and Galloway et al. (1976). Table 4.1 provides a list of the terms used for landform descriptions in each of these studies, together with summarised information relating to elevation, surface sediments and vegetation. The terminology used here for landform units follows Woodroffe et al. (1986).

Descriptions of the age structure of stratigraphic sections are based on radiocarbon analysis of plant organic material presumed to be mangrove, and marine shell collected from various stratigraphic units. All radiocarbon analyses were performed at the Australian National University Radiocarbon Laboratory in Canberra. Samples for dating were collected in the field from auger flights into sealed plastic containers, or in the laboratory from core sections. Fine organics and shell hash samples were sieved from the sedimentary matrix using a 120 micron brass sieve. To aid disaggregation of sediments, the samples were mechanically shaken and, in some cases, immersed in an ultra-sonic bath. Larger wood and shell samples were extracted by hand. All samples were washed or scrubbed in distilled water, oven dried and
<table>
<thead>
<tr>
<th>Morphologic Province</th>
<th>Morphologic unit (Woodroffe et al.)</th>
<th>C.S.I.R.O. Landsystem equivalent</th>
<th>Elevation above AHD (m)</th>
<th>Surface Sediment</th>
<th>Vegetation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coastal Plain</td>
<td>Mangrove</td>
<td>Littoral</td>
<td>up to 2.5</td>
<td>Blue-grey organic muds</td>
<td>Mangrove</td>
</tr>
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<td></td>
<td>Upper intertidal &amp; salt mudflat</td>
<td>Littoral</td>
<td>2.5-3.0</td>
<td>Grey-brown flocculated saline clays</td>
<td>Saltmarsh</td>
</tr>
<tr>
<td></td>
<td>Upper coastal</td>
<td>Cyperus</td>
<td>2.5-3.0</td>
<td>Black cracking clays</td>
<td>Sedgeland</td>
</tr>
<tr>
<td>Deltaic-Estuarine Plain</td>
<td>Salt mudflat</td>
<td>Littoral (part)</td>
<td>2.5-3.0</td>
<td>Light brown flocculated saline clays</td>
<td>Saltmarsh</td>
</tr>
<tr>
<td></td>
<td>Paleochannels</td>
<td>Cyperus</td>
<td>generally &lt; 3.0</td>
<td>Light brown to black cracking clays</td>
<td>Sedge and grass</td>
</tr>
<tr>
<td></td>
<td>Ill-drained depressions</td>
<td>Copeman</td>
<td>&lt;2.5 at mouth</td>
<td>Fine-textured light brown to grey cracking clays</td>
<td>Herbaceous swamp and sedge</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>&lt;3.5 at tidal limit</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Upper Floodplain</td>
<td>Cyperus</td>
<td>&gt;2.5 at mouth</td>
<td>Massive black cracking clays</td>
<td>Sedge and grass</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>&gt;3.5 at tidal limit</td>
<td></td>
<td></td>
</tr>
<tr>
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<td>Backwater Swamps</td>
<td>Pinwinkle</td>
<td>generally &gt; 2.5</td>
<td>Muds, peaty loams</td>
<td>Paperbarks</td>
</tr>
<tr>
<td>Alluvial Plain</td>
<td>Lower Alluvial Plain</td>
<td>Copeman, Pinwinkle</td>
<td>&gt;3.5</td>
<td>Black cracking clays and gleyed muds</td>
<td>Herbaceous swamps and paperbarks</td>
</tr>
<tr>
<td></td>
<td>Upper Alluvial Plain</td>
<td>Fabian, Flatwood</td>
<td>&gt;3.5</td>
<td>Silty alluvium</td>
<td>Grassland, savannah</td>
</tr>
</tbody>
</table>
weighed prior to submission for radiocarbon analysis. At the A.N.U. Radiocarbon Laboratory organic samples were further treated in hot 10 percent hydrochloric acid, while the larger shell samples were surface-cleaned with a dental drill to ensure that only well preserved material was analysed. A detailed description of the laboratory methods employed is provided by Gupta and Polach (1985). Each age determination is quoted in radiocarbon years Before Present (B.P.) based on the Libby half-life of 5568 years, plus/minus a standard age error based on counting statistics (Gupta and Polach, 1985).

Radiocarbon determinations on wood and shell samples are not directly comparable because oceanic waters are depleted in the radioactive isotope C\textsuperscript{14} relative to the atmosphere. Consequently, modern marine organisms which assimilate carbon from the sea, appear by radiocarbon determination to be several hundred years old. Gillespie and Polach (1979) estimate that the appropriate environmental correction for age determinations on marine shell species throughout much of Australia's coastline is the subtraction of 450\textpm{}20 years, so as to render the shell dates directly comparable to ages determined for non-marine organisms. However, it is suspected that this correction is inappropriate for shell dates presented in this study, as the estuarine environments of the South Alligator River are subject to seasonal freshwater flushing and the appropriate environmental correction factor is probably less than that determined for marine shell dates elsewhere. Because of the uncertainty of a suitable correction factor, shell dates reported here remain uncorrected and may not be directly comparable to ages determined for mangrove organics.
Problems relevant to stratigraphic interpretation of radiocarbon ages from different sample types relate to the vertical mixing of sediments and delay between sample growth and stratigraphic preservation. Errors due to the lag between the time of death of marine shells, and the time at which they were finally incorporated into the sedimentary matrix can reach several thousands of years in extreme cases, especially in high-energy coastal environments (Donner and Jungner, 1981). Errors incurred by this means are most likely in shelly chenier deposits, as the contributing shellfish are, by definition, displaced from growth position prior to chenier formation. Shell dates from middens are presumably not affected, as shellfish gathered for food by aborigines are living at the time of collection. The use of shell for determining the age of deposition of intertidal sediments may also be complicated by the presence of burrowing organisms which, if located in situ, will provide anomalously young ages for adjacent stratigraphic levels. Similarly, mangrove roots will provide young ages relative to surrounding stratigraphy.

MORPHOLOGIC PROVINCES

Woodroffe et al. (1986) recognise 3 morphologic provinces within the South Alligator River valley, based on landform type, sediment textures and dominant sedimentary processes. These are the Coastal Plain, the Deltaic-Estuarine System and the Alluvial Plain (Figure 4.1). A number of distinct morphological units, which are to some extent reflected in the distribution of vegetation communities described in Chapter 2, exist within each province.
Figure 4.1 Morphologic provinces of the South Alligator River (after Woodroffe et al., 1986). Insets refer to Figures 4.2 and 4.3.
The Coastal Plain

A broad coastal plain, or chenier plain in the sense defined by Russell and Howe (1935), stretches eastward from the South Alligator River mouth. The plain is 4 to 5 kilometres wide, and includes the Littoral, Cyperus, Copeman and Kosher land systems described by Williams et al. (1969). Detail of a section of this plain in Figure 4.2 shows the distributions of morphologic units, and locations of drill hole and surface sample transects used in this study.

The intertidal zone is subdivided into 3 units, termed lower intertidal, mangrove and upper intertidal. The lower intertidal unit lies from approximately 0 to 3 metres below Australian Height Datum (A.H.D.), which closely approximates mean tide level. Surface sediments are unconsolidated, grey muds which are poor in organics, and may contain admixtures of shelly sand and gravel (marine shell hash). Apart from a thin veneer of marine algae, the mudflat is devoid of vegetation. The mangrove unit lies approximately 0 to 2.5 metres above A.H.D. Surface sediments are blue-grey organic muds, incorporating mangrove roots, stems and leaves, living and dead marine molluscs, and algal mats of varying extent and thickness. Vegetation cover is mangrove forest and shrubland. The sediments are mixed to at least 30 centimetres by resident burrowing animals, particularly fish, crabs and lobsters. At its seaward limit the mangrove unit generally grades smoothly to the lower intertidal mudflat, although adjacent to transect 1 this transition is marked by an erosion scarp 0.5 to 1 metre high. The upper intertidal unit lies between approximately 2.5 and 3 metres above A.H.D. Surface sediments are uniform grey-brown, flocculated saline clays which are poor in organics and crack on drying to from polygons 15 to 30 centimetres across. The sediment surface may be bare or irregularly covered with saltmarsh communities and scattered debris.
Figure 4.2 Morphologic units on the coastal plain. See Inset 1, Figure 4.1 for location (after Woodroffe et al., 1986).
Above the intertidal zone, the coastal plain is subdivided into lower and upper plains units, and chenier ridges. **Lower coastal plain** occurs near the southern edge of the coastal plain on transect 1. The surface of this unit is approximately 2.5 metres above A.H.D, and sediments are similar to those of the upper coastal plain unit. *Eleocharis dulcis* is the characteristic plant in the dense, herbaceous vegetation cover. The unit is poorly drained and remains flooded or saturated for 7 to 8 months each year. **Upper coastal plain** is generally 3 metres above A.H.D., and the transition from upper intertidal mudflat is more clearly marked by a change in vegetation cover than by topography. Surface sediments are black, cracking clays, and a dense and continuous vegetation cover of sedges and grasses is common. Two **chenier ridges**, separated by 4 kilometres of upper coastal plain, lie parallel to the modern coast. The seaward ridge is approximately 25 metres wide with a crest height of about 4 metres above A.H.D. It consists of calcareous sand and shell hash, and is locally capped by low middens of the bivalve *Anadara*. The landward chenier ridge is up to 60 metres wide with multiple crests and a height of approximately 4 metres above A.H.D. Surface sediments consist mainly of unconsolidated, grey quartz sand. The vegetation cover on both chenier ridges varies from grassland to open shrublands and woodlands, described in more detail in Chapter 5.

**The Deltaic-Estuarine System**

The deltaic-estuarine system is the largest of the 3 major morphological provinces described for the South Alligator River valley. Its seaward margin merges with the coastal plain province at the point
where wet season discharges appear to have negligible effect on overbank sedimentation (Woodroffe et al., 1986). The deltaic-estuarine province is so-named because of the strong influence of both tidal and wet season fluvial processes within the river and on the surrounding plains. Within this system the river changes its plan-form from a broad estuarine funnel decreasing exponentially in width in the upstream direction, to a meandering cuspate channel in which the insides of bends are sharply pointed and, finally, to the upstream section of tidal river with alternating irregular straights and bends (Woodroffe et al., 1986).

Figure 4.3 details an area of the deltaic-estuarine system through the mid-tidal reaches of the South Alligator River. The most extensive morphological units within the province fall into the categories of upper and lower floodplain, described briefly below.

The upper floodplain unit ranges in elevation from 2.5 metres above A.H.D. in seaward localities to at least 3.5 metres above A.H.D. in upstream localities. Surface sediments are massive, black cracking clays which become deeply fissured with cracks up to 10 centimetres wide forming polygons 30 to 50 centimetres across (Woodroffe et al., 1986). Low shell middens and thinly scattered shell debris locally veneer the sediment surface, most commonly at sites adjacent to infilled palaeochannels. The upper floodplain supports a dense, herbaceous, vegetation cover dominated by annual sedges and grasses.

Morphologic units within the lower floodplain include salt mudflats, palaeo-river channels, narrow anastamosing channels and ill-drained depressions. These features often remain inundated for more than 9 months of the year. Surface sediments vary from light brown to dark clays which, upon drying, develop cracks and polygonal features smaller than those described for the upper floodplain. The elevation of
Figure 4.3  Morphologic units on the Deltaic-Estuarine plain. See Inset 2, Figure 4.1 for location (after Woodroffe et al., 1986).
lower floodplain surfaces varies from 2.5 to 3.5 metres above A.H.D. according to the nature of the unit and distance from the coast. For example, the surface of salt mudflat varies from 2.5 to 3 metres above A.H.D., while ill-drained depressions range from 2.5 metres above A.H.D. near the coast to 3.5 metres above A.H.D. in upstream localities. Surface elevations for infilled palaeochannels generally lie close to 3 metres above A.H.D. (Woodroffe et al., 1986). The transition from lower floodplain (particularly salt mudflat) to upper floodplain is often marked by a low scarp 30 to 60 centimetres in height. Vegetation on the lower floodplain unit varies according to soil salinities and average duration of seasonal inundation, and includes saltmarsh, herbaceous freshwater swamp and sedge communities.

Other morphological units in the deltaic-estuarine province which do not fall into the "floodplain" categories described above, include mangrove tidal channels, backwater swamp and levee. Mangrove tidal channels are of localised distribution along the river and adjoining tidal waterways. They represent the riverine counterpart of the coastal mangrove unit described earlier, but have a more restricted elevational range, rarely extending as low as the mid-tide level. Tidal channels extend from the river and in some cases connect and drain different units of the lower floodplain group. In places these channels are actively extending their range into the floodplains. The backwater swamp unit forms where gully drainage from the lateritic uplands is impeded by floodplain aggradation. Surface sediments of this unit lie about 2.5 metres above A.H.D., and consist of dark grey to black organic muds and peaty loams. These are commonly inundated by fresh water for long periods each year. Vegetation cover includes herbaceous freshwater swamp and paperbark swamp forest. Discontinuous, low, levees (not shown in Figure 4.3) flank the river along its upper tidal reaches. These
relatively minor features are best developed on the outsides of river bends, and have surface sediments consisting of silt, fine sand and yellow muds. The vegetation cover includes grasses and widely spaced large trees, notably *Bombax ceiba*.

The Alluvial Plain

The alluvial plain province extends into the upper sections of the South Alligator River and Jim Jim Creek valleys beyond the limit of tidal influence. The plain can be divided into upper and lower units which tend to merge with the upper and lower floodplain units of the deltaic-estuarine province. Surface sediments of the lower alluvial plain lie at approximately 3.5 metres above A.H.D., and include black, cracking clays and gleyed muds, subject to prolonged seasonal inundation. Predominant vegetation includes herbaceous swamp communities and paperbark forest. The upper alluvial plain has a surface elevation of at least 3.5 metres above A.H.D. Surface sediments are silty alluvium and the vegetation cover is of grasses and savannah.

Within the alluvial plain province the course of the main river channel becomes indistinct, and does not maintain continuous surface flow throughout the dry season. Rather, it contracts to a system of discontinuous linear waterholes and channels flanked by extensive levees and various sand bodies.

GEOMORPHIC PROCESSES AND CHANGE IN THE TIDAL REACHES

The morphologic units and sediments of the South Alligator River valley are continually adjusted to the influence of geomorphic processes. The relative stability or rate of change of a feature depends to a great extent on the nature and intensity of the processes
involved. Radiocarbon and stratigraphic investigations described by Woodroffe et al. (1986), show that the South Alligator coastal plain is a prograded feature formed since sea level stabilised at approximately its present position around 6000 years ago. However, the progradational trend of the coastline is not necessarily continuous through time. At present the transition from lower intertidal mudflat to mangrove along the coastline adjacent to transect 1 is marked by an irregular scarp, which is approximately 1 metre high and locally subject to slumping. Below this the roots of a few of the most seaward mangrove trees, mostly Sonneratia alba, are exposed or undercut by up to 0.5 metres. Some of the trees are fallen, and gullies up to 1 metre deep have cut back through the mangrove unit, almost to the rear of the seaward Sonneratia and Camptostemon vegetation zone. The erosion apparently reflects recent storm damage, perhaps the passage of a single cyclone, and when viewed on a time scale of hundreds or thousands of years does not necessarily signify a long term change in the progradational process. Travel by boat along the coast from the river mouth reveals that storm damage features extend a few kilometres east and west of transect 1. Elsewhere the transition from lower intertidal mudflat to mangrove is smooth, and characterised by deep, unconsolidated, fine-grained sediments suggesting a stable environment of deposition. Landward on the coastal plain the surfaces of morphological units and transitions between units are smooth and, where salinities permit, are well vegetated, suggesting stable conditions or uninterrupted sedimentation.

In the deltaic-estuarine system infilled palaeo-river channels indicate changes in the river shape, width and course (Woodroffe et al., 1986). The fact that these and other depressions of the lower floodplain unit are infilling, and that backwater swamps are forming as a consequence of vertical development of the upper floodplain unit
sufficient to impede gully drainage from adjacent lateritic uplands, suggests a general vertical sedimentary accretion of floodplain environments.

In some areas, however, the floodplain and backwater swamp units appear threatened by salt incursion. Woodroffe et al. (1986) described the transition between salt mudflats and upper floodplain in seaward sections of the deltaic-estuarine system as marked by a low scarp. In places scarped "islands" of the upper floodplain unit are surrounded by salt mudflat suggesting erosion of the upper unit and expansion of the lower. Further upstream, saltwater creeks have extended their range across the floodplains. Where these have penetrated backwater swamps, rapid and extensive dieback of paperbark forests and other freshwater swamp communities has occurred. Mangrove seedlings, especially Avicennia marina, Lumnitzera racemosa and Sonneratia alba, now colonise the recently extended tidal channels. Initiation of this process has been widely blamed on the activities of fer al buffalo which, through the creation of swim channels through river levees, may facilitate tidal incursion onto the surrounding plains. Although buffalo effects are undeniable in many salt-invaded areas (Lindner, 1987) salt hazard appears to have increased over the last few thousand years because of an increase in tidal range in the upstream section of the river, due to changes in the form and dynamics of the main river channel (Woodroffe et al., 1986).

STRATIGRAPHIC AND RADIOCARBON CHRONOLOGY

The stratigraphy and radiocarbon age structure of sections through the South Alligator River plains are described by Woodroffe et al. (1986), from data collected from 131 drill hole sequences.
Stratigraphic descriptions in this chapter are based on their results combined with information and additional radiocarbon dates from hand cores collected by the writer primarily for the pollen analyses described later in chapters 6 and 7. Details of all radiocarbon dates referred to in this study are given in Table 4.2.

Stratigraphy and Radiocarbon Age Structure of the Coastal Plain

A stratigraphic section of the coastal plain along transect 1 is shown in the upper diagram in Figure 4.4. The transect is approximately 5 kilometres long and runs normal to the present coastline to traverse 2 chenier ridges. The stratigraphic reconstruction is based on data from 5 continuous cores and 9 auger probes described by Woodroffe et al. (1986), 3 continuous hand cores (HC 2, HC 4 and HC 12) and 1 stratigraphic pit. Surface levelling of the transect was done by the Australian Survey Office who established benchmarks close to the sites of HC 2, SAH 14 and SAH 15, so that all sites could be tied into A.H.D. In most cases core and auger sampling continued to the underlying, weathered pre-Holocene surface. North of chenier ridge 2 this basal surface is near-horizontal, lying between 11 and 7 metres below the modern plain (7 to 3 metres below A.H.D), but slopes more steeply south of ridge 2. It represents the subsurface extension of the nearby upland surface typified by the Koolpinyah Land System described in Chapter 2.

Stratigraphic units shown in Figure 4.4 include blue-grey sandy mud, intertidal organic mud, marine shelly sand and mud, oxidised saline mud, freshwater organic clay, chenier deposits and black soil. Uniform blue-grey sandy mud forms a discontinuous thin sheet to 1 metre thick over the pre-Holocene surface. These basal muds are devoid of shell and plant organic material, but are interpreted as marine by their mud
Table 4.2: Radiocarbon dates cited in this study

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Figure 4.4 Stratigraphic section (upper diagram) and radiocarbon chronology (lower diagram) for transect 1 on the South Alligator coastal plain. Radiocarbon dates summarised (x1000). Numbers in parentheses indicate sequence in which dates are listed in Table 4.2 (after Woodroffe et al., 1986; with additional data from present study).
content, colour, and lack of oxidation. A layer of intertidal organic muds extending the entire length of the section, and ranging from 0.3 to 3.5 metres thick overlies the blue-grey sandy muds and the pre-Holocene surface. This unit consists of dark, blue-grey muds containing plant detritus ranging from fines to larger woody fragments, mostly mangrove tree roots. Sand and shell hash lenses, and occasional whole marine shells also occur throughout. This unit is interpreted as intertidal by its organic and shell macrofossil content. Marine sand and mud overlies the intertidal organic layer to a thickness of more than 4 metres. The upper limit of this facies lies close to A.H.D. In the northern half of the section it is overlain by intertidal organic mud in a layer which is continuous with the present mangrove soil. Elsewhere the marine sand and mud grades upwards into a layer of light grey to beige oxidised saline mud approximately 2 metres thick. Black cracking clays, or black soil, veneer the section and flank the chenier deposits to a depth of a metre or so south of chenier ridge 1. The 2 chenier deposits lie approximately 4.5 kilometres apart and sit conformably on oxidised saline mud. The seaward deposit (chenier ridge 1) is comprised of calcareous sand and fine shell hash. The landward deposit (chenier ridge 2) is comprised of fine to medium quartz sand containing infrequent marine shell. Towards the southern end of the section, lenses of freshwater organic clay lie between basal units and intertidal organic mud. The recognition of these as freshwater deposits relies on pollen analyses described in Chapter 6.

The lower diagram in Figure 4.4 provides summarised radiocarbon ages and tentative isochrons for the coastal plain stratigraphic section. The dates are from shell and plant remains from intertidal organic muds, marine sand and mud and cheniers. No ages were determined for samples from oxidised saline muds or black soil, which are poor in
datable carbon. The radiocarbon chronology outlines the sedimentary progradation at the site from the mid-Holocene to present. Radiocarbon ages of around 6300 years for mangrove remains collected at 8.15 metres depth from SAH 29 (ANU 3933; 6330±150 and ANU 4249; 6350±260) at the seaward end of the section, and at 2.45 and 3.95 metres depth in SAH 28 (ANU 3929; 6320±170 and ANU 3930; 6240±130) to landward, suggest that broad mangrove forests established as the sea rose to inundate the pre-Holocene surface. By about 5,000 years ago it seems that these communities were drowned by rising sea level, and consequent infill by marine sands and muds, essentially shallow water depositional facies, occurred throughout the section north of chenier ridge 2. Shoreline progradation began at least 5000 years ago. North of SAH 30 the former presence of mangroves is marked by an upper organic mud layer continuous with modern mangrove. As this unit is not recorded further south it is unclear if mangroves were present throughout the regressive phase. It is possible that the upper mangrove unit in the southern section has been oxidised or eroded away. Radiocarbon ages from the upper organic mud range from 3210±160 (ANU 4245) at 3.0 metres depth in SAH 24, to 104.0±2.4% modern (ANU 3927) at 3.7 metres depth in SAH 15. The modern age is difficult to explain as it derives from mangrove wood, and cannot be related to recent tree root intrusion.

Summary isochrons shown in Figure 4.4 indicate changes in the rate of shoreline progradation since mangroves inhabited the most southern reaches of the section between 5,500 and 6,500 radiocarbon years ago. The maximum progradation rate for the period 5,000 to 6,000 radiocarbon years ago was approximately 300 metres per 1000 years. At 5,000 years B.P. the shoreline was approximately level with chenier ridge 2 in the south of the section. Uncorrected radiocarbon ages (ANU 5147; 4640±190 and ANU 5148; 4950±130) from shells collected at 1.13 and 1.16 metres
depth in a stratigraphic pit through the centre of the ridge, indicate that this feature formed approximately 4,900 to 4,600 years B.P. Progradation between 5,000 and 3,000 radiocarbon years B.P. was rapid, averaging approximately 1700 metres per 1000 years. Since 3,000 radiocarbon years B.P. the rate decreased markedly to average only 200 to 300 metres per 1000 years. Within the mangrove forests of the present coastline there is little evidence of recruitment of seedlings seaward of their parent vegetation zones, suggesting that current progradation rates are slow. Radiocarbon ages from shell hash samples from 0.1 metres depth (ANU 4064, 2120±90) and 1 metre depth (ANU 4243, 1970±70) in SAH 14, indicate that the seaward chenier deposit formed approximately 2,000 years B.P.

Stratigraphy and Radiocarbon Age Structure of the Deltaic-Estuarine Plain

Woodroffe et al. (1986) provide descriptions of the morphologic and stratigraphic features of the tidal section of the South Alligator River. Stratigraphic interpretations are based on numerous drillhole transects shown in Figure 4.5. Block diagrams summarise the relationships between surface features and sedimentary units in the estuarine funnel, sinuous meander, cuspate meander and upstream sections of the tidal river (Figure 4.6). The diagrams suggest geomorphological changes through the evolution of the river estuary, and illustrate the dynamic nature of sedimentary environments. Organic mangrove muds are common to the stratigraphy of each river section. In the estuarine funnel section, these extensively overlie estuarine sediments. In the sinuous meander and cuspate river sections mangrove muds are thickest towards the valley margins, where they are continuous from base to upper levels of the cores. Nearer the valley centre, where sediment reworking
Figure 4.5 Drill hole transects used by Woodroffe et al. (1986) for the stratigraphic description of the South Alligator River estuary.
Figure 4.6 Diagrammatic summary by Woodroffe et al. (1986) of morphologic and stratigraphic relationships in the estuarine funnel, sinuous, cuspate and upstream segments of the South Alligator River.
by channel migration is extensive, they occur in pockets overlying laminated channel sediments and undifferentiated sediments, adjacent to paleoriver channels. Floodplain sediments overlie the mangrove muds throughout all sections.

Figure 4.7 shows the stratigraphy along transect 8a which is described by Woodroffe et al. (1986) interpreted from 13 continuous cores and auger probes. Included in the diagram is the HC 5 core which has been analysed for pollen (see Chapter 7). Transect 8a is approximately 3 kilometres long and runs northwest/southeast across the South Alligator River floodplain to traverse 2 sinuous cut-off meanders of the former river channel, which are clearly delineated in the surface morphology in Figure 4.3. Surface levelling of the drill sites permits vertical reconstruction relative to A.H.D. Six drill holes continued until the underlying basal strata were located, up to 14 metres below the present floodplain surface. Stratigraphic units within the section include laminated channel sediments, palaeochannel, organic muds, oxidised and undifferentiated sediments, freshwater clays and levee.

Laminated channel sediments occur throughout much of the deeper half of the section, overlying basal sediments. They are typically blue-grey silt and clay, and contain prominent laminae of fine sand with a maximum thickness of approximately 4 millimetres and a maximum dip of 25 degrees. Woodroffe et al. (1986) interpret these sediments as channel margin and shoal deposits due to their close proximity to related geomorphological features, and through analogy to similar laminated sediments in modern environments. The 2 palaeochannel units in Figure 4.7 consist of structureless fine mud and clay containing well dispersed dark organic fines, carbonised particles and occasional lenses of compressed organic fragments up to 2 centimetres thick. Organic muds
Figure 4.7 Stratigraphic section (upper diagram) and radiocarbon chronology (lower diagram) for transect 8a. Radiocarbon dates summarised (x1000). Numbers in parentheses indicate sequence in which dates are listed in Table 4.2. After Woodroffe et al. 1986, with additional data from the present study.
with a maximum thickness of 10 metres are also extensive throughout the section, directly overlying both the basal sediments and laminated channel sediments. These resemble the intertidal organic muds described for the coastal plain stratigraphic section (Figure 4.4), with a fine matrix of bluish-grey sulphurous mud and interspersed woody and fibrous fragments. Macrofossil remains and pollen analyses confirm a mangrove origin for this unit. Oxidised muds with a maximum thickness of 2 metres overlie the organic muds throughout the section. In core HC 5 these muds are light brown in colour with occasional orange mottles, and lack conspicuous organic material, shell and carbonised particles. They are overlain by massive dark, cracking clays of the freshwater clay (black soil) unit which is extensive across the river floodplain and coastal plains. Minor levee deposits cap the freshwater clay unit at 2 points in the section. These represent degraded levees associated with former river channels, and consist of yellow to light brown silt and fine sand (Woodroffe et al., 1986).

All radiocarbon determinations for transect 8a derive from mangrove organic material. The results confirm the mid to late Holocene time frame for the development of the deltaic-estuarine plain. Organic samples collected more than 8 metres below A.H.D. indicate mangrove occupation of the area during the closing stages of the marine transgression and through the period of sea level stabilisation. Core HC 5 was collected from the inside bend of a former sinuous meander, and would be expected to contain prograded point bar sediments. The 3 deepest radiocarbon dates from HC 5 (ANU 5262, ANU 5263, ANU 5264) contradict the date from SAH 42 (ANU 3864), and suggest rapid sediment accumulation during the time of mangrove occupation at the site approximately 4000 radiocarbon years B.P. The HC 5 core was collected in the hope that it would provide a vegetation history which could be
compared in detail to the diverse mangrove communities which occupy similar locations on the inside of sinuous meander loops along the Adelaide River (see chapters 5 and 7).

Core HC 9 was collected in a backwater swamp at the eastern edge of the valley, approximately 35 kilometres from the river mouth. Figure 4.8 shows the stratigraphic context and radiocarbon results for the core. Dark grey to black clays cap the section to a depth of 40 centimetres. These overlie oxidised grey to light brown muds, which contain occasional orange mottles and extend to a depth of 125 centimetres. The oxidised nature of these muds suggests that they were subaerially exposed during their formation. Below 125 centimetres are dark grey mangrove muds lacking shells, but with conspicuous organic lumps resembling tree roots. The radiocarbon date of $6410 \pm 160$ (ANU 5266) from 285 centimetres depth indicates that the base of this core penetrates the extensive mangrove unit mapped for this area by Woodroffe et al. (1986).

Pollen sequences, described in Chapter 7, from the hand cores HC 5 and HC 9 provide details of the vegetation history of the deltaic-estuarine system through its geomorphological evolution from before 6000 years ago to present.
Figure 4.8 Stratigraphic and radiocarbon details for core HC 9.
INTRODUCTION

Analyses of modern pollen samples collected from surface sediments and pollen traps from various locations throughout the study area were undertaken to provide a standard by which the fossil pollen record could be interpreted. The inadequacies of fossil pollen assemblages, if taken at face value, to provide a clear fingerprint of former vegetation patterns have long been recognised. Shortcomings in the fossil record derive from the combined effects of differential pollen production (discussed in detail by Faegri and van der Pijl, 1979), dispersal (Tauber, 1965, 1967a, 1967b; Janssen, 1966; Jacobson and Bradshaw, 1981) and deposition (Davis et al., 1971; Davis and Brubaker, 1973; Janssen, 1973). In addition, post-depositional mixing and sediment redeposition may introduce further uncertainties to the fossil record (Davis, 1968). Recognition of the effects of these factors at any given palynological site is important if fossil pollen records are to be interpreted correctly. This is demonstrated to be just as true in mangroves as in other environments by Caratini et al. (1973), who show that pollen assemblages from modern mangrove sediments in India provide a misleading record of the floristic composition of surrounding vegetation due to overrepresentation of high pollen producers such as Rhizophora and Sonneratia, underrepresentation of Avicennia and non-representation of several other mangrove plants. Other mangrove palynological studies have used surface sediment analyses (Spackman et al., 1966; Chappell and Grindrod, 1985; Grindrod and Rhodes, 1984) and a combination of surface sediment and pollen trap analyses...
The combined use of pollen trap and surface sediment samples provides the most detailed description of modern pollen rain and deposition at a given site, though consideration must be given to fundamental differences between the two sampling techniques. Assemblages from surface sediments contain both wind-borne and water-borne pollen. They generally represent an indeterminate period of deposition, which may span several years or perhaps decades, depending on sedimentation rates and depth to which the sediment is sampled. The assemblages are likely, therefore, to integrate seasonal variations in pollen production and dispersal around the site, but because of the indeterminate sampling period, only relative (percentage) pollen data is provided. Surface sediment assemblages may also be affected by differential preservation of pollen, and so show bias towards pollen types which are most resistant to either physical or chemical decay. This will be most prevalent where there is the possibility of microbial attack, and on depositional surfaces subject to periodic wetting and drying.

Pollen traps, which are generally set above ground level, collect airborne pollen grains only, so that their assemblages, when viewed in relation to surrounding vegetation, may be strongly influenced by the direction of prevailing winds. Pollen traps operate over known sampling periods determined by the timing of their placement and subsequent collection, allowing pollen influx determinations to be made, and the independent assessment of the performances of individual taxa. Except where trapping periods are long, trap samples do not integrate seasonal variation in pollen production and dispersal, so that results may represent exceptional seasonal conditions. When trapping periods are of
moderate duration, the differential preservation of pollen types in trap samples is unlikely to pose a significant problem.

POLLEN DATA PRESENTATION

Pollen data are commonly presented in diagrammatic form with values shown as percentages of a pollen sum (Faegri and Iversen, 1966). A disadvantage of this method is that the apparent performance of any single taxon is influenced by the combined performances of all other taxa in the pollen sum. That is, as values are percentages of the pollen sum, increased representation of any given taxon in a sequence will necessarily be accompanied by decreased representation of one or more other taxa in the pollen sum.

Pollen data can also be presented in terms of absolute pollen influx; that is, the number of pollen grains deposited per unit area per unit time (Faegri and Iversen, 1966). This method avoids the shortcomings of relative pollen representation as individual taxon performances are independent, but is possible only where the sampling period is precisely known, such as in pollen trap samples or where there is close chronological control of sedimentary sequences. The method also requires a high level of confidence in total absolute pollen estimations if between-sample comparisons are to be drawn, and is therefore liable to discrepancy through differential sampling efficiencies between pollen traps, due to design faults and atmospheric anomalies in local settings, and the loss of sample from traps during the collection period and/or laboratory preparations.

In this chapter the results of pollen analyses of pollen trap and surface sediment samples are presented in pollen diagram form. The samples derive from surface sample transects set across the South
Alligator River coastal plain, and adjacent to the West Alligator and Adelaide rivers. Detailed descriptions of the vegetation adjacent to each transect precede the pollen results for each of the 3 areas. These are based on plants recorded in 5 metre by 5 metre quadrats, and supplemented by aerial survey (South Alligator River coastal plain) and colour air photographs (South Alligator River coastal plain and Adelaide River).

Results of pollen trap analyses presented in this chapter are based on relative and absolute pollen influx data, while surface samples are shown in relative terms only. The pollen sum comprises all identified angiosperm and gymnosperm pollen grains recorded. In most cases counts were continued to 150 grains in the pollen sum, though fewer grains were recorded in some counts, due to very low pollen concentrations.

THE COASTAL PLAIN

Figure 5.1 shows locations of surface sediment and pollen trap sampling along transects 1 and 2, which run normal to the coast, across the coastal plain. The onshore section of transect 1 landward of the mangrove fringe corresponds to the coastal plain drillhole transect described in Chapter 4. In all, 24 surface sediment samples and 9 pollen trap samples have been analysed from coastal plain environments. The surface samples are from low-tide, mangrove, salt mudflat and upper coastal plain locations along transects 1 and 2. The pollen trap samples are from traps set above ground level in mangrove, salt mudflat and chenier ridge environments along transect 1 only. No pollen trap data are available for mangrove environments seaward of the closed Rhizophora zone or on the extensive upper coastal plain south of chenier ridge 1. Traps placed in the seaward mangroves were not recovered, presumed destroyed by storm damage and/or treefall, and traps set on 3
Figure 5.1 Surface sample and pollen trap locations along transects 1 and 2.
metre tall stakes on the treeless coastal plain were repeatedly damaged by raptors and feral buffalo. A description of vegetation across the plain is provided here for comparison with the pollen data.

Vegetation: Coastal Plain Transects

The summary in Figure 5.2a of vegetation along transect 1 is representative of the South Alligator coastal plain, with halophytic communities at the coast, and non-halophytic herblands and woodlands on the plains and chenier ridges. Figure 5.2b summarises species zonation in the mangroves on transect 1, based on the percentage abundance of mature plants. Three distinct vegetation zones are recorded. The most seaward consists of tall, open forest dominated by Camptostemon schultzii, with Sonneratia alba and occasional Avicennia marina. Sub-canopy strata are absent, and seedlings of resident mangroves and other species are rare. The middle mangrove zone consists of a dense, closed stand of tall Rhizophora stylosa, with infrequent Camptostemon schultzii and Aegiceras corniculatum. Slender seedlings of R. stylosa up to 2 metres tall are sufficiently common to provide a low, sparse understorey. The landward mangrove zone consists of a low, open scrub of Avicennia marina. Aegialitis annulata and Batis argillicola form a near-continuous ground cover, generally less than 0.5 metres high. Other mangrove shrubs include Ceriops tagal, Excoecaria agallocha and Lumnitzera racemosa, though these are not common. This zonation is repeated in the mangrove communities along transect 2.

Sections of the salt mudflats landward of the mangroves are occupied by saltmarsh plants which form low, open shrublands generally less than 0.5 metres high, and provide up to 50 percent ground cover. Batis argillicola occurs in a monospecific band approximately 15 metres wide close to the landward limit of the mangroves. Elsewhere the
Figure 5.2a  Summary of environments, vegetation types and common plant species along transect 1 from the seaward mangrove limit to the upland surface. Details of mangrove zonations and species are given in Figure 5.2b, over page.
Figure 5.2b Details of canopy height and structure, species zonation and surface sample locations through mangroves on transect 1, South Alligator coastal plain.
saltmarshes are dominated by Tecticornia australasica, and may also include stunted Avicennia marina and Aegialitis annulata. The saltmarsh communities are best developed toward the seaward limit of this zone where occasional inundation by tides occurs. They become increasingly sparse to landward, and much of the salt mudflat midway between the mangrove fringe and chenier ridge 1 is bare.

Chenier ridge 1 is flanked by salt mudflat to the north, and upper coastal plain to the south. Vegetation on higher parts of the ridge is characterised by patches of coastal deciduous vine forest, with trees such as Bombax ceiba, Cathormion umbellatum, Peltophorum pterocarpum and Sterculia quadrifida, and woody shrubs Capparis sepiaria and Premna serratulifolia. Outside the forest patches the ridge supports sparse shrublands and annual herbs and grasses. Along its margin with the salt mudflat the ridge is fringed by low, spreading bushes of Tecticornia australasica and well-spaced, mature Avicennia trees, which are apparently protected from excessive soil water salinities by the seepage of fresh water from the raised chenier soils.

The vegetation on chenier ridge 2 is characterised by low, open woodland and occasional dense, closed thickets. Common evergreen trees are Banksia dentata, Syzygium suborbiculare and Terminalia grandiflora. Deciduous trees include Bombax ceiba, Erythrina variegata, Ficus opposita and Sterculia quadrifida. The robust woody liane, Tinospora smilacina is common in association with Syzygium. The sandy soils of chenier ridge 2 lack ground cover during the dry season, but support various annual grasses and herbs during the wet season. Pandanus spiralis forms thickets on the ridge's lower flanks and appears as solitary trees on higher ground. In keeping with the vegetation of many chenier ridges throughout coastal northern Australia, the wooded
communities of both chenier ridges on the South Alligator coastal plain are floristically distinct from upland sclerophyll woodlands in that they lack eucalypts.

The extensive areas of upper coastal plain south of chenier ridge 1 support treeless sedge and grasslands, dominated by grasses such as Elytophorus spicatus, Imperata cylindrica and Paspalum scrobiculatum, and the sedges Fimbristylis dichotoma and F. littoralis. A number of small, annual herbs, shrubs and climbers are also prominent, including Ludwigia octovalvis, Malachra fasciata and Ipomoea aquatica. The herbaceous communities establish a lush and continuous cover across the upper coastal plains during the wet summer months, but are withered, and frequently burned, during the dry winter.

Vegetation of the lower coastal plain is dominated by Eleocharis dulcis, E. sphacelata, Oryza meridionalis and Ludwigia adscendens. Although they are poorly drained, the sections of lower coastal plain adjacent to transect 1 are subject to seasonal drying and do not support the diverse freshwater swamp communities common elsewhere in the region. The southern perimeter of lower coastal plain south of chenier ridge 2 is fringed by dense Melaleuca viridiflora scrub, which forms a transition into the upland, eucalypt-dominated forests to the south.

Pollen Trap Results: Coastal Plain

Relative pollen data

Results for all pollen trap analyses for the coastal plain are presented in Figure 5.3, based on the relative representation of all pollen and spore types recorded. The results include data from 5 pollen trap locations along transect 1. Summary descriptions of the vegetational environments around each pollen trap are provided in Table
Figure 5.3 Pollen diagram for pollen traps along transect 1. Values are percentages of the pollen sum.
5.1, and range from closed mangrove forest to open saltmarsh communities and chenier woodlands. The pollen trap samples in Figure 5.3 are arranged by location along the transect from seaward to landward sites. Results for 2 pollen trapping periods (period 1 and period 2) are provided for each trap site, except PT1. Trapping period 1 extends from July 1984 to August 1985, while trapping period 2 extends from August 1985 to September 1986.

Trapping period 1

Rhizophora is the most strongly represented mangrove pollen type in trapping period 1, with strongest values in the seaward samples PT2 and PT3 and diminishing values to landward. The highest recordings for Ceriops/Bruguiera also appear in the most seaward samples, but never exceed 5 percent of the pollen sum; while Avicennia has strong representation in PT2 and is absent, or nearly so, from other samples. Other mangrove taxa recorded for period 1 are Camptostemon and Lumnitzera, which have minor representation only.

Chenopodiaceae pollen is recorded most frequently in seaward samples, and is rare at landward sites. Batis accounts for 11 percent of the pollen sum in PT2, and is not recorded elsewhere in period 1 samples.

A few non-halophytic taxa are also well represented in trapping period 1. Poaceae pollen has minor representation at seaward locations, and strong representation in landward samples. Cyperaceae pollen is well represented throughout, with values exceeding 60 percent of the pollen sum in the middle of the sequence. Pandanus is very well represented in the most landward sample, and virtually unrecorded elsewhere; while Myrtaceae (undetermined) pollen maintains consistently
Vegetation description

PT 1  tall, closed canopy *Rhizophora stylosa* forest

PT 2  *Avicennia marina* and *Ceriops tagal* shrubland with *Aegialitis annulata* and *Batis argillicola* understorey

PT 3  low saltmarsh containing *Tecticornia australasica* and *Batis argillicola*, between mangrove fringe and chenier ridge 1.

PT 4  grassland on chenier ridge adjacent to *Avicennia marina* and *Tecticornia australasica* at chenier/mudflat verge

PT 5  woodland on chenier ridge with *Pandanus spiralis*, *Erythrina variegata*, *Ficus opposita*, *Syzygium suborbiculatum* and annual grasses

Table 5.1  Vegetation summaries for pollen trap sites along transect 1.
low values throughout the sequence. The other most consistently recorded taxon is Gonocarpus, which appears at very low frequencies only. All other taxa have minor and generally sporadic representation.

Trapping period 2

In most cases, the pollen taxa most strongly represented in trapping period 1 are well represented in trapping period 2. Rhizophora is recorded at a very high frequency in PT1 at the seaward end of the transect, with steadily diminishing values to landward. Ceriops/Bruguiera shows a similar trend, but is recorded at relatively low frequencies. Avicennia attains moderately strong representation in PT2 and PT4 and is unrepresented elsewhere, while Camptostemon is consistently recorded at very low frequencies in all but the most landward sample. Other mangrove taxa - Sonneratia, Lumnitzera and Excoecaria - have only minor representation. The saltmarsh taxa, Chenopodiaceae and Batis, maintain values similar to those recorded in trapping period 1, with the former showing consistently low values at the 3 most seaward localities, and the latter attaining moderately strong representation in PT2 and poor representation elsewhere.

Poaceae pollen has moderate representation throughout the sequence with a general increase in values at landward locations. Cyperaceae has only minor or moderate representation in contrast to very high values recorded for this taxon in trapping period 1. Conversely Myrtaceae (undetermined) and Eucalyptus tetrodonta type pollen, which are poorly represented in the trapping period 1, are strongly represented in all but the most seaward sample. Pandanus is strongly represented in the landward sample, and mostly absent elsewhere. Many other taxa are sporadically represented, at values generally less than 2 percent of the pollen sum. An unidentified pollen type (unknown type 1) is recorded at
very high frequency (954 percent of the pollen sum) in PT4. Although its source is uncertain, the pollen type does not represent plants recorded for the saltmarsh or mangrove communities, which are comprehensively sampled. It is likely it represents a local source on chenier ridge 1, and may derive from an annual plant which was not detected in dry season vegetation surveys. Alternatively, although the pollen traps are protected by fibreglass insect mesh, contamination of this sample by an insect vector cannot be dismissed.

Absolute pollen data

Figure 5.4 shows estimated absolute influx values (pollen grains/cm²/yr) for selected, well represented pollen taxa in the coastal plain pollen trap assemblages, in an attempt to display the data free from the constraints of relative pollen representation. Trends which are evident through both relative and absolute data presentations, are likely to reflect real aspects of pollen distributions rather than artifacts of the statistical techniques.

In general the well represented mangrove and saltmarsh pollen taxa - Rhizophora, Ceriops/Bruguiera, Avicennia, Sonneratia, Camptostemon, Chenopodiaceae and Batis - have local pollen distributions corresponding to the distribution of parent plants along the transect. With the exception of Avicennia the pollen of these taxa have their highest absolute representation at the 2 most seaward pollen trapping sites, accompanied by diminishing values or non-representation at landward locations. Avicennia is strongly represented at site PT2 in the rear mangrove zone, and at PT4 on chenier ridge 1 which is flanked by mature Avicennia trees, some of which overhang the trap site.
Figure 5.4 Absolute influx values for selected taxa for pollen traps along transect 1.
In contrast to the mangrove and saltmarsh taxa, pollen of the strongly represented non-halophytic taxa - Poaceae, Cyperaceae, Myrtaceae and *Eucalyptus tetrodonta* - do not show clear trends in distribution relative to position along the transect. Rather, the results suggest even dispersal of these pollen types by wind. *Pandanus* on the other hand, is well represented at trapping site PT5 only, reflecting the highly localised distribution of this pollen type from parent trees which overshadow the pollen trap. Estimations of the total pollen influx vary from less than 100 to greater than 3,000 pollen grains/cm$^2$/year. The 2 highest recordings are clearly influenced by inordinately high local pollen production from dense mature *Rhizophora* stands which tower over the pollen trap at PT1, and from the unknown pollen type 1 in trapping period 2 at PT4.

An interesting aspect of the absolute pollen data is the variation between estimated values for the different trapping periods of certain non-halophytic pollen taxa. In samples seaward of PT5 Cyperaceae pollen is particularly strongly represented in trapping period 1, relative to trapping period 2. It is likely that the bulk of Cyperaceae pollen trapped at these locations (PT2, PT3, PT4) derives from the extensive coastal plain sedge communities which lie south of chenier ridge 1, and in the upwind direction relative to the dominant southeast Trades. Cyperaceae pollen production may be greatly influenced by the vagaries of weather, particularly the timing and intensity of wet season rains, and burning which is common but sporadic throughout the area with the onset of seasonal dryness. Hence total pollen production may vary considerably year to year. Similar environmental variability may explain the large differences in absolute representation of Myrtaceae (undetermined) and *Eucalyptus tetrodonta* type pollen, which are very strongly represented in trapping period 2 relative to period 1.
Seasonal differences in the quantity of blossom produced by many myrtaceous plants, including eucalypts, are well documented, and are known to be influenced by weather and inherent cyclic flowering patterns specific to particular species (Clemson, 1985).

**Surface Sample Results: Coastal Plain**

Sample locations for 24 surface sediment samples from transects 1 and 2 are shown in Figure 5.1. The results of pollen analysis of these samples are shown in relative terms in Figure 5.5, which includes all identified pollen types and fern spores recorded. The transects provide a matched pair of results, with corresponding samples collected from the same environments. For instance, along each transect samples 1 to 5 represent subtidal to low-tide muds, sample 6 represents the seaward mangrove limit, samples 7 to 9 represent the zoned mangrove forest, samples 10 and 11 represent salt mudflats, and sample 12 represents upper coastal plain a few metres landward of chenier ridge 1.

**Transect 1**

*Rhizophora* is the most strongly and consistently represented pollen type along transect 1. Its strongest representation occurs in the mangrove samples S1.7 and S1.8, with a steady decline in values in both landward and seaward directions. *Ceriops/Bruguiera* is also well represented, with highest values in seaward samples S1.1 to S1.5, and in the mangrove sample S1.8. *Avicennia* pollen is consistently recorded at low frequencies in all samples. *Sonneratia* and *Camptostemon* maintain low frequency representation through most samples seaward of S1.10 at the rear of the mangrove forest. Other mangrove taxa, including *Lumnitzera, Aegiceras, Excoecaria* and *Xylocarpus*, have minor representation in samples from within, or adjacent to, the mangrove
Figure 5.5  Pollen diagram for surface sample transects 1 and 2 on the coastal plain. Values are percentages of the pollen sum.
forest. The saltmarsh pollen taxa Chenopodiaceae and Batis attain strong representation in rear mangrove and salt mudflat samples (SI.9, SI.10 and SI.11), and have minor representation elsewhere.

The most strongly represented non-halophytic pollen taxa are Poaceae, Cyperaceae and Myrtaceae (undetermined). The highest relative values for these taxa are recorded for sites seaward of the mangrove fringe (samples SI.1 to SI.6), and landward of chenier ridge 1 (SI.12). Restionaceae/Centrolepidaceae pollen is recorded consistently at frequencies not exceeding 5 percent of the pollen sum. Many other taxa are recorded sporadically at low frequencies.

Transect 2

Patterns in the pollen representation along transect 2, closely resemble those described for transect 1. Rhizophora is most strongly represented in the mangrove samples, particularly S2.7 and S2.8. Ceriops/Bruguiera pollen has relatively lower values throughout, and shows no clear tendency towards increased representation at mangrove locations. Avicennia is consistently recorded at values generally less than 5 percent of the pollen sum. Sonneratia and Camptostemon also maintain consistent, low frequency representation, with the latter showing slightly higher values in samples from mangrove environments. The only other mangrove types recorded for transect 2 samples are Lumnitzera and Excoecaria. These have minor representation in mangrove and saltmarsh samples and are not recorded elsewhere.

Chenopodiaceae and Batis pollen types have their strongest representation in rear mangrove and saltmarsh samples as in transect 1. Poaceae and Cyperaceae attain strongest representation in samples seaward of the mangrove forest, and in the most landward sample, again
resembling the pattern described for transect 1. Myrtaceae (undetermined) pollen has moderate representation in most samples, and displays no clear tendency towards preferential deposition along the transect. A few other pollen types, notably Restionaceae/Centrolepidaceae, Pandanus, Eucalyptus retrodonta type, Callitris and Gonocarpus, are commonly recorded at low frequencies.

WEST ALLIGATOR RIVER

Figure 5.6 shows the locations of two surface sample transects through mangrove vegetation fringing the West Alligator River, which broadens in its lower reaches into a well-defined estuarine funnel. Well-developed mangrove communities and salt mudflats are extensive, particularly within 10 kilometres of the river mouth. In this section the mangroves are clearly zoned, and display species dominances and species assemblages similar to those of the open coastline.

Vegetation: West Alligator Transects

Vegetation summaries, based on the percentage abundances of mature mangrove plants, for the 2 West Alligator River surface sample transects are provided in Figure 5.7.

Transect 3 extends from the seaward mangrove limit for almost 200 metres into the mangrove forest. The transect was not extended through to the most landward mangrove communities because the area could not be reached between tides. The transect provides data from mature, seaward Sonneratia and Camptostemon forest which is not suffering the ravages of cyclonic activity, in contrast to transects 1 and 2 on the South Alligator coastal plain.
Figure 5.6 Surface sample transect locations on the West Alligator River.
Figure 5.7 Details of canopy height and structure, species zonation and surface sample locations on transects 3 and 4, West Alligator River. Transects begin at the riverbank (right hand side of diagram).
The seaward mangrove zone on transect 3 is approximately 80 metres wide and dominated by *Camptostemon schultzii* and *Sonneratia alba* in near equal proportions. The trees are well-spaced and form an open canopy approaching 20 metres in height. Occasional smaller trees and infrequent saplings of *Rhizophora stylosa* also occur, particularly towards the rear of the zone. Further landward the mangrove forest changes abruptly to a tall, dense stand of *Rhizophora stylosa*, with occasional *Avicennia marina* and *Camptostemon schultzii* scattered throughout. The forest canopy is continuous, and approximately 15 to 18 metres above ground. *Rhizophora stylosa* seedlings and saplings up to 2 metres tall are scattered thinly beneath the larger trees.

Transect 4, located approximately 3 kilometres from the river mouth, extends from the riverbank to salt mudflats, through a mangrove community almost 300 metres wide. Five vegetation zones are recorded within the greater mangrove complex, and transitions between zones are abrupt. A narrow band of bushy *Sonneratia alba* and *Aegiceras corniculatum* 1 or 2 trees wide, dominates the section closest to the river. Behind this lies a tall, dense stand of *Rhizophora stylosa* approximately 50 metres wide. Infrequent tall *Avicennia marina* are the only other trees recorded in this zone, while the sparse understorey and ground layer consists of *Rhizophora stylosa* seedlings and saplings. Further landward, *Bruguiera exaristata* is the dominant tree in an open forest 6 to 8 metres tall. The trees provide a sparse canopy, and are characterised by copious dead timber. Low shrubs of *Aegialitis annulata* and numerous *Bruguiera* and *Rhizophora* seedlings and saplings provide an open ground cover layer. This community adjoins a dense thicket of *Ceriops tagal var australis*, approximately 4 to 5 metres tall and 40 metres wide. Infrequent *Avicennia marina* are the only other canopy trees recorded, while *Aegialitis annulata* forms an open, low shrub
layer. The most landward mangrove vegetation zone consists of a broad, closed-canopy *Avicennia marina* thicket, barely 3 metres tall. Well-spaced saltmarsh plants, including *Batis argillicola*, *Halosarcia indica* and *Tecticornia australasica*, provide an intermittent ground layer. Beyond the mangroves a narrow band of saltmarsh vegetation, dominated by *Batis argillicola* fringes an extensive, barren mudflat.

**Surface Sample Results: West Alligator River**

**Transect 3**

Sampling locations for the 3 surface samples collected along transect 3 are shown relative to the vegetation profile in Figure 5.7. Results of pollen analyses of these samples are shown in Figure 5.8. *Rhizophora* is by far the most strongly represented pollen type, reaching a maximum value of 57 percent of the pollen sum in the most landward sample. *Sonneratia* is also well represented, with a maximum value of 15 percent in sample S3.2. Other mangrove pollen taxa, including *Ceriops/Bruguiera*, *Avicennia*, *Camptostemon*, *Excoecaria* and *Lumnitzera*, have only moderate to poor representation.

*Poaceae, Cyperaceae* and *Myrtaceae* (undetermined) pollen types are relatively well represented in each sample, maintaining values between 5 and 17 percent of the pollen sum. The few other taxa recorded generally have minor representation only.

**Transect 4**

Sampling locations for 5 surface samples along transect 4 are shown relative to the vegetation profile in Figure 5.7, while results of the pollen analyses themselves are presented in Figure 5.9. The best represented mangrove taxa are *Rhizophora* and *Ceriops/Bruguiera*. 
Figure 5.8  Pollen diagram for transect 3 on the West Alligator River. Values are percentages of the pollen sum.
Figure 5.9 Pollen diagram for surface sample transect 4 on the West Alligator River. Values are percentages of the pollen sum.
Strongest representation of the former occurs in the 3 samples collected nearest the river. *Avicennia* is relatively poorly represented, with a highest value of only 6 percent of the pollen sum in the most landward sample. Other mangrove taxa, including *Camptostemon*, *Excoecaria*, *Lumnitzera* and *Sonneratia*, have minor representation. The saltmarsh taxa *Chenopodiaceae* and *Batis* have strong representation at the rear of the mangrove fringe, and poor representation elsewhere.

Poaceae and Cyperaceae are consistently recorded throughout the sequence, but do not display clear tendencies towards preferential deposition at particular locations. *Myrtaceae* (undetermined) pollen is consistently recorded at frequencies less than 5 percent of the pollen sum. All other pollen types have low and generally sporadic representation.

Results similar to those for transect 4 are reported by Chappell and Grindrod (1985) from a surface sample transect through mangrove and saltmarsh communities on the West Alligator River, approximately 25 kilometres from the river mouth. The well represented mangrove pollen types are *Rhizophora*, *Ceriops/Bruguiera* and *Avicennia*. Values for the first 2 types decrease steadily with increasing distance from the river bank. *Avicennia* has its strongest representation at rear mangrove sites (away from the river bank), where parent plants are most abundant. Low pollen concentrations in sediments from the salt mudflat surface rear of the mangroves preclude analyses of some samples. Nearer the mudflat to floodplain transition pollen assemblages are strongly dominated by *Cyperaceae* and *Poaceae*. Saltmarsh plants are poorly represented throughout the pollen sequence, in keeping with their low abundance in the surrounding vegetation.
ADELAIDE RIVER

The diverse mangrove communities of the Adelaide River extend from the river mouth to upstream reaches south of the Arnhem Highway, some 93 river kilometres from the open sea. The mid to upper tidal reaches of the river provide extensive, low salinity mangrove habitat. Consequently, a number of mangrove plants which are either absent or poorly represented in the Alligator Rivers region, flourish along the Adelaide River. Examples of these are Acanthus ebracteatus, A. ilicifolius, Acrostichum speciosum, Avicennia officinalis, Bruguiera gymnorrhiza, Diospyros ferrea and Xylocarpus australasicus. The communities in which these plants thrive display patterns of zonation which are often less clearly defined and less predictable than zonations within communities fringing the open coast, while intra-zone diversity of species is often relatively high.

Pollen analyses of surface sediments from selected areas along the mid to upper tidal section of the Adelaide River were undertaken (1), to gauge the pollen signatures of mangrove species and species assemblages which are rare or absent from the South Alligator study area and (2), to provide pollen assemblages and sequences for comparison with fossil pollen records from cores collected in upstream sections of the South Alligator River.

Vegetation: Adelaide River Transects

Figure 5.10 shows the localities of 3 transects selected for surface sample analysis. Summaries of vegetation zonations and canopy height along each transect, are provided in Figure 5.11. Each transect runs through saline environments from the river bank to the margin of upper floodplain (black soil plain), often marked by a low, crumbling
Figure 5.10 Surface sample transect locations on the Adelaide River.
Figure 5.11  Details of canopy height and structure, species zonation and surface sample locations on transects 5, 6 and 7, Adelaide River. Transects begin at the riverbank (right side of diagram).
scarp. Although the patterns of zonation vary from transect to transect, some similarities are evident. For instance, each transect includes a river edge or "levee" community of closed canopy forest dominated by medium to large trees. The mangrove communities most distant from the river are low open shrublands, and do not grade into saltmarsh communities of the kind typical in coastal settings.

Mangrove vegetation adjacent to transect 5 spreads approximately 570 metres landward from the riverbank to merge with the river floodplain. The riverbank supports a narrow, closed-canopy forest approximately 10 to 15 metres tall and 25 metres wide. The canopy is dominated by Rhizophora stylosa, but also includes Avicennia marina, Camptostemon schultzii and Xylocarpus australasicus. Seedlings of Aegiceras corniculatum, Bruguiera parviflora and Rhizophora stylosa are also common. Away from the riverbank this community merges with a mixed mangrove forest and shrubland characterised by closed forest patches 5 to 7 metres tall. The common canopy species are Bruguiera gymnorrhiza, B. parviflora and Diospyros ferrea, while less frequent trees include Avicennia marina and Rhizophora stylosa. Understorey shrubs are numerous, and include the species listed as trees above, as well as Aegiceras corniculatum and Ceriops decandra. Seedlings and saplings of Acanthus ilicifolius, Avicennia marina, Bruguiera gymnorrhiza, B. parviflora, Ceriops decandra and Rhizophora stylosa are numerous. Outside the forest patches there are low, dense stands of Acanthus ilicifolius forming shrublands 1.0 to 1.5 metres high.

Further from the river, the mixed community merges with a narrow band of tall, closed forest with a canopy dominated by Rhizophora stylosa, and including occasional Camptostemon schultzii. Smaller trees of Bruguiera parviflora 5 to 6 metres high form a dense understorey,
while *Bruguiera gymnorrhiza* and *Ceriops decandra* occur as scattered, smaller shrubs. Landward, the tall closed forest adjoins tall open forest dominated by *Avicennia marina* trees 10 to 15 metres tall, with scattered smaller trees of *Bruguiera parviflora* and shrubs of *Bruguiera gymnorrhiza* and *Ceriops decandra*. Gangling, smaller shrubs of *Acanthus ilicifolius* occur sporadically throughout.

The most landward sections of mangrove vegetation along transect 5 comprise open *Avicennia marina* shrubland, which becomes increasingly low and sparse with distance from the river. The mature *Avicennia* are stunted and carry copious dead wood. The salt tolerant grass, *Sporobolus virginicus*, provides an intermittent ground cover, and bare mud surfaces are extensive.

Transect 6 runs through a relatively narrow mangrove vegetation zone. Close to the river's edge *Avicennia marina* trees ranging from 10 to 15 metres tall dominate the canopy, while *Aegiceras corniculatum* and *Acanthus ilicifolius* provide a discontinuous shrub layer. Further landward lies a broad zone of tall open mangrove forest with a canopy dominated by *Xylocarpus australasicus* up to 20 metres tall and *Bruguiera parviflora* 15 to 17 metres tall. Smaller trees of *Bruguiera gymnorrhiza* and *Diospyros ferrea* are also common, while *Avicennia marina* is present but infrequent. Saplings and seedlings of *Xylocarpus australasicus* are frequent, while *Acanthus ilicifolius* forms low, shrubby thickets in minor, treeless patches.

Landward of the tall open forest, well spaced shrubs of *Lumnitzera racemosa* interspersed with stunted trees and saplings of *Avicennia marina* and shrubs of *Acanthus ilicifolius* form a narrow band of open shrubland 2 to 3 metres tall. Seedlings of *Avicennia* and *Lumnitzera* are numerous, and *Sporobolus virginicus* provides a discontinuous ground
cover. At its upper limit the mangrove merges with salt mudflat, partially covered by Sporobolus.

The river bank community adjacent to transect 7 consists of a 30 metre wide, closed stand of Avicennia marina trees approximately 8 metres tall. Well spaced shrubs of Aegiceras corniculatum and Acanthus ilicifolius provide a sparse understorey. At its landward margin the riverbank forest adjoins a broad, dense shrubland consisting almost exclusively of Acanthus ilicifolius approximately 1.5 metres tall. Within the shrubland infrequent saplings of Avicennia marina and sedge hummocks also occur. Further landward the vegetation changes abruptly to a tall forest belt, approximately 25 metres wide and dominated by massive Xylocarpus australasicus trees up to 20 metres tall. Younger Xylocarpus provide a lower canopy 10 to 15 metres high, while Acanthus ilicifolius form a low, sparse shrub layer. Saplings and seedings of Xylocarpus australasicus, Bruguiera parviflora and Avicennia marina are also common. Behind the tall forest belt, widely spaced Avicennia marina trees and shrubs 3 to 5 metres tall dominate an open woodland community. Mature trees display the effects of dieback and coppicing. The area also supports occasional saplings and numerous seedlings of Avicennia marina. Sporobolus virginicus provides a patchy ground cover, interspersed with extensive areas of bare mudflat.

Surface Sample Results: Adelaide River

The locations of surface sample collections relative to vegetation units along the Adelaide River transects are shown in Figure 5.11. Relative pollen data for these samples are provided in Figures 5.12, 5.13 and 5.14. In each diagram samples are ordered according to distance from the riverbank, with those closest to it at the top.
Figure 5.12  Pollen diagram for surface sample transect 5 on the Adelaide River. Values are percentages of the pollen sum.
Figure 5.13 Pollen diagram for surface sample transect 6. Values are percentages of the pollen sum.
Figure 5.14 Pollen diagram for surface sample transect 7. Values are percentages of the pollen sum.
Transect 5

Figure 5.12 provides pollen data for transect 5. Twelve samples representing riverbank forest, mixed mangrove communities and Avicennia marina open shrubland, have been analysed.

Rhizophora, Ceriops/Bruguiera and Avicennia are the most consistently represented mangrove pollen types. The former shows a general tendency towards decreasing representation with increased distance from the riverbank, although it is also strongly represented in sample S5.9 towards the rear of the mangrove forest, a site dominated by mature Rhizophora stylosa trees (refer Figure 5.11). Ceriops/Bruguiera pollen maintains moderate to strong representation throughout the transect, displaying no clear trend towards preferential representation at any particular location. Avicennia pollen is most strongly recorded at the 3 most landward locations, and has steadily decreasing values towards the river. Acanthus pollen is present in most samples, but is not recorded at frequencies greater than 2 percent of the pollen sum. The remaining mangrove pollen types recorded are Aegiceras, Camptostemon, Excoecaria, Lummitzera, Sonneratia and Xylocarpus. These generally maintain low frequency, sporadic representation. The saltmarsh component, Chenopodiaceae, is also poorly represented.

Of the predominately non-halophytic elements, Poaceae, Cyperaceae and Myrtaceae (undetermined) are most strongly and consistently represented, with values generally not exceeding 10 percent of the pollen sum. These types do not display clear tendencies towards stronger representation at particular locations along the transect. Many other pollen taxa representing plants common to the area or region are recorded at very low frequencies. Undifferentiated fern spores also maintain minor and sporadic representation.
The strong, localised representation of Mimosaceae (monads) and Asteraceae (Tubuliflorae) pollen types cannot be explained in terms of local vegetation, as plants providing these pollen types are not recorded in mangrove environments. It is possible that these occurrences represent the remains of decomposing flowers carried to the sampling site by tidal flooding. Because of the uncertainty regarding the source of these pollen types, both taxa are excluded from the pollen sum.

Transect 6

Figure 5.13 shows the results of pollen analysis of 5 surface samples collected along transect 6. *Rhizophora* maintains values in the range 26 to 45 percent of the pollen sum, with strongest representation at the riverbank. *Ceriops/Bruguiera* and *Avicennia* are also well represented throughout the sequence, but do not display obvious trends relative to distance along the transect. Other mangroves which attain minor representation include *Acanthus, Camptostemon, Excoecaria, Lumnitzera* and *Xylocarpus*.

*Poaceae* and *Myrtaceae* (undetermined) pollen are strongly and consistently represented, while all other non-mangrove taxa are recorded at low frequencies only.

Transect 7

Figure 5.14 provides relative pollen data for 5 samples collected along transect 7. The major pollen types recorded are the same as those described for transects 5 and 6. *Rhizophora* is the most abundant pollen type in the riverbank sample S7.1, but maintains relatively low values elsewhere. *Ceriops/Bruguiera* pollen is consistently recorded at frequencies between 5 and 20 percent of the pollen sum, with highest
values in sample S7.2, approximately 45 metres from the riverbank. Avicennia pollen is most strongly recorded in the 3 most landward samples, with values around 17 to 19 percent of the pollen sum. Acanthus is present in all but the most landward sample at frequencies below 5 percent. The other mangrove and saltmarsh pollen types recorded are Camptostemon, Lumnitzera, Sonneratia, Xylocarpus and Chenopodiaceae. Each of these has low frequency and inconsistent representation.

Poaceae is the major non-mangrove pollen type with strongest representation in sample S7.2, close to the riverbank. Cyperaceae and Myrtaceae (undetermined) pollen are consistently recorded at frequencies not greater than 5 percent of the pollen sum. Eucalyptus tetrodonta type pollen is recorded at very low frequencies in all samples but one. Other pollen types and fern spores recorded attain only minor and inconsistent representation.

DISCUSSION

Tauber (1965, 1967a) proposed a model for pollen transfer from deciduous forest to a lake surface in Denmark. Major components in the pollen rain arriving at the site of deposition included pollen carried through the forest trunkspace, pollen carried above the forest canopy, pollen delivered from the atmosphere in rain, and pollen filtered out of the atmosphere by vegetation and subsequently remobilised by runoff. These separate components derived from source areas at different distances from the site with trunkspace and above-canopy components being of local and regional significance respectively, while the rainout component incorporated a long distance element (Tauber, 1965, 1967a).
Tauber also demonstrated that airborne pollen moving within the vegetation is filtered by impaction on trunks, branches and leaves. The filtration efficiency is determined by such factors as wind speed, density of vegetation, and pollen grain size (Tauber, 1965). Wind speeds within vegetation are also affected by the density of foliage, so that conditions in openly-structured communities are more likely to be suitable for wind pollination than those in closed-canopy communities.

Kershaw and Hyland (1975) applied aspects of the Tauber model to a lake catchment in tropical rainforest in northeastern Queensland, and concluded that the trunkspace pollen component was negligible in dense, closed-canopy rainforest due to efficient filtration of pollen by draping vegetation at the forest edge, low wind speeds beneath the forest canopy, and the high proportion of entomophilous (insect-pollinated), low pollen producing, species. Flenley (1973) discusses these factors in relation to a number of rainforest community types throughout the tropics. From pollen trap analyses, this author concludes that, in tropical lowland rainforest in Malaysia, the major components of pollen rain are comparable to those proposed by Tauber for temperate forests, with the trunkspace component consisting largely of fern spores.

At the present study site the main source areas for pollen delivered to intertidal sediments are closed-canopy mangrove forests which are similar in structure to and floristically related to tropical rainforest, and more open sclerophyll forests and woodlands which are structurally analogous to temperate, deciduous forests. Consideration of the pollination strategies of plant taxa with regard to the vegetation community types in which they occur, is important to a general understanding of modern pollen rain in littoral zone environments.
This section discusses aspects of the pollination ecology and pollen dispersal of a number of important plants in the study area, based on the surface sample and pollen trap data. Where possible, reference is also made to descriptions of the floral biology and palynological observations in the published literature.

Pollen from Mangrove Sources

The mangrove flora displays a range of pollination strategies common in rainforest, with a high proportion of entomophilous species. According to Tomlinson (1986) mangrove plants are almost exclusively pollinated by animal vectors, of which there is a diverse array. Interaction and perhaps even competition between mangroves is said to maximise the efficient use of the pollinator resource. The most obvious exception to a reliance on animal pollination is the genus *Rhizophora*, which exhibits a floral morphology and flowering behaviour suited to wind pollination. Features suggesting wind dispersal of pollen include short functional life of the flowers, pendulous flowers below the leafy canopy, lack of pollinator attractants such as nectar and fragrance, and high pollen/ovule ratios which are as much as one order of magnitude greater than those of related entomophilous species. In spite of this *Rhizophora* flowers are known to be visited by insects (Tomlinson *et al.*, 1979; Tomlinson, 1986).

The high pollen/ovule ratios of *Rhizophora* are reflected in the strong representation of the pollen type in coastal and marine sediments. Muller (1959) concluded that the pollen of *R. mangle* is suited to wind dispersal, and that strong representation in offshore localities reflects copious pollen production and effective wind-borne
and water-borne dispersal. In the present study, Rhizophora pollen also shows a tendency towards localised distribution close to the source plants, particularly along the coastal plain transects. Similar results are recorded in other studies, for example, for R. stylosa in northeastern Queensland (Grindrod, 1985) and R. samoensis in Fiji (Southern, 1986). Ceriops/Bruguiera is generally poorly represented in comparison with Rhizophora. This is probably due to the greater reliance on animal pollination and hence lower pollen production in these genera. The floral biology of C. decandra suggests unspecified insect pollination, while C. tagal and all species of Bruguiera contain elaborate "spring loaded" pollen ejection mechanisms which ejaculate pollen onto the head of the pollinator. The flowers of different species appear to be attractive to specific pollinators; thus the large-flowered Bruguiera (B. exaristata, B. gymnorrhiza and B. sexangula) are bird-pollinated, the smaller-flowered Bruguiera (B. cylindrica, B. hainesii and B. parviflora) are pollinated mainly by insects in daylight, while C. tagal is pollinated by small, nocturnal moths (Tomlinson, 1986). Other floral characteristics suggesting animal pollination in Ceriops and Bruguiera include relatively low pollen/ovule ratios and pollinator attractants such as showy flowers and copious nectar production (Tomlinson et al., 1979). The relatively small size of the pollen grains, especially in B. exaristata, B. parviflora and the Ceriops species, may also mitigate against efficient wind dispersal.

In the surface and pollen trap samples Ceriops/Bruguiera pollen generally maintains moderate to low representation, and except for relatively strong values in samples S6.3 and S6.4 from the Adelaide River where B. parviflora is prolific, there is little tendency towards localised pollen distributions. This may be partly due to a general lack of extensive mangrove communities clearly dominated by either
Geriops or Bruguiera. The pollen type is recorded in highly localised distributions in northeastern Queensland where C. tagal-dominated communities are extensive (Grindrod, 1985). Similarly, Southern (1986) describes localised deposition of B. gymnorrhiza pollen in Fijian mangrove swamps.

Avicennia species have a floral structure suited to pollination by short-tongued insects, particularly bees. Indeed, A. germinans and A. marina are considered commercial honey sources in Florida (Tomlinson, 1986) and eastern Australia (Boland et al., 1984). The pollen of the latter species remains adhesive to the theca, and can apparently only be removed by contact with an insect. All Avicennia species provide nectar as the pollination reward (Tomlinson, 1986).

Although Avicennia pollen is generally poorly represented in coastal sediments, it occasionally displays marked, localised distributions. For instance, A. officinalis is poorly represented by pollen in mangrove sediments in India (Caratini et al., 1973). This seems generally true of the common Australian species A. marina and A. officinalis, with their pollen type consistently recorded at low but consistent frequencies in cores (Grindrod and Rhodes, 1984; Hope et al., 1985; Woodroffe et al., 1985c). However, Muller (1959) concluded that A. nitida pollen in modern sediment samples from the Orinoco Delta, showed a distribution closely related to the source area, and Grindrod (1985) recorded highly localised distributions of the pollen type in surface sediment samples, with high values corresponding to communities dominated by the source plant. In the present study a tendency towards localised distributions of Avicennia pollen is recorded in transect 5 (samples S5.10, S5.11 and S5.12), where Avicennia-dominated communities are extensive. Highly localised distributions are
also recorded in pollen traps PT2 and PT4 on transect 1, adjacent to or beneath mature source plants. The consistently low values recorded for the pollen type elsewhere in modern pollen samples reflects the general lack of mangrove communities clearly dominated by Avicennia and the poor dispersal of this pollen type.

Pollination in Sonneratia alba is said to be achieved by nocturnal animals, especially bats and hawkmoths. The flowers generally open at dusk, last 1 night only, and exude a sour, milky nectar. In west Malaysia several species of bats visit S. alba flowers; at least 1 species is thought to be almost totally reliant on Sonneratia as a food source (Tomlinson, 1986). In eastern Australia S. alba flowers are frequently visited by the hawkmoth Psilogramma menephron menephron. Pollen is produced in very large quantities, with as many as 500,000 grains on a single flower (Primack et al., 1981). The floral and pollen morphologies of S. lanceolata closely resemble those of S. alba, suggesting similar pollination behaviour.

Although Caratini et al. (1973) record strong representation of S. apetala pollen in sediments relative to the abundance of the parent plants at Pichavaram, species in the present study area maintain low to moderate representation, with a tendency towards stronger localised representation. For instance, the highest relative values for Sonneratia pollen are recorded in sample S3.2 (transect 3), where mature S. alba trees dominate the seaward mangrove community. Here the pollen type accounts for 15 percent of the pollen sum, in spite of strong representation of Rhizophora from nearby sources. Sonneratia pollen is also consistently recorded at low to moderate frequencies in Holocene core samples by Anderson and Muller (1975), Hope et al. (1985), and Woodroffe et al., (1985c).
Little information is available on the pollination biology of *Camptostemon schultzii*. In the present study, the species has poor pollen representation, even in samples collected beneath mature *Camptostemon* stands, such as in the seaward mangrove communities on transects 1, 2 and 3. The pollen type is not recorded in other mangrove palynological studies within its present geographical range. The poor pollen representation of the species, showy flowers and large and ornate pollen grains suggest low pollen production and a reliance on pollination by animal vectors rather than by wind.

The floral biology of the two species of *Lumnitzera* in the study area indicates that they are primarily pollinated by animal visitors. The red flowers and abundant nectar of *L. littorea* are attractive to birds, especially sunbirds and smaller honeyeaters, although they are also visited by insects. *L. racemosa* produces smaller, white flowers with less nectar and characteristically shallow calyx tubes. These are predominantly visited by day-active moths, butterflies, bees and wasps (Tomlinson et al., 1978; Tomlinson, 1986).

Palynological evidence from Pichavaram (Caratini et al., 1973) and northeastern Queensland (Grindrod and Rhodes, 1984; Grindrod, 1985) indicates that *L. littorea* and *L. racemosa* maintain low pollen representation in surface sediments equivalent to the relative scarceness of source plants. Occasional, high values for *Lumnitzera* pollen are recorded in pollen trap samples (Grindrod, 1985), presumably as a result of trap placement close to flowering *Lumnitzera* trees. Similar results are recorded in the present study, with *Lumnitzera* pollen recorded in very low values throughout mangrove environments in which source plants are infrequent.
Excoecaria agallocha produces small catkin-like flowers with yellow nectar and sticky pollen suited to transport by insects. Bees are common flower visitors, and probably the chief vectors of pollination. The poor representation of this species in pollen assemblages from mangrove sediments in the present study seems in keeping with a low pollen production and the infrequent occurrence of source plants in most mangrove environments. Caratini et al. (1973) conclude that the pollen representation of E. agallocha is approximately one third the expected value, given the abundance of source plants.

The pollen of Aegialitis annulata is rarely recorded in published mangrove palynological studies. It has not been recorded in the present study, even though a number of surface sediment samples derive from sites where Aegialitis is profuse in the mangrove understory (e.g. samples S1.9, S2.9, S4.3). At these sites flowering specimens are common throughout the dry season, and although no animal visitors have been observed, the non-representation of pollen in sediments, and the very large dimensions of the pollen grain, which is approximately 70 microns in diameter, suggest specialised animal vector pollination.

The floral structure of the conspicuous, blue flowers of Acanthus ilicifolius suggests a reliance on bird-pollination. Dense, outwardly pointing hairs within the corolla tube are likely to deny access by small insects (Tomlinson, 1986). Nectar-feeding birds are reported to visit Acanthus flowers in Queensland, although large bees may also be potential pollinators (Primack, et al., 1981).

Acanthus ilicifolius pollen is very poorly represented in mangrove sediments. Caratini et al. (1973) conclude that the feeble representation of the pollen type at Pichavaram is in keeping with the sparse distribution of source plants. In the present study, pollen
assemblages derived from surface muds collected from "meadows" dominated by *A. ilicifolius* to the near exclusion of other plants (S7.2 and S7.3) contain only minor amounts of Acanthus pollen (a maximum of 4 percent of the pollen sum). A similar result (not shown in the pollen diagrams) was obtained from a sediment sample collected from a defunct irrigation channel joining the Adelaide River and choked with mature *A. ilicifolius* plants.

The flowers of *Xylocarpus* are suited to pollination by short-tongued insects, particularly bees. Nectar produced in small quantities by the ovary disc accumulates in the floral cup as incentive to flower visitors (Tomlinson, 1986). As with other insect-pollinated plants, the pollen of *Xylocarpus* is poorly represented in sediments. The pollen type is rarely recorded in palynological studies, and is all but absent from samples collected from Adelaide River mangroves where mature *X. australasicus* are prolific (samples S6.2, S6.3 and S6.4).

*Aegiceras corniculatum* is pollinated by bees and similar insects, and is considered a useful source of honey in eastern Australia (Clemson, 1985). The species is poorly represented by pollen in coastal sediments. The pollen type was not recorded at Pichavaram by Caratini et al. (1973), although the source plant is considered a principal species in the mangrove flora of the study site. In the present study the pollen type is recorded at very low frequencies at 2 surface pollen sites only, even though the species is common in low salinity mangroves along the Adelaide River, and also appears as scattered individuals in coastal mangrove communities.

One other mangrove tree species deserves consideration. *Diospyros ferrea* is a common component of low salinity mangroves of the Adelaide River, often in conjunction with *Bruguiera gymnorrhiza* and *Xylocarpus*
australasicus, but does not dominate mangrove communities adjacent to the surface sample transects. The non-representation of this species in pollen assemblages suggests low pollen production and/or poor pollen dispersal.

Pollen from Saltmarsh Sources

Chenopodiaceae pollen is strongly represented in numerous palynological studies. Macphail and McQueen (1983) consider the pollen type to be effectively wind-dispersed and over-represented in pollen assemblages. Dispersal by wind is confirmed by inclusion of the pollen type at relatively high frequencies in pollen traps in arid, inland Australia (Singh, 1981) and in coastal environments (Grindrod, 1985). Despite the potential for wind dispersal however, the pollen type is clearly prone to strong local deposition in coastal sediments (Caratini et al., 1973; Grindrod, 1985), and has proven to be a useful indicator of depositional environment. Results from the present study are in clear agreement with the above findings, with Chenopodiaceae pollen recorded at low frequencies at sites remote from source plants, and at high frequencies in pollen traps and sediment samples from saltmarsh environments on transects 1 and 2, indicating strong pollen production and wide dispersal.

Batis pollen exhibits relatively strong, localised distribution and poor dispersibility in modern environments. The pollen type is rarely recorded away from the source plant, but is well represented in pollen trap and surface sediment samples from rear mangrove and saltmarsh environments on transects 1, 2 and 4, where B. argillicola is prominent.
Pollen from Plains and Upland Sources

Seventy-five percent of the pollen types recorded in surface samples and pollen traps derive from non-halophytic environments landward of the mangrove and saltmarsh communities. Along all surface sample transects the mangrove and saltmarsh communities are flanked by extensive, treeless coastal plains or river floodplains, while upland sclerophyll communities are at least a few kilometres distant. Many pollen types from plains and upland communities are recorded rarely (once only in some cases) and will not be discussed here. Those which are consistently recorded in intertidal and offshore sediments derive from prolific pollen producers which achieve effective wind-dispersal of their pollen grains. The exposed nature of floodplains and the open structure of sclerophyll forests and woodlands, provide conditions suited to pollen dispersal by wind.

The Poaceae and Cyperaceae pollen types are consistently recorded in modern pollen samples throughout the study area. High relative abundances occur in most pollen trap samples, and in subtidal muds up to 900 metres seaward of the mangroves on transects 1 and 2, indicating effective dispersal by wind and perhaps by seasonal flooding. It is likely that the bulk of Poaceae and Cyperaceae pollen in littoral sediments derives from the extensive grass and sedge communities of the coastal plains and river floodplains, although pollen of both types may also come from sclerophyll communities further afield. The high production and dispersibility of these pollen types is also noted in many other palynological studies (e.g. Dodson, 1983; Grindrod, 1985).

Restionaceae/Centrolepidaceae and Typha pollen types are recorded consistently at low frequencies. These probably have relatively local pollen dispersal and derive from floodplain environments. Pandanus
pollen is recorded at low frequencies in a number of samples remote from the source plants, while high relative and absolute values are recorded in pollen trap PT5, which was placed close to mature *P. spiralis* trees on chenier ridge 2. These results indicate some potential for regional dispersal of the pollen type, and relatively strong localised deposition close to flowering plants. A similar degree of localised deposition is indicated for *Pandanus* pollen in northeastern Queensland (Grindrod and Rhodes, 1984) and for *P. pyriformis* pollen in Fiji (Southern, 1986).

Myrtaceae pollen types particularly from *Eucalyptus*, are well represented in pollen assemblages throughout Australia. In the present study, Myrtaceae (undetermined) pollen comes from upland sclerophyll communities, and perhaps from paperbark swamplands. The major contributing genus is likely to be *Eucalyptus*, although *Melaleuca* may also be important. It is unlikely that other myrtaceous genera recorded in the area, such as *Calytrix*, *Leptospermum*, *Syzygium* and *Xanthostemon* contribute significantly to the Myrtaceae (undetermined) pollen type, due to their relative scarceness, and in some cases distinctive pollen morphologies. Myrtaceae (undetermined) pollen is ubiquitous in surface sediment and pollen trap samples remote from upland source areas, indicating effective, regional dispersal by wind. Similarly *Eucalyptus tetrodonta* type pollen exhibits some capacity for wind dispersal, despite the fact that its conspicuous creamy-white flowers are frequently visited by lorikeets and insects, suggesting some degree of animal pollination. Pollen studies in Queensland also indicate *E. tetrodonta* type pollen to be effectively dispersed by wind (Grindrod, 1983).
A few other pollen types achieve regional or long distance dispersal, with occasional or consistent low frequency representation at sites remote from the source plants. These include Callitris, Casuarina, Gonocarpus type and Podocarpus. The latter is not recorded in plant species lists for the Northern Territory, but is present in Papua New Guinea and Queensland. Each of these pollen types are thought to be effectively wind dispersed.

Acacia pollen is often poorly represented in pollen assemblages (e.g. Hope 1974; Dodson, 1983). However, Head (1984) concluded that the genus in southeastern Australia exhibits relatively strong pollen deposition near to source plants, and shows some capacity for dispersal over longer distances, presumably by wind. In the present study Acacia pollen maintains low frequency representation in many samples (including pollen traps) from sites which are at least a few kilometres from the nearest source plants, suggesting some capacity for wind dispersal.

Salient aspects of plant pollination behaviour and pollen dispersals in the study area are summarised in Table 5.2. The table includes entries for the prominent taxa discussed in the preceding section and additional information regarding some infrequently recorded pollen types. The information confirms that the surface sample and pollen trap assemblages include pollen from local and distant sources relative to each sampling location. In this regard Tauber's notions of local, extra-local, regional and long distance components within the pollen rain are useful.

Figure 5.15 provides a conceptual framework for major components in the pollen rain across the South Alligator coastal plain, following the format suggested by Tauber (1965). Grindrod (1985) provides a similar model for a chenier plain in northeastern Queensland, but did not extend
<table>
<thead>
<tr>
<th>Plant taxon</th>
<th>Representative pollen type</th>
<th>Plant description</th>
<th>Pollen dispersal and representation (present study)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acacia spp.</td>
<td>Acacia</td>
<td>trees/shrubs, widespread in upland communities</td>
<td>pollen poorly dispersed, low frequency representation</td>
</tr>
<tr>
<td>Acanthus ilicifolius</td>
<td>Acanthus</td>
<td>shrub in low salinity mangroves</td>
<td>poor pollen representation even where source plants are prolific</td>
</tr>
<tr>
<td>Aegiceras corniculatum</td>
<td>Aegiceras</td>
<td>mangrove shrub</td>
<td>poor pollen representation</td>
</tr>
<tr>
<td>Aeschynomene indica</td>
<td>Aeschynomene</td>
<td>annual shrub on coastal and riverine plains</td>
<td>poor pollen representation in surface samples in keeping with scarcity of source plants; strong representation in cores (see chapters 6 &amp; 7) suggests strong pollen production and localised distribution</td>
</tr>
<tr>
<td>Avicennia marina</td>
<td>Avicennia</td>
<td>mangrove shrubs and trees</td>
<td>strong localised pollen representation, poor pollen dispersal</td>
</tr>
<tr>
<td>Banksia dentata</td>
<td>Banksia</td>
<td>tree at coastal plain fringe</td>
<td>poor pollen dispersal</td>
</tr>
<tr>
<td>Batis argillicola</td>
<td>Batis</td>
<td>saltmarsh and mangrove shrub</td>
<td>moderate, localised pollen representation</td>
</tr>
<tr>
<td>Bruguiera spp.</td>
<td>Ceriops/Bruguiera</td>
<td>mangrove trees and shrubs</td>
<td>most species apparently entomophilous (Tomlinson et al., 1979), moderate pollen production and moderate to poor dispersal</td>
</tr>
<tr>
<td>Callitris intratropica</td>
<td>Callitris</td>
<td>sclerophyll tree</td>
<td>widespread pollen dispersal, low frequency representation</td>
</tr>
<tr>
<td>Camptostemon schultzii</td>
<td>Camptostemon</td>
<td>mangrove tree</td>
<td>low pollen representation, even where source plants are prolific</td>
</tr>
<tr>
<td>Plant</td>
<td>Habitat</td>
<td>Pollen Characteristics</td>
<td></td>
</tr>
<tr>
<td>---------------------</td>
<td>----------------------------------</td>
<td>--------------------------------------------------------------</td>
<td></td>
</tr>
<tr>
<td>Casuarina spp.</td>
<td>trees fringing fresh water rivers</td>
<td>efficient wind dispersal, low frequency representation</td>
<td></td>
</tr>
<tr>
<td>Restionaceae/</td>
<td>herbs on flood-plain and upland</td>
<td>consistent, low frequency representation</td>
<td></td>
</tr>
<tr>
<td>Centrolepidaceae</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ceratopteris</td>
<td>ground fern in ephemeral swamps and on floodplain</td>
<td>low frequency representation in keeping with infrequent occurrence of source plants</td>
<td></td>
</tr>
<tr>
<td>Ceriops spp.</td>
<td>mangrove shrubs and trees</td>
<td>may be predominantly entomophilous (Tomlinson et al. 1979); moderate pollen production and dispersal; Grindrod (1985) reports highly localised dispersal of C. tagal pollen</td>
<td></td>
</tr>
<tr>
<td>Chenopodiaceae</td>
<td>saltmarsh shrubs</td>
<td>high pollen production and localised dispersal</td>
<td></td>
</tr>
<tr>
<td>Cyperaceae</td>
<td>sedges on flood-plains and upland</td>
<td>consistent representation; strong pollen production and effective dispersal</td>
<td></td>
</tr>
<tr>
<td>Dodonaea spp.</td>
<td>trees and shrubs of upland forests</td>
<td>infrequent representation</td>
<td></td>
</tr>
<tr>
<td>Diospyros ferrea</td>
<td>mangrove tree</td>
<td>pollen not recorded, even in surface samples close to prolific source plants</td>
<td></td>
</tr>
<tr>
<td>Eucalyptus tetrodonta</td>
<td>sclerophyll tree</td>
<td>pollen widely dispersed by wind</td>
<td></td>
</tr>
<tr>
<td>Excoecaria aggalocha</td>
<td>mangrove shrub</td>
<td>minor pollen representation in keeping with low frequency of source plants</td>
<td></td>
</tr>
<tr>
<td>Gonocarpus</td>
<td>sclerophyll shrub</td>
<td>consistent, low frequency representation suggests good pollen dispersal</td>
<td></td>
</tr>
<tr>
<td>Family</td>
<td>Common Name</td>
<td>Pollen Representation</td>
<td>Notes</td>
</tr>
<tr>
<td>----------------</td>
<td>-----------------------------------</td>
<td>-----------------------</td>
<td>----------------------------------------------------------------------</td>
</tr>
<tr>
<td>Grevillea spp.</td>
<td>Grevillea sclerophyll trees and shrubs</td>
<td>Low pollen representation suggests low pollen production and/or poor dispersal</td>
<td></td>
</tr>
<tr>
<td>Luminitza spp.</td>
<td>Luminitza mangrove trees and shrubs</td>
<td>Poor pollen representation, in keeping with scarcity of source plants</td>
<td></td>
</tr>
<tr>
<td>Myrtaceae undet.</td>
<td>Myrtaceae very common trees and shrubs in upland sclerophyll environments</td>
<td>Moderate pollen representation indicates effective dispersal</td>
<td></td>
</tr>
<tr>
<td>Pandanus spp.</td>
<td>Pandanus trees of upland sclerophyll forest floodplain and swamp verge</td>
<td>Localised pollen dispersal</td>
<td></td>
</tr>
<tr>
<td>Poaceae</td>
<td>Poaceae widespread in floodplain and upland environments</td>
<td>Strong pollen production and effective dispersal</td>
<td></td>
</tr>
<tr>
<td>Podocarpus spp.</td>
<td>Podocarpus not recorded in the study area</td>
<td>Effective, long distance dispersal by wind</td>
<td></td>
</tr>
<tr>
<td>Restionaceae/</td>
<td>Restionaceae/herbs of floodplain and upland communities</td>
<td>Consistent, low frequency representation suggests effective pollen dispersal</td>
<td></td>
</tr>
<tr>
<td>Centrolepidaceae</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rhizophora stylosa R. apiculata</td>
<td>Rhizophora mangrove trees</td>
<td>Very strong pollen representation in most mangrove and nearshore samples</td>
<td></td>
</tr>
<tr>
<td>Selaginella uliginosa</td>
<td>Selaginella fern ally</td>
<td>Infrequent representation of spores in keeping with minor occurrence of this plant in modern vegetation of the study area</td>
<td></td>
</tr>
<tr>
<td>Sonneratia alba S.lanceolata</td>
<td>Sonneratia mangrove tree</td>
<td>Low to moderate representation where source plants are prolific</td>
<td></td>
</tr>
<tr>
<td>Typha spp.</td>
<td>Typha rushes in fresh swamp environments</td>
<td>Pol len recorded at low values only</td>
<td></td>
</tr>
<tr>
<td>Xylocarpus australasicus</td>
<td>Xylocarpus mangrove tree</td>
<td>Pollen very poorly represented where source plants are prolific</td>
<td></td>
</tr>
</tbody>
</table>
Figure 5.15 Components in the pollen transfer across the coastal plain.
surface sampling beyond the lower limit of mangrove growth. It can be seen in Figure 5.15 that pollen assemblages from any sampling point will generally include representatives of all major source components. For instance, samples from within the mangrove fringe will include local mangrove pollen types, extra-local saltmarsh pollen types, regional pollen from plains and upland communities, and perhaps long distance pollen from much further afield. The absolute pollen data in Figure 5.4 indicate, as would be expected, that regional pollen types have relatively even absolute fallout across the entire plain, while locally produced and dispersed pollen types have highly variable between-site representation. Hence values for the regional pollen components such as Myrtaceae (undetermined) and Eucalyptus tetrodonta type are relatively constant regardless of distance from the upland sclerophyll source plants, while pollen types such as Avicennia, Sonneratia, Chenopodiaceae, Batis and Pandanus have markedly localised absolute representation. The imprint in intertidal sediments of locally deposited pollen types relative to the regional and long distance pollen rain provides a useful index of environment of deposition (Grindrod 1985), and is used in the description of trends in surface sample pollen distributions described below.

Trends in the Surface Sample Data

In this section summary diagrams of trends in pollen distributions along all surface sample transects are presented. The diagrams (Figures 5.16 to 5.20) graph the individual performances of locally produced pollen types as a percentage of the combined representation of major regional and long distance components (the regional/long distance pollen group). Similarly derived pollen ratios are used by Chappell and Grindrod (1985) and Grindrod (1985) as an index of vegetational
Figure 5.16  Percentage ratios for local pollen types relative to the regional/long distance pollen group for surface sample transect 1.
Figure 5.17 Percentage ratios for local pollen types relative to the regional/long distance pollen group for surface sample transect 2.
Figure 5.18 Percentage ratios for local pollen types relative to the regional/long distance pollen group for surface sample transects 3 and 4.
Figure 5.19  Percentage ratios for local pollen types relative to the regional/long distance pollen group for surface sample transect 5.
Figure 5.20  Percentage ratios for local pollen types relative to the regional/long distance pollen group for surface sample transects 6 and 7.
environments in coastal localities elsewhere. For each transect the local pollen types invariably include *Rhizophora, Ceriops/Bruguiera* and *Avicennia*. *Sonneratia, Chenopodiaceae* and *Batis* are also included where strongly represented. The regional group is comprised of *Poaceae, Cyperaceae, Myrtaceae* (undetermined), *Eucalyptus tetrodonta* type, *Acacia, Callitris, Casuarina, Gonocarpus* and *Podocarpus*.

With the exception of *Avicennia*, all local pollen types graphed for transect 1 (Figure 5.16) have very strong representation relative to the regional and long distance group at or adjacent to the sites of pollen production. Hence *Rhizophora* and *Ceriops/Bruguiera* have peak values at mid and landward mangrove sites respectively, while *Chenopodiaceae* and *Batis* have peak values in saltmarsh samples close to the upper mangrove limit. The relatively minor importance of *Avicennia* in the vegetation along this transect is reflected by moderate pollen representation. However, greatest values for this pollen type appear in landward mangrove environments, coinciding with the densest occurrence of source plants. Very similar trends are recorded for transect 2 (Figure 5.17), the only inconsistency being the peak value for *Ceriops/Bruguiera* pollen in a saltmarsh sample collected just landward of the mangroves.

The coastal plain results are comparable to surface pollen results from Princess Charlotte Bay (Chappell and Grindrod, 1985; Grindrod, 1985), where highest local pollen values for mangroves relate strongly to the distribution of source plants. Accordingly values for *Rhizophora, Ceriops/Bruguiera* and *Avicennia* decrease dramatically with increasing distance landward from the mangrove fringe, and provide a precise index of depositional environment. Although similar trends are evident in the present study, there is a less precise relationship between mangrove pollen deposition and the distribution of source
plants. This may be a consequence of greater scatter of pollen by wind. At Princess Charlotte Bay the Southeast Trades are consistent throughout the year, blowing offshore at the study site, and thereby limiting the landward movement of pollen. Although at the present study site the dominant Southeast Trades blow offshore, a considerable volume of wind comes from the northern sector (see Figure 2.5), thus aiding the spread of mangrove pollen landward across non-mangrove environments.

The relatively clear trends in local pollen distributions described for the coastal plain transects, also relate to the fact that specific plant assemblages are discrete and geographically isolated from other similar communities. Clear trends in mangrove and saltmarsh pollen distributions are less evident along transects 3 to 7, which border riverbanks (Figures 5.18 to 5.20). This may be partly due to the fewer number of samples in most transects, but must also relate to the fact that plant species segregation is often less clear, and vegetation communities are less discretely isolated, with similar vegetation types on opposing riverbanks, or in nearby meander loops. However, salient aspects of local deposition along the riverbank transects include relatively strong representation of Sonneratia pollen in transect 3, and strong representation of Avicennia pollen in rear mangrove communities along transects 5 and 7 where parent plants are abundant.

General Summary

The pollen assemblages from modern littoral zone environments include wind-dispersed pollen types from regional and long distance sources (mainly coastal plains, river floodplains and upland sclerophyll environments), and locally produced and deposited pollen types from mangrove and saltmarsh plants.
With the exception of Rhizophora, mangrove pollen types are poorly represented in pollen assemblages. This was previously demonstrated for a few mangrove genera at other sites e.g. Avicennia, Ceriops, Bruguiera, Excoecaria, Acanthus and Aegiceras (Caratini et al., 1973; Grindrod, 1985). In the present study similar results are obtained for a number of taxa not previously palynologically investigated e.g. Aegialitis, Camptostemon, Dyospyros and Xylocarpus. The poor representation of most mangrove taxa reflects pollination strategies which rely primarily on animal vectors rather than wind.

Despite generally poor representation, a few mangrove and saltmarsh pollen types, notably Rhizophora, Ceriops/Bruguiera, Avicennia, Sonneratia, Chenopodiaceae and Batis provide useful indicators of vegetational environment across the relatively narrow, linear mangrove and saltmarsh communities of coastal plain and riverbank localities. The surface sample results demonstrate that: 1. sediments from Rhizophora communities contain 200 to 475 percent Rhizophora pollen relative to the regional pollen component, 2. sediments from Ceriops communities at the rear of the mangrove contain 70 to 130 percent Ceriops/Bruguiera pollen relative to the regional pollen component, 3. sediments from Avicennia communities contain 50 to 100 percent Avicennia pollen relative to the regional component. 4. sediments from saltmarsh communities contain 50 to 300 percent Chenopodiaceae and 60 to 200 percent Batis pollen relative to the regional pollen component, where source plants are locally abundant. The coastal plain surface sample results also indicate that sediments within Rhizophora and Ceriops-dominated mangroves, and from well developed saltmarsh communities contain an estimated 2000 or more pollen grains per gram of dry sediment.
Comparison of these results with similarly derived results from Princess Charlotte Bay (after Chappell and Grindrod, 1985; Grindrod, 1985) and Missionary Bay (after Grindrod and Rhodes, 1984) are provided in Table 5.3. Results from the present study most closely resemble those from Princess Charlotte Bay which come from similar narrow fringing mangrove and saltmarsh communities. Sediments from the expansive mangrove communities at Missionary Bay contain much higher pollen concentrations, and generally show stronger local to regional pollen ratios. The Missionary Bay results are based on samples collected close to the edge of the mangrove swamp (samples S6, S7, S8 and S9, Grindrod and Rhodes, 1984), and even greater pollen concentrations and higher local to regional pollen ratios may be expected from localities more central to the mangrove forest.

In the following chapters pollen concentrations and local to regional pollen ratios are used to interpret fossil pollen sequences. Values derived from fringing mangroves in the study area are likely to be most useful for interpretation of fossil pollen assemblages derived from similar environments, and may not be expected to compare closely with pollen assemblages from widespread mangrove communities of the scale of the mid-Holocene South Alligator River extensive mangrove communities ("big swamp"), as these will contain significant proportions of regional mangrove pollen. Assemblages from the former extensive mangroves may compare more closely to surface pollen assemblages from Missionary Bay.
Table 5.3 Estimated pollen concentrations in mangrove sediment and percentage ratios of 6 local pollen types to the regional/long distance pollen group for surface samples from the present study, Princess Charlotte Bay (Chappell and Grindrod, 1984; Grindrod, 1985) and Missionary Bay (Grindrod and Rhodes, 1984). Pollen ratios relate to sites where the source plants for the local pollen type are abundant, and so provide maximum scores for each study.

* Estimated pollen concentrations for Princess Charlotte Bay and Missionary Bay unpublished data. Pollen concentrations for these localities expressed as grains cm$^{-3}$ of sediment, while values for the present study are grains per gram dry sediment. Bulk densities of down-core samples in the present study range from 1.0 to 1.9 grams cm$^{-3}$. Bulk density variations in surface samples are less than this due to minimal compaction and between-site similarity of organic/inorganic ratios. The values for the three different locations are therefore only roughly comparable, and indicate much stronger pollen concentrations for Missionary Bay.
CHAPTER 6

FOSSIL POLLEN SEQUENCES FROM THE COASTAL PLAIN

INTRODUCTION

This chapter describes and discusses pollen sequences from 4 sediment cores from the South Alligator River coastal plain. These provide detailed information of coastal vegetation changes during the late stages of the last marine transgression and through the ensuing period of coastline progradation. Results are presented in pollen diagram form with individual taxon performances graphed relative to the pollen sum which, except where otherwise noted, includes all identified angiosperm and gymnosperm pollen grains. Included in the pollen diagrams are the recorded stratigraphies, relevant radiocarbon ages and results of organic fraction determinations for all samples. Details of all radiocarbon determinations are listed in Table 4.1. Summary diagrams of the ratios of the most strongly represented mangrove taxa, and of pollen taxon groups representing distinct vegetation complexes, are also provided. Components of the summary diagrams vary between cores, depending on the major pollen taxa recorded. Individual pollen curves are shown for all pollen and spore types recorded, beginning with the mangrove and saltmarsh taxa, followed by all other identified pollen types, pteridophyte spores, and finally degraded/unidentified grains.

Interpretation of each pollen sequence in terms of local vegetation changes at the core site follows each pollen diagram description. Interpretations of regional changes in mangrove vegetation are provided in the discussion section at the end of the chapter.
Zonation and Description of the Pollen Diagrams

Pollen diagrams are often subdivided into zones to facilitate description, interpretation, comparison and in some cases correlation with other stratigraphic and chronological sequences (Gordon and Birks, 1972). Zone boundaries are generally placed where a high degree of dissimilarity exists between adjacent samples in the sequence, while the zones themselves exhibit internal consistency in pollen and spore content (Birks, 1972). The placement of zone boundaries can be made either by simple inspection of the data or by numerical methods (e.g. Gordon and Birks, 1972; Yarranton and Ritchie, 1972; Dale and Walker, 1970). In the present study, pollen zones have been established by simple inspection of the data because it is considered that major changes in the pollen content in each core are sufficiently obvious to allow appropriate placement of boundaries without use of mathematical methods. The zones are intended only to facilitate description of the pollen sequences and not intended to strengthen interpretation of the pollen record in terms of plant succession or other processes.

The locations of cores described in this chapter are shown in Figure 6.1, which reproduces the stratigraphy and radiocarbon chronology along transect 1, described in detail in Chapter 4.

CORE SAH 29

Core SAH 29 was collected by the Pioneer "Mole" drilling rig approximately 70 metres landward from the mangroves and 180 metres seaward from chenier ridge 1, on transect 1. The core site is close to the upper limit of normal high tides and is surrounded by low, sparse saltmarsh vegetation. Figure 6.2 shows the results of pollen analysis of 49 samples from SAH 29, ranging from 1 to 855 centimetres depth.
Figure 6.1 Location of pollen cores, and summarised stratigraphy and radiocarbon chronology for the coastal plain along transect 1. Numbers in parentheses refer to sequence in which dates are listed in Table 4.2.
Figure 6.2  Pollen diagram for core SAH 29. Values are percentages of the pollen sum.
Major breaks in the sequence occur between 170 and 450 centimetres depth and between 600 and 660 centimetres depth. Preparations of samples between these levels contained insufficient pollen for analysis.

**Stratigraphy and radiocarbon ages**

The upper 120 centimetres of core SAH 29 consists of uniform beige muds. Root penetration from saltmarsh plants occurs to a depth of 40 centimetres. Below 120 centimetres the muds are mottled brown and grey, becoming darker with depth. Conspicuous red wood fragments, presumed to be mangrove roots, occur sporadically between 125 and 170 centimetres. Between 450 and 740 centimetres the sediments are uniform, light grey muddy sands containing sparse, fine shell fragments. These overlie a band of grey to dark grey muds with sand lenses, marine shell fragments and larger woody organic fragments. Below 815 centimetres grey muddy sands predominate, with sparse marine shell and organic detritus. The fine organic content of sediments, estimated by loss on ignition, ranges from 7 to 19 percent by weight. Highest values occur between 800 and 820 centimetres depth, corresponding to a layer rich in larger organic fragments.

Summarised radiocarbon ages for 3 samples from SAH 29 are shown in Figure 6.2. Two samples of organic material from 815 centimetres return ages of 6330 +150 and 6350 +260 radiocarbon years (ANU 3933 and ANU 4249), while woody material at 150 centimetres was dated at 2200 +60 radiocarbon years (ANU 3932).

**Zonation and pollen content**

The SAH 29 core diagram is divided into three zones, with the upper zone boundary between 150 and 160 centimetres depth, and the lower zone boundary between 740 and 750 centimetres depth.
Zone 1 (855 to 750 centimetre levels)

In this zone mangroves are strongly represented and, except in the 3 lowest samples, account for more than 90 percent of the pollen sum. *Rhizophora* is the best represented mangrove pollen type, and is consistently recorded at greater than 50 percent of the pollen sum. *Ceriops/Bruguiera* also maintains strong representation throughout the zone. *Avicennia* pollen is commonly recorded at low frequencies, while other mangrove types including *Sonneratia, Camptostemon* and *Lumnitzera* have sporadic, minor representation.

The only saltmarsh pollen type recorded in zone 1 is *Chenopodiaceae*, which appears at frequencies less than 2 percent of the pollen sum in most samples. *Poaceae* and *Myrtaceae* (undetermined) are the best represented non-halophytic pollen types, with strongest values in the 3 bottom samples. All other taxa recorded in the zone have low and sporadic representation. Estimated pollen concentrations in zone 1 range from less than 1000 to greater than 50,000 grains per gram dry sediment. Strongest values occur between 760 and 825 centimetres depth.

Zone 2 (740 to 160 centimetre levels)

In zone 2 *Rhizophora* and *Ceriops/Bruguiera* are the most strongly represented mangrove pollen types, with the former contributing between 40 and 80 percent of the pollen sum. *Avicennia* and *Sonneratia* pollen is consistently recorded at low frequencies, while other mangroves, including *Camptostemon, Excoecaria, Lumnitzera* and *Aegiceras* have minor representation. *Chenopodiaceae* pollen is consistently recorded at low frequencies.
Poaceae, Cyperaceae, Callitris and Myrtaceae (undetermined) each show stronger values than those recorded for zone 1, while other taxa are poorly represented. Estimated pollen concentrations for samples in zone 2 are very low relative to those recorded for zone 1, generally not exceeding 2000 grains per gram dry sediment.

Zone 3 (150 to 0 centimetre levels)

In zone 3 Rhizophora has its poorest representation with values tending to decrease towards the surface. Ceriops/Bruguiera also has relatively low values in lower and upper levels, but is strongly represented at 60 and 80 centimetres depth. Of the other mangrove pollen types, Avicennia, Sonneratia and Camptostemon maintain the most consistent representation, with values never exceeding 10 percent of the pollen sum. The saltmarsh pollen types, Chenopodiaceae and Batis have their strongest representation in zone 3. Values for the former generally increase towards the surface, while Batis has its strongest representation midway through the zone, with minor values in upper and lower levels.

Poaceae and Cyperaceae are also consistently represented throughout the zone, with values for the latter tending to increase in upper levels. Myrtaceae (undetermined) pollen is consistently recorded at values not exceeding 8 percent of the pollen sum. Estimated pollen concentrations are stronger than those recorded for zone 2, with values generally exceeding 2000 grains per gram dry sediment.

Vegetation reconstruction: SAH 29

The high values for combined mangrove taxa and moderate to strong pollen concentrations in the 4 deepest samples in Zone 1 indicate mangrove forest developing at the core site; radiocarbon dates show
that this was before 6400 years B.P. Moderate values for non-mangrove taxa suggest a relatively narrow mangrove community or the nearby presence of upland communities, at a time when marine incursion at the core site was still very recent. Above 835 centimetres in zone 1 very high estimated pollen concentrations and very low representation of non-mangrove plants suggests that mangrove forest was widespread around the core site. This forest established around 6300 B.P. and continued for some time. Near to the core site Rhizophora was the dominant tree, while Ceriops and/or Bruguiera were common. Other mangroves present at this time included Avicennia, Sonneratia, Camptostemon, Lumnitzera and Excoecaria.

The very low pollen concentrations in zone 2 may be a consequence of the decline of local vegetation surrounding the core site, or increased sedimentation rates, or a combination of these factors. The former explanation is preferred because there is no obvious change in sediment texture or type, which may be expected to accompany greatly increased sedimentation rates, and the sediments contain no macrofossil remains such as tree roots or shells, which are common in mangrove sediments. Pollen assemblages from this section have high proportions of non-mangrove pollen types relative to lower levels in the core, suggesting a reduction of mangroves at the core site. The evidence suggests that mangroves did not occupy the core site during the period represented above 700 centimetres depth in zone 2. Pollen assemblages through these levels do show that Rhizophoraceae-dominated mangroves remained in the vicinity, presumably along nearby shorelines.

The pollen sequence in zone 3 provides a record of mangrove and saltmarsh successions at the site. Relatively strong pollen concentrations and high proportions of Rhizophora pollen from 150 to 110
centimetres depth indicate the establishment of *Rhizophora* forest. From 135 to 80 centimetres high *Batis* values suggest well developed saltmarsh communities at the rear of the mangroves. The decline in *Rhizophora* above 110 centimetres and the subsequent peaks in representation of *Ceriops/Bruguiera* and Chenopodiaceae suggest a transition to a rearward mangrove forest and adjacent saltmarsh. Relatively low values for mangroves and increased representation of Chenopodiaceae in the upper 2 samples of the core are consistent with the salt mudflat environment presently surrounding the core site.

This general reconstruction of vegetation change through core SAH 29 can be refined by comparing the performance of selected pollen taxa with zonal pollen thresholds determined from surface samples, following the method used to describe trends in the surface sample data in Chapter 5. This approach, previously applied in the mangrove context by Chappell and Grindrod (1984) and Grindrod (1985), relies on surface sample data presented in the previous chapter. Figure 6.3 shows variations down the core of *Rhizophora*, *Ceriops/Bruguiera*, Chenopodiaceae and *Batis*, each expressed as percentage ratios relative to the regional/long distance pollen group (Poaceae, Cyperaceae, Myrtaceae (undetermined), *Eucalyptus tetrodonta* type, *Acacia*, *Callitris*, *Casuarina*, *Gonocarpus* type and *Podocarpus*) defined in Chapter 5. Dotted lines through the individual taxon curves represent the minimum or threshold value at which each pollen type is recorded in surface sediments in the study area where mature source plants are locally prolific. Similarly, the dotted line through the pollen concentration curve indicates the minimum value estimated from surface sediments from well developed mangrove and saltmarsh communities on the coastal plain. Stages marked A to G in Figure 6.3 relate to the interpretation given below.
Summary of trends in pollen representation in core SAH 29 showing estimated pollen concentrations and percentage ratios of local pollen types to the regional/long distance pollen group defined in Chapter 5. Pollen concentrations: dotted line indicates lowest value (threshold) for local deposition in well developed mangrove communities on the modern coastal plain. Pollen ratios: dotted line indicates threshold value where source plants are locally abundant, based on surface sample results for the South Alligator River study area (see Table 5.3). Note change in scale for Rhizophora and Ceriops/Bruguiera below 170 centimetres.
A. From 855 to 840 centimetres pollen concentrations range from 2000 to 6000 grains per gram dry sediment, consistent with values for fringing mangrove forests in the present study and at Princess Charlotte Bay (see Table 5.3). Rhizophora and Ceriops/Bruguiera marginally exceed threshold values for local pollen deposition. These levels represent the initial establishment of mangroves, which were dominated by Rhizophoraceae, at the core site.

B. From 840 to 780 centimetres pollen concentrations are generally very high, ranging from 2000 to 53,000 grains per gram dry sediment. Similarly strong values are estimated for Missionary Bay (Table 5.3) which has extensive mangrove forests. Rhizophora and Ceriops/Bruguiera exceed the threshold for deposition from local sources by a factor of 6 to 50. Excesses of this magnitude are not recorded in surface sediment samples in the present study or elsewhere, except at Missionary Bay (Table 5.3). This section of the core is taken to represent mangroves growing at the core site at a time when extensive mangrove communities occurred elsewhere in the region. Radiocarbon dates of around 6300 years at 815 centimetres depth confirm contemporaneity with the "big swamp" mangrove phase in the river estuary, identified by Woodroffe et al. (1985c, 1986).

C. From 775 to 660 centimetres pollen concentrations decline from a maximum of 15,000 grains per gram dry sediment to minimum values below the threshold for local mangrove deposition. Rhizophora and Ceriops/Bruguiera values also decline dramatically through these levels to approximately the threshold value for a local pollen source in modern fringing mangroves. The data suggest that Rhizophoraceae-dominated mangrove surrounded the core site throughout this interval, while regionally extensive mangroves steadily declined.
D. For most of the interval between 660 and 150 centimetres low pollen concentrations did not allow pollen counts. In the 7 samples from 600 to 450 centimetres, pollen concentrations fall below minimum values for local deposition in fringing mangroves, while Rhizophora and Ceriops/Bruguiera values lie close to threshold values for local source plants. The entire interval between 660 to 160 centimetres is taken to represent low tide or sub-tidal environments at the core site following the demise of mangroves, presumably due to sea level rise. As mentioned above, the lower pollen concentrations may simply reflect an increased sedimentation rate, but the relatively low mangrove to regional/long distance pollen ratios cannot be explained by this means. The pollen assemblages from 600 to 450 centimetres suggest, however, that Rhizophoraceae mangroves remained on nearby shorelines.

E. From 150 to 120 centimetres Rhizophora exceeds the minimum value for local deposition by a factor of 2 or less, suggesting the establishment at the core site of a narrow mangrove forest similar to that of the present South Alligator coastal plain. Moderate pollen concentrations through these levels also suggest a narrow or poorly developed mangrove community. A peak in Batis values at 130 centimetres depth also suggests a local source for this pollen type, but it is more likely to represent a well developed saltmarsh community at the rear of the mangroves.

F. Except at 60 centimetres depth, pollen concentrations exceed the threshold value for local deposition in all levels from 110 to 60 centimetres. Rhizophora decreases steadily with decreasing depth to fall below minimum values for a local source. Values exceeding the threshold for Ceriops/Bruguiera, Chenopodiaceae and Batis are interpreted to represent Ceriops - dominated mangroves adjacent to
saltmarsh communities, similar to rear mangrove communities presently growing on the South Alligator coastal plain.

G. Relatively strong pollen concentrations, low ratios for mangrove taxa and strengthening values for Chenopodiaceae from 40 to 0 centimetres indicate the establishment of saltmarsh communities, consistent with the vegetation presently surrounding the core site.

CORE SAH 30

Core SAH 30 was collected by the drilling rig near the centre of the South Alligator River coastal plain on transect 1, approximately 2.4 kilometres landward of the mangroves. The core site is surrounded by expansive, treeless plains largely covered by annual grasses and sedges. Results of pollen analysis of the core are shown in the pollen diagram in Figure 6.4, which includes 36 samples from 0 to 100 centimetres and from 570 to 750 centimetres depth. Prepared samples from levels between 100 and 570 centimetres (at 140, 180, 260, 340 and 550 centimetres depth) contained insufficient pollen for counting.

Stratigraphy and radiocarbon ages

The upper 100 centimetres of the core consist of massive, dark brown organic clays without evidence of oxidation. Penetration by living roots occurs to a maximum depth of 10 centimetres. Brown muddy sands containing sparse organic fines and shell fragments lie between 570 and 620 centimetres depth. Whole shells of the marine mollusc Turittella sp. were located at 594 and 695 centimetres depth. Between 620 and 695 centimetres the sediments are predominantly dark grey organic muds with sparse sand pockets and shell hash. Between 695 and 750 centimetres lie dark grey muddy sands, intermixed with occasional yellow-brown clayey mottles, and lacking visible organic and shell
Figure 6.4 Pollen diagram for core SAH 30. Values are percentages of the pollen sum.
Figure 6.4 contd.
fragments. Values in the organic content curve range from 7 to 19 percent. The richest samples derive from the dark grey organic muds between 630 and 700 centimetres depth.

Radiocarbon analysis of marine shell from 605 centimetres provides an age of 5530±170 years B.P. (ANU 3935). Another radiocarbon determination on shell hash collected at 410 centimetres returned an age of 4030±120 years B.P. (ANU 4250).

Zonation and pollen content

The SAH 30 pollen diagram is divided into 3 zones, with a zone boundary immediately below 100 centimetres, and another between 710 and 720 centimetres depth.

Zone 1 (750 to 720 centimetre levels).

The 4 pollen assemblages which comprise zone 1 are dominated by the mangrove pollen taxa Rhizophora and Ceriops/Bruguiera, which maintain strong representation in all levels. Avicennia pollen is consistently represented at very low frequencies. Lumnitzera is the only other mangrove pollen type represented, and is recorded in 1 sample only. Chenopodiaceae pollen has minor representation in all samples.

The most strongly represented non-halophytic taxa are Poaceae, Pandanus and Myrtaceae (undetermined). Each maintains strong values ranging between 6 and 14 percent of the pollen sum. The few other taxa recorded have minor and sporadic representation. Estimated pollen concentrations in zone 1 are relatively low, ranging from 2000 to 5000 grains per gram dry sediment.
Zone 2 (710-570 centimetre levels)

Throughout this zone Rhizophora maintains values between 40 and 80 percent of the pollen sum. Similarly Ceriops/Bruguiera is consistently well represented throughout. Other mangroves, particularly Avicennia and Sonneratia are most commonly represented in upper levels of the zone, but are recorded at low frequencies only. Chenopodiaceae pollen is poorly represented.

Myrtaceae (undetermined) and Poaceae pollen types are recorded at low frequencies in most samples. The other most consistently recorded taxa are Cyperaceae, Restionaceae/Centrolepidaceae and Callitris, which never exceed 4 percent of the pollen sum. Estimated pollen concentrations in zone 2 vary from less than 2000 to more than 40,000 grains per gram dry sediment. Highest values are recorded between 620 and 700 centimetre levels, with consistently low values elsewhere.

Zone 3 (100 to 0 centimetre levels)

No mangrove or saltmarsh pollen types are recorded in zone 3. The pollen assemblages are dominated by Poaceae and Cyperaceae, with Myrtaceae (undetermined) and Typha type showing occasionally strong representation. The only other taxa recorded are Eucalyptus tetrodonta type, Callitris, Casuarina and undifferentiated fern spores, each of which has minor representation. Estimated pollen concentrations in zone 3 decrease steadily with depth from 6500 grains per gram dry sediment at the surface, to less than 1000 grains per gram dry sediment at 100 centimetres depth. The relatively low estimated pollen concentrations through this section seem to reflect poor preservation of pollen grains, which is clearly evident during pollen counting.
Vegetation reconstruction: SAH 30

The strong representation of mangrove pollen types in zone 1 represent the earliest establishment of mangroves around the SAH 30 core site. These were dominated by Rhizophoraceae, but included Avicennia. The relatively strong representation of non-mangrove pollen, especially the poorly dispersed Pandanus pollen type, suggests the near proximity of non-marine environments. The Pandanus pollen may have derived from freshwater or brackish swamps just landward of the mangrove communities, or from dryland scrub communities which existed on the basement surface prior to inundation by rising seas.

The high proportions of Rhizophora and Ceriops/Bruguiera pollen in zone 2 indicate continued occupation of the site by Rhizophoraceae-dominated mangroves around 5500 years B.P. The low but continuous representation of Avicennia and Sonneratia through the upper half of this zone suggests an increased presence of each of these plant taxa. Very low pollen concentrations and continued accumulation of marine sediments (as indicated in Figure 6.1), probably reflect the decline of mangrove vegetation around the core site due to drowning by rising sea levels. Radiocarbon dates indicate that this occurred sometime between 5500 and 4000 years B.P.

Pollen assemblages in zone 3 represent non-marine environments at the core site, through the period of coastal plain development. Local vegetation was dominated by Poaceae and Cyperaceae, suggesting seasonally flooded environments consistent with those of the modern coastal plain.
The dearth of pollen between 100 and 570 centimetres depth in the core means that no information is available regarding plant occupations through the upper levels of the core prior to coastal plains development. It seems unlikely that mangroves never re-established at the site as they would be expected to colonise the regressive shoreline, as was the case for SAH 29. The lack of pollen through this section may be due to loss through oxidation, or removal of the mangrove organic unit by erosion.

The foregoing local vegetation reconstruction for core SAH 30 is refined in Figure 6.5, which shows pollen concentrations, and percentage ratios relative to the regional/long distance pollen group for Rhizophora, Ceriops/Bruguiera, Avicennia, Sonneratia and Pandanus. Except for Pandanus, dotted lines mark threshold values as described for Figure 6.3. Stages A to E refer to stages in the interpretation outlined below.

A. From 750 to 710 centimetres depth pollen concentrations range from approximately 2600 to 5000 grains per gram dry sediment, exceeding the threshold value for local deposition in mangroves of the present study area. Rhizophora and Ceriops/Bruguiera marginally exceed minimum values for local deposition, while Avicennia and Sonneratia have poor representation and non-representation respectively. Pollen ratios for Pandanus range from 40 to 70 percent relative to the regional/long distance pollen group. Although no threshold value for pollen deposition in Pandanus-dominated communities is available, the pollen type shows localised dispersal relative to source plants, as discussed in Chapter 5. The data in stage A are interpreted to represent newly established Rhizophoraceae-dominated mangroves at the core site, with adjacent Pandanus swamp or scrub communities landward.
Figure 6.5  Summary of trends in pollen representation in core SAH 30, showing estimated pollen concentrations and percentage ratios of local pollen types to the regional/long distance pollen group. Threshold values indicated as for core SAH 29 in Figure 6.3.
B. From 700 to 610 centimetres pollen concentrations are generally high, with strongest values from 690 to 625 centimetres ranging from 11,000 to 42,000 grains per gram dry sediment. These values exceed minimum pollen concentrations for fringing mangroves of the present study by a minimum factor of 5, and are similar to concentrations for recorded for Missionary Bay (Table 5.3). Percentage ratios for Rhizophora and Ceriops/Bruguiera are also strong, each with peak values at 665 centimetres exceeding threshold values for local deposition in the present study site by a factor greater than 30. Similar excesses are recorded for Rhizophora and Ceriops/Bruguiera between 835 and 775 centimetres depth in core SAH 29 (Figure 6.3). The pollen data for stage B are thought to represent mangroves growing at the core site, and a strong regional mangrove component. The radiocarbon date of 5,530 years between 605 and 610 centimetres depth confirms the levels in stage B to be contemporaneous with the "big swamp" phase described by Woodroffe et al (1985c, 1986).

C. From 605 to 570 centimetres pollen concentrations are moderate to low, falling below the threshold value in upper levels. Rhizophora and Ceriops/Bruguiera ratios are generally lower than in stage B, but exceed the minimum values for local deposition. Ratios for Sonneratia are strong relative to elsewhere in the core, exceeding the threshold value for this taxon at 605, 595 and 575 centimetres. This stage represents mangroves dominated by the Rhizophoraceae at the core site. Sonneratia was also present and may have been a major constituent of this vegetation. The low pollen concentrations and moderate ratios for Rhizophora and Ceriops/Bruguiera relative to some deeper levels in the core suggest a regional contraction of the extensive mangroves interpreted from stage B. The radiocarbon age of 5530 years at 605 to 610 centimetres is consistent with the timing of the demise of "big
swamp" in the estuary (Woodroffe et al., 1985c, 1986). Anticipating interpretation of the following stage in the diagram, the mangrove communities represented in stage C may have been adjusting to deeper water conditions with rising sea level. Under these conditions Sonneratia would be expected to be well represented, as S. alba is characteristic of the most seaward (deep water) mangrove locations.

D. Insufficient pollen for counting was extracted from sediments between 570 and 100 centimetres depth. It is apparent that mangroves did not occupy the core site through this stage, and their demise is attributed to drowning through continued sea level rise.

E. The generally low pollen concentrations, lack of mangrove pollen types, and very strong representation of Poaceae and Cypercaceae (shown in Figure 6.4) from 100 to 0 centimetres, indicate the establishment of coastal plains communities around the core site.

CORE SAH 31

Core SAH 31 was collected by the drilling rig on transect 1, approximately 270 metres south of chenier ridge 2. The area surrounding the core site consists of sedge-covered lower flood plain, which generally retains surface water from wet season flooding well into the dry season. Figure 6.6 shows the results of pollen analysis of 43 samples from the core. A major gap in the sequence occurs between 40 and 130 centimetres due to poor recovery of this section by the drilling rig.
Figure 6.6 Pollen diagram for core SAH 31. Values are percentages of the pollen sum.
Figure 6.6 contd.
Stratigraphy

The upper 40 centimetres of the core consist of dark brown to black, organic cracking clays, containing fibrous organic fragments in the upper 5 to 10 centimetres. The sediments between 130 and 195 centimetres are uniform light grey and brown muds, which become increasingly dark with depth. These are devoid of shell fragments, visible organic detritus and sand. The muds continue between 195 and 345 centimetres depth, but contain organic detritus becoming more abundant below 230 centimetres. A very organic layer, resembling mangrove roots is recorded between 315 and 325 centimetres depth. Dark grey, organic sandy clays lie between 345 and 360 centimetres. Deeper drilling showed that the clay unit overlies light grey muddy sands to a depth of at least 5 metres. This lower unit proved to be very sparse in pollen. The organic fraction of sediments ranges from slightly less than 10 to 25 percent by weight, with a general trend towards higher values with increasing depth.

Zonation and pollen content

The pollen diagram for core SAH 31 is divided into 4 zones. Zone boundaries are placed between 40 and 130 centimetres, 190 and 200 centimetres, and between 345 and 350 centimetres depth.

Zone 1 (360 to 350 centimetre levels)

In zone 1 Rhizophora values range from 6 to 66 percent, with progressively lower values in deeper levels. Ceriops/Bruguiera shows a similar trend, with values ranging from 4 to 22 percent. Lumnitzera is consistently recorded with a maximum value of 5 percent. Myrtaceae (undetermined) and Poaceae are strongly represented, with a maximum value for the latter of 63 percent of the pollen sum in the deepest
sample. While other pollen types have only minor representation, Selaginella spores are abundant at 355 and 360 centimetre levels, with a maximum value of 175 percent of the pollen sum. Estimated pollen concentrations for zone 1 are high, ranging from 20,000 to almost 50,000 grains per gram dry sediment.

Zone 2 (345 to 200 centimetre levels)

In zone 2 Rhizophora is the most strongly represented pollen taxon, showing a general tendency towards decreased values towards upper levels. Ceriops/Bruguiera is also well represented, with slightly stronger values in upper samples. Avicennia is consistently recorded at low frequencies, while other mangroves have only minor and sporadic representation. All other pollen and spore types have low frequency representation, with Poaceae, Myrtaceae (undetermined) and Gonocarpus type the most consistently recorded. Estimated pollen concentrations are generally high throughout zone 2, ranging from 6000 to greater than 60,000 grains per gram dry sediment.

Zone 3 (190-130 centimetre levels)

In zone 3 Rhizophora values decrease with depth to zero representation at the 130 centimetre level, while Ceriops/Bruguiera remains strongly represented throughout. Avicennia values are high relative to zone 2, with the strongest recording of 22 percent of the pollen sum in the uppermost sample. Other mangrove types are poorly represented, while Chenopodiaceae is consistently recorded at low frequencies.

Myrtaceae (undetermined) pollen is well represented in all samples, maintaining values between 4 and 14 percent of the pollen sum. Poaceae and Cyperaceae are strongly represented in the uppermost level in the
zone, and have moderate representation elsewhere. Aeschynomene pollen accounts for 38 percent of the pollen sum at 130 centimetres depth, and is poorly represented or absent elsewhere. Banksia pollen is also consistently represented in this zone, with a maximum value of 6 percent of the pollen sum at the 170 centimetre level. Other recorded taxa have minor and generally sporadic representation. In contrast to zone 2, estimated pollen concentrations are low, ranging from 4000 to 14,000 grains per gram dry sediment.

Zone 4 (40 to 0 centimetre levels)

No mangrove pollen is recorded in this zone, the pollen assemblages being dominated by Poaceae and Cyperaceae. Values for the former increase towards the surface, while for the latter the opposite is true. Myrtaceae (undetermined) is the only other well represented pollen type, reaching its' highest value in the lowest level of the zone. Estimated pollen concentrations in zone 4 are low compared to deeper sections of the core, and range from less than 2000 to 5000 grains per gram dry sediment.

Vegetation reconstruction: SAH 31

The pollen content of the deepest sample in zone 2 of the SAH 31 pollen diagram suggests a freshwater swamp community dominated by Poaceae and Selaginella, and with Cyperaceae in relatively low abundance. No other taxa clearly representative of freshwater swamps are recorded. The moderate abundance of Myrtaceae (undetermined) pollen in this sample may represent Melaleuca swamp communities, but may also derive from upland sclerophyll forests. The presence of poorly dispersed mangrove pollen types Sonneratia and Lumnitzera, and low abundances of Rhizophora and Ceriops/Bruguiera pollen, indicate that mangrove forests existed near to the core site.
The upper 2 assemblages in zone 1 record the transition to marine environments. The earliest mangrove communities to establish around the site were dominated by Rhizophora and Ceriops and/or Bruguiera, while Lumnitzera and Avicennia, though present, were apparently of minor importance.

The pollen assemblages in zone 2 represent an extended period of mangrove occupation of the core site. The Rhizophoraceae was clearly the dominant plant family, while less important mangroves included Avicennia, Sonneratia, Camptostemon, Lumnitzera and Excoecaria.

The pollen sequence in zone 3 records a transition towards drier mangrove communities. From 190 to 140 centimetres depth values for Rhizophora decline steadily, while those for Ceriops/Bruguiera remain strong, suggesting the increased importance of Ceriops in a rearward mangrove community. This trend is also indicated by increased representation of Avicennia pollen above 180 centimetres depth. At 130 centimetres both Rhizophora and Ceriops/Bruguiera pollen are no longer recorded. In this sample Avicennia is strongly represented along with non-mangrove elements including Poaceae, Cyperaceae, Myrtaceae (undetermined) and Aeschynomene, indicating that the core site then lay near to the upper limit of mangrove growth, adjacent to non-halophytic vegetation of the developing coastal plain.

No mangrove pollen types are recorded in zone 4. The dominance of Poaceae and Cyperaceae pollen in all samples suggests grass and sedge communities consistent with modern environments local to the core site.
The local vegetation reconstruction for SAH 31 is summarised in Figure 6.7, which graphs the pollen concentrations in sediments and percentage ratios for selected taxa (Rhizophora, Ceriops/Bruguiera, Avicennia, Aeschynomene and Selaginella) relative to the regional/long distance pollen group. Dotted lines for pollen concentrations and mangrove taxa mark threshold values for local deposition following the procedure outlined for preceding core descriptions. No threshold values are available for Aeschynomene and Selaginella. Stages in the diagram marked A to E refer to stages in the vegetation reconstruction described below.

A. At 360 centimetres depth all mangrove pollen ratios are below the minimum value for deposition from local sources. In contrast, Selaginella is very strongly represented, with a value of more than 200 percent relative to the regional/long distance pollen group. This stage is interpreted to represent a freshwater swamp in which Selaginella was prolific, with mangrove communities nearby.

B. From 355 to 200 centimetres pollen concentrations are very high, ranging from 7000 to 67,000 grains per gram dry sediment. These values exceed the minimum value for local pollen deposition in fringing mangroves of the study area by factors of 3.5 to 33, and resemble the very strong pollen concentrations from the extensive mangrove environments at Missionary Bay (Table 5.3). Ratios for Rhizophora and Ceriops/Bruguiera are also strong throughout this stage, exceeding the threshold value by factors of up to 11 and 20 respectively. Avicennia values exceed the threshold value at the 290, 275, 265, 255, 245 and 200 centimetre levels. The pollen sequences through this stage are interpreted to represent mangrove communities at the core site, dominated by Rhizophora and Ceriops and/or Bruguiera, with Avicennia a
Figure 6.7 Summary of trends in pollen representation in core SAH 31, showing estimated pollen concentrations and percentage ratios of local pollen types to the regional/long distance pollen group. Threshold values indicated as for core SAH 29 in Figure 6.3.
further important element. The very strong pollen concentrations in all levels of this stage suggest that widespread mangroves were established in the area by the time of initial mangrove establishment at the core site. Although there are no radiocarbon dates from SAH 31, dates from nearby cores confirm that the earliest mangrove occupations around the site occurred less than 7000 years B.P. (Figure 6.1), within the extensive mangrove phase interpreted from core SAH 29, and identified by Woodroffe et al. (1985c, 1986).

C. From 190 to 140 centimetres depth Rhizophora ratios are low relative to most deeper levels of the core, and generally fall below the threshold value. Ceriops/Bruguiera ratios are also lower relative to some deeper levels in the core, but always exceed the threshold for a local pollen source. Avicennia values are strong relative to other sections of the core, and exceed threshold values in all levels from 180 to 140 centimetres. This stage represents the establishment of a drier, landward mangrove zone at the core site, dominated by Ceriops and Avicennia.

D. At 130 centimetres depth Rhizophora and Ceriops/Bruguiera are unrecorded, while the percentage ratio for Avicennia exceeds the threshold value for this taxon. This indicates the transition to a landward Avicennia zone, while the strong value for the annual, aquatic Aeschynomene suggests that the core site lay at or near non-saline, or at least seasonally non-saline, environments.

E. The lack of mangroves and predominance of Poaceae and Cyperaceae pollen (shown in Figure 6.6) from 40 to 0 centimetres, indicate the establishment of mixed grassland and sedgeland, consistent with the vegetation presently surrounding the core site.
Core HC 4 was collected by the hand coring technique approximately 540 metres south of chenier ridge 2 on transect 1. Vegetation surrounding the core site consists of lower floodplain sedgeland dominated by *Eleocharis dulcis* and grasses. To facilitate core collection, the upper 1 metre of cracking clays was removed by shovel, so that coring commenced at 1 metre below present ground level. Figure 6.8 shows the results of analysis of 40 samples from the core. Samples from 105 to 220 centimetres depth have been analysed for pollen. A prepared sample from 100 centimetres depth contained insufficient pollen for analysis. A sampling interval of 5 centimetres is employed between 105 and 200 centimetres depth, while an interval of 1 centimetre is used from 200 to 220 centimetres depth.

**Stratigraphy and radiocarbon ages**

Overlying the stratigraphic section shown in Figure 6.8 are massive, cracking clays similar to those described for the upper section of the SAH 31 core. Between 105 and 183 centimetres the sediments consist of uniform light brown to light grey muds with occasional orange-yellow mottles and carbonised fragments up to 2 millimetres in diameter. The muds are sparse in visible organic material except for large organic fragments between 155 and 165 centimetres depth. At 183 centimetres there is a transition to dark grey muds containing layered organics and infrequent carbonised particles. The more organic nature of these muds is reflected in the organic content curve which shows relatively strong and consistent values below 190 centimetres depth. At 220 centimetres there is a sharp transition to coarse, light grey muddy sands (not shown in Figure 6.8) which continue to a depth of at least 4 metres (see Figure 6.1)
Figure 6.8 Pollen diagram for core HC 4. Values are percentages of the pollen sum.
Figure 6.8 contd.
A radiocarbon age of 5760±110 (ANU 5373) was returned for wood fragments, presumed to be mangrove, collected from 155 to 165 centimetres depth in the core. Another date of 6060±190 (ANU 5150) on wood fragments resembling mangrove roots was drawn from a sample collected at 185 centimetres depth. Organic muds at 217 to 220 centimetres provide an age of 6440±90 radiocarbon years B.P. (ANU 5934).

Zonation and pollen content

The pollen diagram for core HC 4 is divided into 4 zones with zone boundaries between 115 and 120 centimetres, 145 and 150 centimetres, and between 216 and 217 centimetres depth.

Zone 1 (220 to 217 centimetre levels)

Values for mangrove pollen in zone 1 are relatively low. **Rhizophora** and **Ceriops/Bruguiera** maintain values below 24 percent of the pollen sum in all levels. **Lumnitzera** is consistently recorded at around 4 percent of the pollen sum. Other mangrove pollen types - **Avicennia**, **Sonneratia**, **Camptostemon**, and **Excoecaria** - have minor representation.

**Poaceae** has strong representation in 220 to 218 centimetre levels, and weaker representation in the uppermost sample. **Myrtaceae** (undetermined) pollen is well represented throughout the zone, with its strongest value in the uppermost sample. Other consistently recorded pollen types include **Cyperaceae**, **Typha**, **Gonocarpus** type and **Leguminosae** (undetermined). These maintain moderate to low frequency representation. **Selaginella**, has relatively strong representation in zone 1, especially in the 3 deepest levels. Estimated pollen concentrations are moderate for the 3 deepest samples, ranging from 10,000 to 20,000 grains per gram dry sediment, while in the uppermost
sample the estimated value is 88,000 grains per gram dry sediment.

Zone 2 (216 to 150 centimetre levels)

The most strongly represented mangrove pollen type in zone 2 is Ceriops/Bruguiera, which maintains values in the range 26 to 76 percent of the pollen sum. Rhizophora values are relatively low, with a maximum value of 38 percent in the lowest level of the zone. Avicennia and Lumnitzera are consistently recorded, with highest values for the latter occurring between 202 and 214 centimetres depth. Other mangrove pollen taxa have minor and erratic representation. Myrtaceae (undetermined) has moderate to strong representation (5 to 14 percent) in mid and lower sections of the zone, and relatively poor representation elsewhere. Poaceae is recorded at relatively low frequencies in all levels. Gonocarpus type is the next most consistent pollen taxon recorded but, in common with many other pollen types, achieves only low frequency representation.

Estimated pollen concentrations in zone 2 are very high between 216 and 190 centimetre levels, with values ranging from 30,000 to greater than 90,000 grains per gram dry sediment. Above 190 centimetres depth, the concentrations decrease markedly, to a minimum value of about 6000 grains per gram dry sediment.

Zone 3 (145 to 120 centimetre levels)

In zone 3 Rhizophora values decrease to less than 6 percent of the pollen sum. Above 145 centimetres Ceriops/Bruguiera is poorly represented in comparison to zone 2, with values no greater than 7 percent of the pollen sum. Conversely, Avicennia is well represented, with a maximum value of 12 percent in the 130 centimetre level. Chenopodiaceae is consistently recorded above 140 centimetres, in contrast to other sections of the core.
Values for Poaceae increase steadily towards upper levels of the zone from 6 percent of the pollen sum at the 145 centimetre level, to 34 percent in the 120 centimetre level. Cyperaceae and Myrtaceae (undetermined) have moderate representation with values ranging from less than 2 percent to 8 percent of the pollen sum.

A striking feature of zone 3 is the strong representation of Aeschynomene pollen which is recorded at particularly high frequencies in the 140 to 130 centimetre levels. Similarly, Leguminosae (undetermined) pollen is also well represented in most samples. The maximum value for estimated pollen concentrations for samples in zone 3 is 22,000 grains per gram dry sediment at 145 centimetres depth. Above this level values range from 4000 to 8000 grains per gram dry sediment.

Zone 4 (115 to 105 centimetre levels)

The pollen assemblages in zone 4 are dominated by Poaceae, which accounts for between 50 and 70 percent of the pollen sum in each sample. Cyperaceae is also strongly represented, with values ranging from 18 to 25 percent of the pollen sum. Myrtaceae (undetermined) has moderate representation in all levels, while Aeschynomene is well represented in the lower 2 samples and not recorded in the uppermost sample. Other pollen and spore types recorded have only minor representation. Estimated pollen concentrations in zone 4 are low, ranging from less than 2000 to almost 4000 grains per gram dry sediment.
Vegetation reconstruction: HC 4

The pollen sequence from core HC 4 provides detail of local vegetation changes from freshwater swamps, through mangrove to lower floodplain communities.

The high proportions of Selaginella spores and Poaceae pollen in the 3 deepest samples in zone 1 are interpreted to represent local freshwater swamp communities, analogous to those interpreted from the deepest sample of SAH 31. It is possible that the strong representation of Myrtaceae pollen in the same levels derives from Melaleuca swamp communities at or near the core site, although it may also represent the nearby upland sclerophyll communities. The moderate representation of mangrove pollen types, particularly the poorly dispersed pollen of Lumnitzera, indicates that mangrove communities grew adjacent to the freshwater swamps throughout the period represented.

In zone 2 moderate Rhizophora values, very strong Ceriops/Bruguiera values, and consistent representation of Avicennia and Lumnitzera suggest a landward mangrove community dominated by Ceriops. The data suggest that Rhizophora did not occupy the area immediately surrounding the core site, but was presumably growing some distance to seaward. The continued presence of a landward Ceriops zone is consistent with the nearness of the core site to the upland surface at the rear of the coastal plain.

In zone 3 the decline of the Ceriops/Bruguiera and Rhizophora, the relatively strong representation of Avicennia, and dramatic increases in Poaceae and Aeschynomene pollen indicate a transition through a landward mangrove community towards coastal plains communities. Consistently low values for Chenopodiaceae pollen and the absence of Batis throughout
this section, indicate that well developed saltmarsh communities were not a feature of this transition.

The predominance of Poaceae and Cyperaceae pollen types in zone 4 indicates the eventual establishment of herbaceous, freshwater communities, consistent with those presently occupying the lower floodplain environments surrounding the core site.

The local vegetation reconstruction for core HC 4 is summarised in Figure 6.9. Estimated pollen concentrations and percentage ratios relative to the regional/long distance pollen group for Rhizophora, Ceriops/Bruguiera, Avicennia, Lumnitzera, Aeschynomene and Selaginella are graphed against depth in the core as in preceding core interpretations. Threshold values for pollen deposition from local source plants are indicated for the first 3 taxa only. The interpretation is described through stages A to D below.

A. From 220 to 217 centimetres depth mangrove pollen types are poorly represented with ratios for Rhizophora, Ceriops/Bruguiera and Avicennia below threshold values for deposition from local sources. Selaginella has strong representation, with a maximum value of 60 percent of the regional/long distance pollen group at 218 centimetres. This stage is taken to represent a freshwater swamp at the core site, in which Selaginella was an important component. The pollen data in Figure 6.8 indicate that Poaceae is well represented through these levels. This is consistent with the freshwater swamp interpretation. As mentioned earlier, the strong representation of Myrtaceae (undetermined) pollen (Figure 6.8) may represent a Melaleuca swamp component, although the contribution from upland Myrtaceae is unknown.

B. From 216 to 145 centimetres pollen concentrations are very strong,
Figure 6.9 Summary of trends in pollen representation in core HC 4, showing estimated pollen concentrations and percentage ratios of local pollen types to the regional/long distance pollen group. Threshold values indicated as for core SAH 29 in Figure 6.3.
ranging from 6000 to 83,000 grains per gram dry sediment, and far exceed minimum values estimated for fringing forests of the present study. Ceriops/Bruguiera is clearly the most strongly represented pollen type through this stage, with ratios exceeding threshold values by a factor greater than 10 in some samples. Percentage ratios for Rhizophora and Avicennia are low, and fall below threshold values in most levels. Lumnitzera is consistently represented at less than 50 percent of the regional/long distance group. The data are interpreted to represent a landward mangrove zone at the core site dominated by Ceriops. Avicennia and Lumnitzera were also important elements of this zone. Rhizophora did not dominate at the core site, but was growing nearby. This interpretation of a landward mangrove zone is consistent with the landward orientation of the core site, which is close to the upland surface.

The very strong ratios of Ceriops/Bruguiera, particularly between 200 and 150 centimetres suggest an extensive Ceriops dominated zone. The maximum width of this zone along transect 1 would not exceed 500 metres as Rhizophora was clearly established at the SAH 31 core site (approximately 270 metres to the north) throughout this period, and the upland surface was probably no more than 200 metres to the south.

C. From 140 to 120 centimetres depth pollen concentrations are moderate, ranging from 8000 to 4600 grains per gram dry sediment. Percentage ratios for Rhizophora and Ceriops/Bruguiera are low, falling well short of minimum values for local source plants. Ratios for Avicennia are relatively high compared with other sections of the core, but do not exceed the threshold value. Aeschynomene ratios are high, with maximum values exceeding 300 percent of the regional/long distance group. This stage is interpreted to represent the transition from
mangrove to non-saline environments, with *Avicennia* mangroves adjacent to the core site. *Aeschynomene* was probably a local wet season component, relying on seasonally lowered soil water salinities.

D. The near absence of mangrove pollen and predominance of Poaceae and Cyperaceae pollen from 115 to 105 centimetres indicates the establishment of grassland and sedgeland consistent with vegetation communities presently surrounding the core site.

**DISCUSSION**

The pollen assemblages from deeper sections of the South Alligator River coastal plain represent initial mangrove occupations and extensive mangrove communities which developed in the last stages of the post glacial sea level rise, at the same time as the expansion of the mangrove "big swamp" approximately 6800 to 5500 radiocarbon years B.P. (Woodroffe *et al.*, 1985c, 1986).

The lowest 25 to 40 centimetres in SAH 29 and SAH 30 are characterised by moderate pollen concentrations, and moderate ratios of *Rhizophora* and *Ceriops/Bruguiera* to the regional pollen component, similar to those estimated for surface sediment samples from fringing mangroves of the present coastal plain shoreline. However, the earliest mangrove communities represented in SAH 29 and SAH 30 were not narrow fringing forests, as mangrove establishment at the respective core sites was contemporaneous, suggesting a mangrove zone at least 2 kilometres wide. This is presumed to be a reflection of the very rapid marine inundation across the low gradient land surface, which would have proceeded from SAH 29 to SAH 30 in less than 100 years. The relatively low pollen concentrations in the deepest core samples probably reflect low luxuriance and immaturity in broad mangrove communities which were
initially struggling to develop in thin marine sediments overlying the formerly exposed lateritic surface. In both cores, very strong pollen concentrations appear soon after the initial marine sediments were deposited. These higher concentrations, generally in the range from 9000 to more than 50,000 pollen grains per gram dry sediment, are far in excess of estimated pollen concentrations for sediments from modern coastal plain mangrove environments, and more closely resemble the very high concentrations estimated for sediments from the extensive mangrove environments at Missionary Bay in northern Queensland (Table 5.3). Samples with very high pollen concentrations, such as those in SAH 29 between 775 and 835 centimetres depth (Figure 6.3) which exceed threshold values by a factor of 5 or more, are interpreted to represent extensive mangrove communities. They occur in all pollen core sequences from the coastal plain transect, and are generally aged between 6500 and 5500 radiocarbon years B.P., within the estimated age range proposed by Woodroffe et al. (1985c, 1986) for "big swamp" in the South Alligator River estuary. The very high pollen concentrations generally coincide with very high ratios of Rhizophora and Ceriops/Bruguiera pollen to the regional pollen component. This trend is also reflected to some degree in the results shown for Missionary Bay surface samples, and is to be expected due to the regional influx of mangrove pollen types, and may be further influenced by the filtration of non-mangrove pollen by dense and continuous mangrove forest canopies. Aspects of pollen transfer within extensive mangrove communities are discussed more fully in Chapter 8. The very high pollen concentrations from the lowest levels in SAH 31 and HC 4 represent high local pollen influx from freshwater swamp communities (Selaginella swamps). High pollen concentrations in the earliest mangrove-dominated sediments suggest that extensive mangrove swamps were already well developed in or adjacent to the estuary by the time of marine incursion at these sites.
Pollen assemblages in cores SAH 29, SAH 30 and SAH 31, representing the period of extensive mangrove communities are clearly dominated by Rhizophora. Ceriops/Bruguiera is also well represented, while other mangrove types recorded include Avicennia, Sonneratia, Camptostemon, Lumnitzera, Excoecaria, and Aequiceras. In core HC 4 the dominant mangrove pollen type is Ceriops/Bruguiera, with Rhizophora maintaining only moderate representation. Avicennia and Lumnitzera are also consistently recorded. These results suggest that the extensive mangrove communities represented in these cores were dominated by Rhizophora, with a zone of Ceriops and more frequent representation of Avicennia and Lumnitzera, towards the landward edge. Other mangroves were present in the extensive mangrove phase, but it is difficult to speculate about their regional significance, due to their generally poor representation by pollen.

The fossil pollen sequences from the South Alligator River coastal plain also provide evidence of a number of vegetation changes which accompanied sea level changes and associated geomorphological adjustments. Major vegetation changes occurred with the initial inundation of terrestrial landscapes by seawater during the mid Holocene, the drowning of mangrove communities with continued sea level rise, the replacement of mangroves by non-halophytic communities with early coastal plain development, and the re-establishment of mangroves and first appearance of saltmarsh communities near the present, prograding shoreline.
Plant Successions on the Transgressive Shore

The lowest levels in cores SAH 30, SAH 31 and HC 4 provide evidence of non-halophytic plant communities which existed on the former land surface prior to marine incursion. Strong representation of Pandanus pollen in SAH 30 indicates the near proximity to the core site of Pandanus communities which may have taken the form of coastal swamps immediately landward of the mangrove fringe. Fresh to brackish water Pandanus swamp communities adjacent to mangroves are common elsewhere, but are a more usual feature of humid, tropical coasts, for example at Hinchinbrook Island in Queensland (Grindrod and Rhodes, 1984) and in Fiji (Southern, 1986). Pandanus swamps directly adjacent to mangroves are not recorded in the South Alligator River study area, and are not known to the author elsewhere in the Northern Territory. The lack of sedimentary evidence for a non-marine swamp in core SAH 30 does not preclude the Pandanus swamp interpretation, as the Pandanus pollen in the relevant pollen assemblages is considered to be from extralocal rather than local sources relative to the core site. Alternatively, the strong Pandanus pollen values may represent Pandanus scrub communities, which are common on low nutrient, lateritic soils throughout the study area. They may form narrow fringing communities adjacent to sclerophyll and monsoon forests, or cover extensive areas with canopy strata dominated by, or wholly comprised of, P. spiralis (see Chapter 2).

Well developed Selaginella swamp communities existed at the landward end of the coastal plain transect prior to marine incursion. The swamps do not seem to have been long term features of the landscape, at least at core sites SAH 31 and HC 4, as they are represented by thin sedimentary layers, and probably developed in response to local changes in the freshwater table influenced by sea level rise. The Selaginella
spores in fossil assemblages closely resemble reference spores of *S. uliginosa*. This species is uncommon in the South Alligator River region today, and could not be located during extensive surveys of freshwater swamps at the margin of the coastal plain. Specimen records held at the Conservation Commission of the Northern Territory herbarium indicate that *S. uliginosa* is locally abundant in coastal freshwater swamps adjacent to mangroves on Melville Island, some 200 kilometres west of the study site, where it forms dense, erect clumps in association with swampland grasses. This is consistent with the recorded ecology of this plant in other places (e.g. Jones and Clemesha, 1976).

Transitions from non-halophytic communities of the former land surface to mangroves were rapid following the marine transgression. There is no evidence in the pollen record that this transition was marked by clearly zoned mangroves and saltmarsh communities migrating steadily landward. If this was the case the pollen record would be expected to show the reverse sequence of taxon representation generally recorded from regressive, intertidal environments, with initial establishment of saltmarsh or rear mangrove communities, followed by transitions to intermediate *Ceriops* and then more seaward *Rhizophora*-dominated communities. Instead, the 3 most seaward core sequences from the coastal plain suggest a direct transition to *Rhizophora*-dominated communities, without previous occupations by more landward mangrove zones. In HC 4 the transition from *Selaginella* swamp to *Ceriops*-dominated mangroves is equally abrupt. *Rhizophora*-dominated communities did not establish at this site, presumably because of its landward, and hence relatively upper intertidal, location throughout the period of marine influence. The lack of evidence for clear mangrove zonations with the transition to the earliest mangrove vegetation communities on transgressive shores may reflect the rapid nature of the
marine transgression across the low gradient former land surface. This would not be expected to favour the development of highly saline upper intertidal environments suited to saltmarsh and rear mangrove species such as *Avicennia* and *Ceriops*. The transitions may also reflect the high mobility of and aggressive recruitment by species of *Rhizophora*.

**Drowned Mangroves**

The pollen sequences in SAH 29 and SAH 30 suggest that mangroves retracted from lower lying sections of the estuary due to rising sea level, sometime after 5500 radiocarbon years B.P. This interpretation is based primarily on very low pollen concentrations and lack of macrofossil remains through the mid sections of both cores. Arguments against dilution of pollen concentrations by greatly increased sedimentation rates are outlined previously in this chapter. The interpretation could be tested by refined radiocarbon chronologies through relevant sections of the cores, to facilitate comparison of sedimentation rates and pollen concentrations in sediments. If the interpretation is correct, mangroves drowned presumably because sea level rise outstripped vertical sediment accretion. In both cores, this occurred after an extended period of mangrove occupation. There is little evidence in SAH 29 to suggest successional changes within the mangrove communities as drowning proceeded. In SAH 30 relatively strong *Sonneratia* to regional pollen ratios between 605 and 570 centimetres depth suggest the increased importance of *Sonneratia* at the core site prior to the final decline of mangroves. As mentioned earlier, *Sonneratia alba* grows at the seaward edge of coastal mangrove communities where tidal inundation is deepest, often in association with *Camptostemon schultzii*. The increased relative representation of *Sonneratia* may represent an increased importance of *Sonneratia* as tidal
inundation progressively deepened, to the greater disadvantage of other mangroves. The lack of evidence for a similar trend in *Camptostemon* is not surprising as pollen representation for this plant is unreliable. Apart from the slight increase in representation of *Sonneratia* in SAH 30, the pollen records hold little to suggest successional changes in drowning mangrove forests, and the local decline of mangroves is marked only by a slight increase in the relative representation of non-mangrove taxa and a steady decrease in pollen concentrations to levels which, in most cases, do not support pollen analysis. Moderate pollen concentrations in SAH 29 between 600 and 450 centimetres depth (Figure 6.3) suggest mangrove communities located near to the core site, along estuarine shorelines, and perhaps on shoals near the mouth of the infilling estuary.

**Plant Successions on the Regressive Shore**

Successions through mangrove to non-mangrove communities of the upper intertidal zone and coastal plains are relatively clearly recorded in the pollen record. The sequence in SAH 29 above 160 centimetres suggests a local vegetation succession through *Rhizophora* and *Ceriops* mangrove communities to saltmarshes dominated by chenopods. There is no indication of an initial occupation by a zone of *Sonneratia alba* and *Camptostemon schultzii*, such as presently exists seaward of the *Rhizophora* zone. It cannot be inferred that such a zone did not exist, as these taxa are poorly represented by pollen in sediments. Strong representation of *Batis* pollen in samples dominated by *Rhizophora* and *Ceriops/Bruguiera* indicate the establishment of well developed saltmarsh communities at the back of the mangroves, and is therefore of extralocal rather than local significance. The sequence interpreted in this way is compatible with present plant zonations in the coastal plain littoral.
zone and resembles plant successions described for similar environments from northern Queensland (Grindrod, 1985). There is no pollen evidence for well developed saltmarsh communities elsewhere in the coastal plain fossil pollen record, suggesting that hypersaline, littoral zone environments have developed only recently in this area.

Vegetation successions from mangrove to non-halophytic communities reconstructed from the 2 most landward pollen cores are characterised by a more direct change from mangrove to plains vegetation. The sequence in SAH 31 shows a change from Rhizophora-dominated mangroves, through a mixed Ceriops and Avicennia zone to a landward Avicennia zone, and the subsequent establishment of grasslands and sedgelands of floodplain environments. An identical sequence is recorded for HC 4, except that Rhizophora was never a locally abundant mangrove plant. In both sequences strong representation of Aeschynomene coincides with high Avicennia values immediately following the decline of Ceriops. The Aeschynomene pollen type in fossil pollen assemblages closely resembles reference pollen for A. indica (see Chapter 3), which is the only native species of this genus recorded for the Northern Territory. It grows as an annual shrub on the seasonally flooded plains, and is not common in the present vegetation of the study area (Taylor and Dunlop, 1985). The pollen type is not recorded in modern pollen assemblages in the present study.

The strong but temporally restricted representation of Aeschynomene pollen in core samples, including those from upstream locations described in Chapter 7, indicates the pollen type to have highly localised distribution. The pollen sequences from SAH 31 and HC 4 suggest that Aeschynomene was locally abundant at the mangrove to coastal plains transition approximately 5000 radiocarbon years B.P., and
that saltmarsh communities did not develop subsequent to mangrove decline, indicating that hypersaline environments characteristic of upper-intertidal reaches of the present coastline, did not develop around the landward core sites. This may be partly or wholly attributable to the location of chenier ridge 2 which lies just seaward of the SAH 31 and HC 4 core sites. The base of the ridge lies at least 2 metres below the present level of the surrounding floodplain surface, indicating that its formation was initiated prior to the final demise of mangroves at the core sites. The ridge converges with the upland surface a few kilometres to the southwest, and extends many kilometres to the east as a low, treeless mound, behind which are impounded extensive, seasonal freshwater swamps. Formation of the ridge would be expected to have a moderating effect on soil salinities around the core sites by restricting or excluding tidal incursion, and by impounding wet season flood water. Clearly it continues in the latter function today. Subsequent to the ridge's development Avicennia was the best represented mangrove local to the core sites. Ground water salinities in surface sediment layers would have been low during the wet season, and relatively high during periods of late dry season desiccation. These conditions would not be expected to favour the development of saltmarsh or permanent freshwater swamp communities, but may have been ideally suited to the annual, fresh water, semi-aquatic Aeschynomene. Continued freshwater sedimentation at the site eventually led to permanent sedge and grass swamps. In contrast to the impounded environments at the landward core sites, areas supporting well developed saltmarsh communities along the present coast are open to tidal inundation, and not subject to prolonged wet season flooding by fresh water.
Summary: Environmental Changes at the Coastal Plain Core Sites

Figure 6.10 summarises the reconstructed history of events for the section along transect 1 based on pollen sequences from SAH 29, SAH 30, SAH 31 and HC 4, and radiocarbon and stratigraphic results described in Chapter 4. Seven time horizons are illustrated. Initial establishment of mangroves occurred at SAH 29 and SAH 30 before 6500 B.P. Pandanus was also growing near the SAH 30 core site at this time. Between 6500 and 6000 B.P. mangroves dominated by Rhizophora occupied SAH 29 and SAH 30. The pollen evidence suggests extensive mangrove communities in the region during this interval. Freshwater swamps with abundant Selaginella occurred at the SAH 31 and HC 4 sites. Between 6000 and 5500 B.P. mangrove forest covered the transgressed surface from core sites SAH 29 to HC 4. Rhizophora dominated the 3 most seaward core localities, while a landward Ceriops community grew around HC 4, close to the upland surface. Between 5500 and 5000 B.P. it seems that rising sea levels outstripped sediment accretion at SAH 29 and SAH 30, causing the mangroves to drown. Rhizophora forests at SAH 31 and Ceriops communities at HC 4 persisted through this interval. At approximately 5000 B.P. low tide or subtidal environments surrounded SAH 29 and SAH 30. Chenier ridge 2 formed seaward of core site SAH 31. The area behind the ridge was cut off from tidal influence, and experienced seasonally fresh groundwater conditions. Ceriops and Avicennia persisted for some time after the formation of the chenier ridge, and occurred in conjunction with the annual, freshwater aquatic, Aeshynomene. By 1500 B.P. zoned mangrove and saltmarsh communities occupied the area around SAH 29, seaward of chenier ridge 1. Freshwater swamps dominated by grasses and sedges had formed at the SAH 31 and HC 4 core sites. Since 1500 B.P. the fringing mangrove and saltmarsh communities have migrated seawards on the prograding shore, while freshwater swamps have persisted behind chenier ridge 2.
Figure 6.10 Summary of reconstructed events from before 6500 B.P. to present, leading to the evolution of the South Alligator coastal plain. Based on radiocarbon chronology described in Chapter 4 and pollen analysis of cores SAH 29, SAH 30, SAH 31 and HC 4.
CHAPTER 7

FOSSIL POLLEN SEQUENCES FROM UPSTREAM LOCATIONS

This chapter provides descriptions and discussion of pollen sequences from 2 sediment cores from upstream sections of the South Alligator River estuary. The results are presented in pollen diagrams following the format and concepts used in Chapter 6.

CORE HC 5

Core HC 5 was collected by the hand coring technique on the river floodplain adjacent to Bullocky Point, approximately 43 kilometres from the river mouth. The core site is on the inside of a former sinuous meander of the river channel on transect 8a, described in morphologic and stratigraphic detail in Chapter 4. A location map and summary diagrams of the stratigraphic and radiocarbon results for a section of the transect around HC 5 are provided in Figure 7.1. The HC 5 site was expected to provide a detailed record of mangrove succession on a prograding point bar, giving valuable insights into environmental changes suggested by broader geomorphological features of the surrounding area. In particular, the narrow, sinuous nature of the former river channel closely resembles tidal sections of the present Adelaide River channel upstream from its estuarine funnel. It was possible that fossil pollen assemblages from the HC 5 core would provide evidence of former mangrove communities with floristic diversity and organisation similar to those characteristic of the Adelaide River. Results of pollen analysis of core HC 5 are presented in the pollen diagram in Figure 7.2, which includes 43 samples from 0 to 380 centimetres depth. A break in the sequence occurs between 60 and 165 centimetres depth, due to poor pollen preservation through this section.
Figure 7.1 Location of core HC 5, and details of stratigraphy and radiocarbon results for a section of transect 8a. Numbers in parentheses refer to sequence in which dates are listed in Table 4.2.
Figure 7.2  Pollen diagram for core HC 5. Values are percentages of the pollen sum.
Figure 7.2 contd.
Stratigraphy and radiocarbon ages

The upper section of the core between 0 and 40 centimetres depth is composed of dark brown, cracking clays. These become progressively lighter in color with depth. At approximately 100 centimetres depth (not shown in Figure 7.2) there is a transition to brown, oxidised muds which are continuous to 165 centimetres. Below 165 centimetres are light brown muds containing occasional orange mottles, and lacking conspicuous organic material, shell and carbonised particles. Between 215 and 360 centimetres the muds are grey to dark grey, and contain larger organic fragments and occasional carbonised particles. At 369 centimetres there is an abrupt transition to brown and light grey muddy sands which appear vaguely laminated, and lack visible organics. Values in the organic content curve for core HC 5 range from 8 to 20 percent, with strongest values from 250 to 270 centimetres depth.

Radiocarbon dates for HC 5 suggest rapid sedimentation from the base of the core to 215 centimetres depth. Statistically equivalent ages of 4030 +130 (ANU 5263) and 4050+200 (ANU 5264) were returned for organic samples from depths of 375 and 295 centimetres respectively. At 215 centimetres depth a slightly older age of 4490+110 (ANU 5262) was derived, also from organic material. Given that the organic mud section of the core is expected to represent a prograded point bar sequence, these dates appear out of sequence with the date of 2600+130 (ANU 3864) reported by Woodroffe et al. (1986), for organic material from Core SAH 42. Analysis of marine shell fragments, mainly *Cerithidea obtusa* from a depth of 95 centimetres, near the base of the freshwater clay unit in core HC 5, provides an age of 980+170 (ANU 5261).
Zonation and pollen content: HC 5 diagram

The HC 5 pollen diagram is divided into 3 zones, with zone boundaries immediately below the 60 centimetre level, and between the 205 and 210 centimetre levels.

Zone 1 (380 to 210 centimetre levels)

Pollen assemblages in zone 1 are dominated by rhizophoraceous pollen types. *Rhizophora* is well represented in all levels, values ranging from 10 to more than 50 percent of the pollen sum, with lowest values between 325 to 275 centimetre levels. Values for *Ceriops/Bruguiera* range from 19 to 57 percent of the pollen sum, highest between the 325 and 275 centimetre levels. *Avicennia, Sonneratia* and to a lesser extent *Camptostemon* are consistently recorded, at values less than 8 percent of the pollen sum. The other mangrove taxa recorded are *Lumnitzera, Excoecaria* and *Xylocarpus*, which have minor and inconsistent representation. The saltmarsh taxa, *Chenopodiaceae* and *Batis*, have sporadic, low frequency representation.

*Poaceae, Cyperaceae* and *Myrtaceae* (undetermined) maintain even representation throughout the zone, with values ranging from less than 2 percent to 16 percent of the pollen sum. *Callitris* is also consistently recorded, at a maximum value of 4 percent of the pollen sum. All other taxa recorded have only minor representation.

Estimated pollen concentrations are relatively low throughout zone 1, ranging from 1000 to 14000 grains per gram dry sediment, with highest values at 210 and 215 centimetre levels at the top of the zone.
Zone 2 (205 to 165 centimetre levels)

In zone 2 values for *Rhizophora* and *Ceriops/Bruguiera* decrease steadily with decreasing sample depth. *Avicennia* has strong representation in all levels relative to its performance in zone 1, with a peak value of 22 percent of the pollen sum in the 190 centimetre level. *Sonneratia* and *Camptostemon* are consistently recorded at relatively minor frequencies, while other mangroves have sporadic representation. *Chenopodiaceae* is the only saltmarsh taxon recorded, and has low frequency representation in 3 samples only.

Values for Poaceae and Cyperaceae are strong, and increase toward the upper levels of the zone. *Myrtaceae* (undetermined) maintains values between 6 and 9 percent of the pollen sum in all levels. *Aeschynomene* pollen, which is not recorded in other zones, has generally strong representation through the 190 to 165 centimetre levels. Undifferentiated fern spores are also consistently recorded through these levels. The very low estimated pollen concentrations for zone 2 coincide with poor pollen preservation in this section of the core.

Zone 3 (60 to 0 centimetre levels)

In zone 3 *Rhizophora* and *Avicennia* are the only mangrove pollen types recorded, and appear at low frequencies only. Poaceae is by far the most strongly represented pollen type with values between 49 and 72 percent of the pollen sum. Cyperaceae is unrecorded in the 60 centimetre level, but is strongly represented in the upper 2 samples. *Myrtaceae* (undetermined) is also well represented, with values between 4 and 14 percent of the pollen sum. Estimated pollen concentrations are between 1000 and 2500 grains per gram dry sediment, with highest values in the upper 2 levels.
In summary the HC 5 pollen sequence below 205 centimetres depth is clearly dominated by mangrove pollen types, particularly Ceriops/Bruguiera and Rhizophora, although the combined performance of plains and other taxa accounts for 12 to 33 percent of the pollen sum. This section of core is characterised by grey, organically enriched muds, with relatively strong pollen concentrations. Between 205 and 165 centimetres depth, Avicennia and Aeschynomene maintain strong representation, while total mangrove pollen declines steadily relative to the combined performances of all other pollen types. Through this section organic and estimated pollen concentrations are low. Plains taxa, particularly Poaceae and Cyperaceae, dominate the sequence between 60 and 0 centimetres depth, to the near exclusion of mangrove pollen types.

Vegetation reconstruction: HC 5

The pollen sequence from HC 5 provides evidence of vegetation changes in the central section of the South Alligator River estuary from approximately 4000 radiocarbon years ago to present. The base of the core lies between 45 and 50 centimetres below A.H.D. Although outliers of riverine mangroves on the South Alligator River presently grow as low as 1 metre below A.H.D. (Woodroffe et al., 1986), the normal lowest limit of well developed mangrove communities does not exceed 0.5 metres below A.H.D. The lowest level of mangrove growth along the sinuous section of the Adelaide River is not accurately known, due to a lack of benchmarks levelled to A.H.D., but is not expected to differ greatly from the South Alligator River. It is likely that the HC 5 core penetrates to the base, or nearly so, of the point bar mangrove sediments associated with the former sinuous meander loop. The deepest pollen assemblages in the core confirm a mangrove origin for these
sediments, in keeping with interpretations of macrofossil remains from the nearby core SAH 42 (see Figure 7.1). Consistent and relatively strong representation of Rhizophora, Ceriops/Bruguiera, Avicennia and Sonneratia in zone 1 of the pollen diagram suggest a mixed mangrove community around the core site, in which Rhizophoraceae was the dominant plant family. The relatively strong and consistent representation of Poaceae and Cyperaceae throughout this zone suggests that river floodplain communities were forming nearby.

In zone 2 the steady decline in Rhizophora, followed by a similar fall in Ceriops/Bruguiera and strong values for Avicennia are interpreted to represent a transition to a drier mangrove community type dominated by Ceriops and Avicennia, such as is typical of upper intertidal environments. The strong Aeschynomene values in this zone suggest that this plant was also locally present and that conditions near the core site were at least seasonally fresh, similar to reconstructed environments at the mangrove to plains transition around core sites SAH 31 and HC 4 on the coastal plain. There is no pollen evidence for saltmarsh development at the upper mangrove margin. The strengthening values for Poaceae and Cyperaceae towards the top of zone 2 indicate the development of freshwater floodplain environments at close proximity to the core site. The pollen assemblages in zone 1 represent floodplain communities dominated by Poaceae and Cyperaceae, consistent with the vegetation presently surrounding the core site.

Extra detail in the local vegetation reconstruction for HC 5 can be gleaned from Figure 7.3, which shows percentage ratios of local pollen types Rhizophora, Ceriops/Bruguiera, Avicennia, Sonneratia and Aeschynomene relative to the regional pollen group, following the procedure used in Chapter 6. Except for Aeschynomene, dotted lines mark
Figure 7.3  Summary of major trends in pollen representation in core HC 5 showing estimated pollen concentrations and percentage ratios of local pollen types to the regional/long distance pollen group defined in Chapter 5. Pollen concentrations: dotted line indicates lowest value (threshold) for local deposition in well developed mangrove communities on the modern coastal plain. Pollen ratios: dotted line indicates threshold value where source plants are locally abundant, based on surface sample results for the South Alligator River study area (see Table 5.3). This value for Sonneratia based on surface samples S3.1 and S3.2 only.
the lowest value for each pollen type where parent plants are locally abundant, based on surface sample results described in Chapter 5 (see Table 5.3). This information is not available for Aeschynomene which is infrequent in the present vegetation of the study area. Stages in the vegetation reconstruction are marked A to C.

A. Rhizophoraceae-dominated mangroves surrounding the core site. Ratios for Rhizophora below 345 centimetres exceed the minimum value for pollen deposition from local source plants. Similar values are recorded for riverbank mangroves of the Adelaide River (surface sample transects 5, 6 and 7). High ratios for Sonneratia in these levels also suggest riverbank communities. Higher up the core Rhizophora ratios fall below the recorded value for local plant growth. A similar trend is seen along surface sample transect 7, where low Rhizophora ratios apply to mangrove samples 50 metres or more from the riverbank (Figure 5.14). The low Rhizophora ratios and strong values for Ceriops/Bruguiera between 345 and 205 centimetres depth suggest a mid mangrove zone away from the riverbank. The peak in Rhizophora values at 235 centimetres does not contradict this interpretation, as this may represent isolated Rhizophora fringing a tidal creek. In a similar context, a narrow band of Rhizophora trees fringing a tidal creek is clearly represented in surface pollen samples away from the riverbank on surface sample transect 5 (Figure 5.12). Interpreted in this way the pollen sequence in HC 5 below 205 centimetres depth provides evidence of a point bar succession with the change from Rhizophora and Sonneratia - dominated riverbank forest to a more landward Bruguiera and/or Ceriops community. Although the interpretation is supported by aspects of modern pollen distributions along the Adelaide River, it is proposed tentatively because of the high potential for spreading and mixing of pollen types in riverine environments.
B. Above 205 centimetres depth Rhizophora and Ceriops/Bruguiera ratios decrease. To a lesser extent this is true of Sonneratia, while strengthening values for Avicennia and the appearance of Aeschynomene suggest the development of upper tidal to lower floodplain environments at the core site.

C. The replacement of mangrove pollen types and Aeschynomene by the regional component (largely Poaceae and Cyperaceae) indicates the change to river floodplain.

**CORE HC 9**

Core HC 9 was collected by the hand coring technique at the margin of back backwater swamp and river floodplain on the eastern side of the South Alligator River, approximately 35 kilometres from the river mouth. The backwater swamp adjacent to the core site has recently been encroached upon by saltwater due to tidal creek extension across the floodplain. Extensive dieback of tall, dense Melaleuca forest and associated freshwater plants has resulted, leaving large areas of unvegetated ground. Mangrove seedlings and saplings, especially *Avicennia marina*, *Sonneratia lanceolata* and *Lumnitzera racemosa*, are colonising the recently extended tidal channel.

Figure 7.4 reproduces the location map and stratigraphic summary for core HC 9, which was collected with the aim of producing a detailed record of vegetation transitions accompanying the change from intertidal to freshwater swamp environments in the upper estuarine funnel, for comparison with similar changes along the open coast. The base of the core penetrates the mid Holocene organic mangrove unit representing the "big swamp" mangrove phase described by Woodroffe et al (1985c, 1986).
Figure 7.4 Location, stratigraphy and radiocarbon details for core HC 9.
Figure 7.5 provides the results of pollen analysis of 21 samples from 20 to 280 centimetres depth from core HC 9. Pollen in a prepared sample from 0 centimetres in the core was too sparse and degraded to permit a pollen count. Difficulties in preparing samples from other levels in the core limited the number of samples which were finally analysed. No organic content determinations are available for core HC 9 due to problems encountered during the loss on ignition procedure, as described in Chapter 3.

Stratigraphy and radiocarbon ages

Between 20 and 43 centimetres depth the sediments consist of dark grey to black clays. These overlie grey and orange-brown oxidised muds between 43 and approximately 73 centimetres depth. Below 73 centimetres the muds turn to light brown, but progressively darken with depth. Below 125 centimetres depth, these grade into grey organic muds with frequent large organic fragments, and no visible shells or carbonised particles.

Two radiocarbon determinations relate to the HC 9 stratigraphic sequence. Both are derived from organic fines which were separated from the sedimentary matrix with a 120 micron mesh sieve. They return ages of 4570\(\pm\)220 (ANU 6265) at 140 centimetres depth, and 6410\(\pm\)160 (ANU 5266) at 280 centimetres depth.

Zonation and pollen content: HC 9 diagram

The HC 9 pollen diagram is divided into 3 zones with zone boundaries between 70 and 75 centimetre levels, and between 95 and 100 centimetre levels.
Figure 7.5 Pollen diagram for core HC 9. Values are percentages of the pollen sum.
Figure 7.5 contd.
Zone 1 (280 to 100 centimetre levels)

*Rhizophora* is the most strongly represented pollen type in zone 1 with values ranging from 32 to 82 percent of the pollen sum. *Ceriops/Bruguiera* and *Avicennia* are also well represented in all levels, with values between 8 and 22 percent for the former, and between 3 and 12 percent for the latter. Other mangrove pollen types recorded are *Sonneratia*, *Camptostemon*, *Lumnitzera*, *Aegiceras*, *Excoecaria* and *Xylocarpus*. Each of these has minor representation only.

*Poaceae, Cyperaceae and Myrtaceae (undetermined)* have low to moderate representation in most levels, while all other recorded taxa have minor and inconsistent representation. Estimated pollen concentrations for zone 1 are relatively high, ranging from 3000 to 19,500 grains per gram dry sediment.

Zone 2 (95 to 75 centimetre levels)

In zone 2 *Rhizophora* values decrease markedly relative to zone 1, with very low values recorded in 3 samples only. *Ceriops/Bruguiera* values are high in the lowest sample, and decrease progressively towards upper levels. Conversely, *Avicennia* is strongly represented throughout the zone, with values ranging from 23 to 57 percent of the pollen sum. Other mangroves have poor and sporadic representation.

*Poaceae* values are high relative to this taxon's performance in zone 1. Similarly *Cyperaceae and Myrtaceae (undetermined)* are well represented, with peak values exceeding those recorded in zone 1. *Aeschynomene* is well represented at the 95 to 85 centimetre levels, with maximum values reaching 8 percent of the pollen sum. The fern *Ceratopteris* is also well represented compared to its performance in other zones. *Restionaceae/Centrolepidaceae* and *Pandanus* have
consistent, low frequency representation. Other recorded taxa have minor representation. Estimated pollen concentrations for zone 2 are very low, and do not exceed 2000 grains per gram dry sediment.

Zone 3 (70 to 20 centimetre levels)

Pollen assemblages throughout zone 3 are dominated by Poaceae, with values ranging from 56 to 72 percent of the pollen sum. Mangrove pollen types are very poorly represented, with *Avicennia* and *Rhizophora* the only mangrove taxa recorded. Cyperaceae and Myrtaceae (undetermined) have strong representation relative to other zones, while all other pollen types have only minor representation. Estimated pollen concentrations are generally low, ranging from 1500 to 6000 grains per gram dry sediment.

In summary the major changes in the HC 9 pollen diagram occur with the transition from mangrove dominated assemblages in zone 1 to grass and sedge dominated assemblages in zone 3. *Rhizophora* and *Ceriops/Bruguiera* are the best represented mangrove pollen taxa in most levels, but give way to high *Avicennia* values between the 90 and 75 centimetre levels. In this section also, *Aeschynomene* has its strongest representation. Values for mangrove pollen types decline abruptly above 75 centimetres depth, when Poaceae, Cyperaceae and Myrtaceae (undetermined) pollen types become dominant. This change coincides with a colour change recorded in the stratigraphy at approximately 73 centimetres depth. In keeping with the records from cores previously described, the highest estimated pollen concentrations relate to assemblages dominated by rhizophoraceous mangrove pollen taxa.
Vegetation reconstruction: HC 9

The pollen sequence from HC 9 outlines vegetation changes around the HC 9 core site beginning approximately 6400 radiocarbon years ago. Relatively wide sampling intervals through most sections of this core, limit the detail of the vegetation reconstruction. The strong representation of Rhizophora and moderate to low representation of Ceriops/Bruguiera throughout zone 1 indicate that Rhizophora-dominated mangroves occupied the core site until sometime after 4500 radiocarbon years B.P. Avicennia is also well represented through this period, indicating that it was also an important component of the mangrove communities. Declining values for Ceriops/Bruguiera pollen through the lower levels of zone 2, coinciding with the virtual absence of Rhizophora pollen and steadily increasing representation of Avicennia, indicate a mangrove transition from Rhizophora forest through a mixed Ceriops and Avicennia community to Avicennia mangrove. The strong representation of Poaceae and Cyperaceae also indicate the development of river floodplains in the near vicinity. Consistent with the pollen records already described for cores SAH 31, HC 4 and HC 5, the strongest representation of Aeschynomene coincides with the transition to landward mangrove types, suggesting the local abundance of this plant near to the mangrove to plains transition.

Very strong representation of Poaceae and Cyperaceae, and the virtual absence of mangroves from zone 3, indicates the transition to a freshwater environment. The relatively strong representation of Myrtaceae (undetermined) probably reflects Melaleuca swamp communities surrounding the core site, although the likelihood that some of this pollen derives from upland sclerophyll communities is high. Extensive areas of dead Melaleuca swamp forest now stand adjacent to the core
site, having recently succumbed to saltwater incursion resulting from extension of tidal creeks away from the main river channel.

The main stages in the vegetation reconstruction for core HC 9 are summarised in Figure 7.6, which shows pollen concentrations in sediments and percentage ratios for local pollen types relative to the regional/long distance pollen group, following the procedure for preceding core interpretations. Stages A to E relate to stages in the vegetation reconstruction given below.

A. Pollen concentrations at 280 and 250 centimetres depth are strong, with values of 19,000 and 18,000 grains per gram dry sediment respectively. Rhizophora ratios for these levels are high, and exceed the threshold value for local deposition by a factor of approximately 7 at 280 centimetres and 11 at 250 centimetres. Ceriops/Bruguiera and Avicennia ratios are moderate, but exceed threshold values. This stage is interpreted to represent Rhizophora - dominated mangrove near the core site during the extensive mangrove phase in the river estuary. The radiocarbon date of 6410 ±160 (ANU 5266) at 280 centimetres (shown in Figure 7.5) is consistent with this interpretation.

B. Pollen concentrations from 220 to 110 centimetres range from 3000 to 12,000 grains per gram dry sediment. Rhizophora pollen ratios are generally lower than in the preceding stage, and fall below threshold values at 190 and 130 centimetres depth. Similarly, Ceriops/Bruguiera and Avicennia ratios are lower than in the preceding stage, and are lower than threshold values at some levels. This stage is tentatively interpreted to represent a mixed mangrove community, with Rhizophora, Avicennia and Ceriops and/or Bruguiera growing close to the core site. The moderate pollen concentrations and mangrove ratios suggest a contraction of the regional mangrove interpreted from Stage A. This is
Figure 7.6 Summary of major trends in pollen representation in core HC 9 showing estimated pollen concentrations, and percentage ratios of local pollen types to the regional/long distance component. Threshold values indicated as for core HC 5 in Figure 7.3.
consistent with the radiocarbon date of $4570 \pm 220$ (ANU 5265) between 130 and 140 centimetres depth (shown in Figure 7.5). The relatively strong representation of non-mangrove taxa, particularly Poaceae, Cyperaceae and Myrtaceae (undetermined) through these levels (see Figure 7.5), suggest that plains or freshwater swamp communities were formed nearby.

C. At 100 and 95 centimetres depth, Ceriops/Bruguiera and Avicennia ratios generally lie close to threshold values, while Rhizophora ratios fall below the threshold value. Aeschynomene is recorded at 15 to 20 percent of the regional/long distance group. This stage is taken to represent a landward, mixed Ceriops and Avicennia mangrove zone with Aeschynomene at the mangrove to non-mangrove transition.

D. Between 90 and 70 centimetres pollen concentrations fall below the threshold value for pollen deposition in mangrove recorded for modern environments. Rhizophora and Ceriops/Bruguiera values are very low, while Avicennia is strongly represented with values exceeding the threshold. Aeschynomene is recorded at 20 percent relative to the regional/long distance group at 85 centimetres depth. Even though pollen concentrations are low, this stage presumably represents a rear Avicennia mangrove zone with Aeschynomene an important annual component.

E. The virtual non-representation of mangrove taxa from 70 to 20 centimetres depth, and the strong representation of Poaceae, Cyperaceae and Myrtaceae (undetermined) (shown in Figure 7.5), indicate the transition to freshwater swamp or floodplain at the core site.
DISCUSSION

The radiocarbon date of 6410±160 (ANU 5266) from organic material at 280 centimetres depth in core HC 9 indicates that the lowest samples in the core derive from the period of mid Holocene extensive mangrove forests (the 'big swamp' phase) in the South Alligator River estuary. Pollen assemblages from levels below 190 centimetres derive from pollen rich sediments, and are characterised by very high proportions of Rhizophora pollen, and low proportions of all other mangrove and non-mangrove pollen types, even though the core site is within a few hundred metres of upland environments. These assemblages closely resemble pollen assemblages interpreted to derive from the big swamp phase in cores SAH 29, SAH 30 and SAH 31, which date from approximately 6500 to 5000 radiocarbon years B.P.

The pollen records from cores HC 5 and HC 9 provide details of plant successional events which accompanied the evolution of the tidal river. In both cases the records of transitions from mid-tidal to upper intertidal mangrove environments follow a sequence from Rhizophoraceae-dominated mangrove to mixed Ceriops and Avicennia and then to predominantly Avicennia communities. Similar successional sequences are recorded towards the upper levels of mangrove facies in cores SAH 29, SAH 31 and HC 4 from the coastal plain, as well as at other sites in northern Australia (Grindrod, 1985).

Vegetation successions in cores HC 5 and HC 9 from mangrove to freshwater environments seem to be direct, without the development of saltmarsh communities as an intermediate stage. Aeschynomene is strongly represented in the upper mangrove levels. Similar occurrences of this taxon in the most landward core sequences from the coastal plain, were explained in terms of prolonged seasonal freshwater
inundation of the core sites due to local impedence of drainage by a chenier ridge. Similarly, seasonally fresh conditions would be expected around the HC 5 and HC 9 core sites, due to the greater influence of wet season freshwater flooding at these more upstream localities. Although Aeschynomene seems to be poorly represented in the modern vegetation of the South Alligator River region today, the pollen evidence suggests that it was a locally abundant associate of upper intertidal mangrove communities throughout the area during the mid to late Holocene. The strong influence of wet season flooding at the upstream core sites was also sufficient to inhibit the development of upper intertidal hypersaline environments suited to saltmarsh plants.

Comparison with other pollen records from the South Alligator River Estuary

Three published pollen records from sediment cores collected from mid to upper tidal sections of the South Alligator River estuary provide evidence of Holocene plant successional changes. Hope et al. (1985) and Russell-Smith (1985) describe a pollen record from Ki'na swamp, a freshwater lagoon which lies adjacent to the upper limit of tidal influence on the South Alligator River, some 70 kilometres from the river mouth. The sequence (summarised in Figure 7.7) commences before 6200 B.P. and is assumed by Hope et al. (1985) to continue to the present. Assemblages in the lower half of the sequence contain very high proportions of Rhizophora pollen and low proportions of all other taxa, consistent with samples interpreted to be of "big swamp" origin in core HC 9, and in other cores from the coastal plain.
Figure 7.7 The Ki'na Swamp pollen diagram, summarised after Hope et al. (1985).
The sequence traces a transition from Rhizophora-dominated mangrove to Avicennia mangrove and the eventual establishment of freshwater swamp. There is no evidence of Ceriops being more abundant subsequent to the demise of Rhizophora as is indicated at other sites. This may be due to the relatively coarse sampling interval throughout the Ki'na Swamp core sequence. The upper 2 samples in the record contain high proportions of Rhizophora pollen suggesting the return of mangrove communities. There are no well developed mangrove communities close to the site at present, and the authors interpret this change in pollen values in terms of recent tidal incursion and the reworking of mangrove pollen types from older sedimentary deposits.

Two other pollen sequences are described for the South Alligator River estuary. Core SAH 40 (Chappell and Grindrod, 1985; Woodroffe et al., 1986) was collected from transect 8a (see Figure 7.1), close to the HC 5 core site. The pollen sequence (summarised in Figure 7.8) shows Rhizophoraceae mangrove from before 6700 radiocarbon years B.P., accompanying the last stage of the marine transgression until sea level had reached its approximate present level, at 3.0 metres depth in the core. Above this level the record suggests a succession through mangrove communities dominated by Sonneratia, Rhizophoraceae and Avicennia and the early development of river floodplain communities. A similar sequence is shown for core SAH 67 described by Woodroffe et al. (1986), and summarised in Figure 7.9. This core was collected near the landward floodplain margin approximately 60 kilometres from the rivermouth. Rhizophoraceae-dominated mangroves established at the site prior to 6800 radiocarbon years ago. In keeping with other records described for the estuary, the SAH 67 pollen sequence defines a transition from Rhizophoraceae-dominated mangroves to an Avicennia-dominated community coinciding with the early development of floodplain communities (Woodroffe et al., 1986).
Figure 7.8 The SAH 40 pollen diagram (after Chappell and Grindrod, 1984; Woodroffe et al., 1985c, 1986).
Figure 7.9 The SAH 67 pollen diagram (after Woodroffe et al., 1986).
The published pollen sequences from the South Alligator River estuary provide broadly similar records of vegetation change to those interpreted from cores HC 5 and HC 9. All sequences except HC 5 contain evidence of well developed mangrove communities dominated by Rhizophoraceae around 7000 to 6000 radiocarbon years ago, confirming the existence of the mid-Holocene 'big swamp' as defined by Woodroffe et al. (1985c, 1986), extending as far upstream as Ki'na Swamp, at least 70 kilometres direct from the river mouth. The sequences also show in relative detail the transition from mangrove to freshwater swamp and floodplain communities. There is no evidence in the upstream pollen sequences that saltmarsh communities developed as an intermediate stage in this transition. Local variations in recorded plant successions from site to site are apparent, and these are summarised in points A to C below:

A. Ceriops/Bruguiera pollen remains well represented in cores HC 9 and HC 5 following the decline of Rhizophora pollen values, suggesting a brief transition to Ceriops-dominated communities as the sediment surface accreted to drier, upper intertidal levels. A similar trend is less clearly represented in the SAH 40 and SAH 67 sequences, partly because these data are smoothed by use of running averages (Chappell, pers. comm.). As mentioned earlier, the absence of stronger Ceriops/Bruguiera values in the Ki'na swamp record may be related to coarse sampling intervals.

B. The SAH 40 sequence includes strong representation of Sonneratia pollen following sea level stabilisation, and suggests a regressive mangrove succession from Sonneratia forest, through Rhizophoraceae forest to an Avicennia community, consistent with the present sequence of mangrove zonations along the open coast adjacent to the river mouth.
Similarly strong representation of *Sonneratia* is not recorded in other pollen sequences from the area. 

*C. Aeschynomene* does not appear to have been a prominent element in the upper intertidal mangrove to freshwater swamp and floodplain transitions at the sites represented by published pollen records. This is in contrast to the interpreted vegetation records from HC 5 and HC 9.

Mangroves in the Sinuous Phase of the South Alligator River

Numerous palaeochannels throughout the modern floodplains provide evidence for the former existence of a sinuous, meandering tidal river channel. Woodroffe *et al.* (1986) conclude from extensive geomorphological and radiocarbon analyses that the sinuous river phase occurred subsequent to the retreat of the mangrove 'big swamp', lasted from approximately 4000 to 2500 radiocarbon years B.P., and that the main river channel had some features in common with the present sinuous meandering channel of the Adelaide River. For instance, the relationship between channel width and distance from the rivermouth is similar for both rivers, and stratigraphic drilling indicates that the inside bends of palaeomeanders on the South Alligator floodplain contain organic mangrove sediments consistent with those presently deposited beneath luxuriant mangrove forests from similar locations along the Adelaide.

Core HC 5 was collected from the inside bend of a former sinuous meander on the South Alligator floodplain with a view to comparing the reconstructed vegetation succession with modern mangrove zonations and pollen assemblages of selected sites along the Adelaide River, described in Chapter 5 (surface sample transects 5, 6 and 7). A feature of the Adelaide River vegetation is the prominence of a number of mangrove
plants which are absent or infrequent in the South Alligator River estuary today. These include *Acanthus ebracteatus*, *A. ilicifolius*, *Avicennia officinalis*, *Diospyros ferrea* and *Xylocarpus australasicus*. With the exception of *Avicennia officinalis*, the pollen of these taxa are easily distinguished from all pollen types commonly recorded in modern pollen assemblages in the South Alligator River region. The mangrove environments in which these taxa occur along the Adelaide River are characterised by relatively low soil water salinities. Similar environments may have occurred along the former sinuous South Alligator River, as tidal discharges are calculated to have been less than presently experienced in the relatively broad, cuspate river channel (Woodroffe et al., 1986).

Results described in Chapter 5 of surface sample analyses from mangrove transects on the Adelaide River indicate that plant zonation patterns associated with inside meander loops are not clearly represented in patterns of pollen deposition. The major trends in representation along each transect are relatively stronger values for *Rhizophora* close to the riverbank, and stronger values for *Avicennia* in rear mangrove communities adjacent to the river floodplain. Furthermore, only 3 of the mangrove taxa listed above as characteristic of the diverse Adelaide River mangrove communities are recorded in surface pollen assemblages. *Acanthus* pollen is consistently recorded at between 2 and 4 percent of the pollen sum in samples from transect 7, where source plants are locally prolific, while *Aegiceras* and *Xylocarpus* pollen appears at very low frequencies (less than 2 percent) in samples collected beneath stands of mature source plants.
These results suggest that clear pollen evidence of Adelaide River-like communities cannot be expected in cores from prograded sections of meander loops. Although a general trend from Rhizophoraceae to Avicennia mangrove communities may be recorded; the relatively poor detail in vegetation record is largely a consequence of inmixing of dominant Rhizophoraceous pollen between vegetation zones, and very poor pollen representation of many key mangrove taxa. However, sediment samples from broad Acanthus communities would be detectable by low frequency representation of Acanthus pollen.

The HC 5 pollen record confirms mangrove occupation of the inside meander loop of the former sinuous South Alligator River channel from at least 4000 to sometime prior to 1000 years B.P., and details the eventual decline of mangrove in the face of floodplain development. Xylocarpus pollen is identified in 4 samples from the core, with only 1 or 2 grains recorded in each case, suggesting the former presence of this plant in the area. Similar low frequency representation of Xylocarpus pollen occurs in surface sediments collected where the plant is prolific on the Adelaide River. However, a single Xylocarpus grain is also recorded on surface transect 1 from the coastal plain, where the parent plant is locally unrecorded. The data are therefore inadequate to allow comment on the former abundance of Xylocarpus, and the former existence of other mangroves such as Acanthus, Aegiceras and Diospyros in the South Alligator estuary during the late Holocene sinuous meandering phase. However, the low representation of each of the diagnostic taxa in the pollen data from the Adelaide River indicate that the question could be resolved with very large surface and fossil pollen counts, sufficient to provide a basis for statistical comparison between samples.
In contrast to the Adelaide River surface samples, *Sonneratia* is consistently recorded in the HC 5 core sequence. Two species of *Sonneratia* occur in the region. *S. alba* is widespread in coastal and lower estuary localities, and is never abundant in the mid to upper tidal reaches of rivers. *S. lanceolata* is restricted to mid or upper tidal reaches of some rivers, and has not been recorded for the Adelaide River despite intensive searching (Ball, pers. comm.). Consequently the presence of *Sonneratia* in the sinuous section of the Adelaide River is restricted to the sporadic occurrence of *S. alba*, and this is reflected in the very poor pollen representation of this genus in the surface samples. In contrast, *S. lanceolata* is common along the upper tidal reaches of the South Alligator River, and the pollen record from HC 5 suggests that this has been the case for at least the past 4000 years.
CHAPTER 8

CONCLUSIONS

Pollen Preservation in Sediments and its Effect on Vegetation Reconstructions

The quality of pollen preservation varies considerably through the different sediment types analysed in this study. The vagaries of pollen preservation in mangrove and upper intertidal mudflat sediments are outlined in Chapter 1. As a general rule, pollen preservation is good in mangrove sediments which are frequently inundated by tides, and remain saturated during subaerial exposure at low tide. Poor pollen preservation occurs in upper intertidal mangrove and salt mudflat sediments where periodic drying increases the potential for oxidation. These variations are manifest in both surface sample and core sequences through intertidal sedimentary environments. For similar reasons, there is a high degree of variation in pollen preservation in freshwater clays. Transgressed clays from former Selaginella swamps in cores SAH 31 and HC 4 show little evidence of oxidation, and contain high concentrations of well preserved pollen. Presumably these facies derive from perennial swamps. By contrast, pollen preservation is generally poor in the freshwater clay unit of the coastal and river floodplains. Wet season flooding, subaerial exposure during the dry season, and vigorous plant growth provide conditions suited to rapid degradation of pollen through oxidation and microbial attack in the 'living' soil. It is common to record relatively strong values for pollen concentration at the surface of floodplain sediments, but rapid depletion with increasing depth, so that below about 40 centimetres the pollen is noticeably degraded and pollen extraction in quantities sufficient for counting is often very difficult.
The consequence of variations in pollen preservation in different environments is evident in pollen diagrams. Gaps in the record commonly occur following the transition from mangrove sediments, where these are succeeded by floodplain freshwater clays. Salt mudflats may also provide meagre pollen records, although where saltmarsh communities have been prolific, pollen counts of local taxa are generally possible because of the high pollen production of Chenopodiaceae, and the distinctiveness of its pollen grain even when degraded.

The Extensive Mangrove in the South Alligator River

Pollen assemblages older than 5500 years B.P. from the South Alligator River cores provide evidence of the floristic makeup of the extensive mangrove swamp which formerly filled the estuary. Table 8.1 lists the mangrove plant/pollen taxa presently inhabiting the estuary and/or represented by pollen in sediments, including data from Russell-Smith (1985). Inevitably the pollen record will be incomplete, due to the inherently poor representation of many mangrove plants. There is no evidence in the pollen record that either the list of plant species, or the relative abundances of particular mangrove taxa during the extensive mangrove phase were substantially different from today. Rhizophoraceae was the dominant mangrove family, with Rhizophora probably the most common genus in areas where tidal inundation was frequent. Both Bruguiera and Ceriops were probably also abundant, with the latter commanding higher intertidal localities towards the rear of the mangrove, as suggested by the HC 4 pollen record. Avicennia was also a common and widespread plant. Other mangrove genera recorded in the present study from the extensive mangrove phase include Aegiceras,
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<th>Presently inhabiting S.A.R. estuary</th>
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<th>in fossil sediments this study</th>
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* Present  
- Absent

Table 8.1 Representation of plant and pollen taxa in the South Alligator River vegetation and in surface and core pollen samples. Ki'na Swamp data after Russell-Smith, 1985. Uncertainties in the right hand column relate to pollen grains of unspecified age, identified by Russell-Smith (1985).
Excoecaria, Camptostemon, Lumnitzera and Sonneratia (Table 8.1). The low pollen representation of these taxa in sediments from the former extensive mangrove is consistent with their recorded pollen dispersals in modern environments throughout the area. Russell-Smith (1985) also records the pollen of Cynometra irripa, Acanthus ilicifolius and Osbornia octodonta in the Kiöna Swamp profile, though the stratigraphic age of these recordings is unspecified. The pollen record for the former species is interesting as this plant is not known in the vegetation of the Northern Territory. Apart from this recording there is no pollen evidence that any mangrove species not presently inhabiting the South Alligator estuary did so during the former extensive mangrove phase.

**Pollen Transfer in the Extensive Mangrove**

Structurally the former extensive mangrove community of the South Alligator River probably resembled the broad mangrove communities of Missionary Bay in northeastern Queensland, with a dense and continuous intertidal forest canopy, punctuated by meandering tidal channels. Through comparison of the pollen record from cores and surface samples, aspects of pollen transfer and deposition within the extensive mangrove community can be inferred. Relative to sediments from the narrow mangrove fringe on the coastal plain, sediments from the extensive mangrove contain very high concentrations of pollen, and provide pollen assemblages with characteristically high mangrove to non-mangrove pollen ratios. Differences between pollen sedimentation in the two environments can be linked to conceptual models of pollen transfer shown in Figure 8.1. The upper diagram summarises aspects of pollen transfer at a coastal mangrove fringe, following the model based on surface sediment and pollen trap results in Chapter 5 (Figure 5.15). The lower
Figure 8.1  Comparison of aspects of pollen transfer in contrasting mangrove environments. Fringing mangrove: moderate mangrove to non-mangrove pollen ratios and pollen concentrations result from a predominantly non-mangrove regional pollen influx, and dispersal of locally produced pollen through the trunkspace. Extensive mangrove: high mangrove to non-mangrove pollen ratios and pollen concentrations result from a predominantly mangrove regional pollen influx, and subdued trunkspace pollen dispersal due to the sheltering effect of the extensive forest canopy.
diagram provides a model for pollen transfer in a section of extensive mangrove. In both cases local pollen deposition derives from mangroves. Non-mangrove pollen is reasonably well represented in surface sediments from the fringing forest because regional pollen derives from non-mangrove sources. At the same time, pollen concentrations in sediments are moderated because pollen is transported away by air movement in the trunkspace and perhaps by tidal flushing. In sediments from the extensive mangrove forest, high mangrove to non-mangrove pollen ratios are maintained because the regional pollen component is predominantly mangrove, and pollen concentrations are high because of subdued trunkspace air movement, providing sheltered conditions for pollen deposition. The effects of tidal flushing may be similarly subdued by the extensive mangrove cover.

**Sea Level and Tidal Range Reconstructions and the Problem of Compaction.**

Woodroffe et al. (1987) describe the evidence for former sea levels relative to the South Alligator River estuary from approximately 8000 radiocarbon years B.P. to present. Their sea level curve (reproduced in Figure 8.2) is based on dated mangrove organics. Mangroves are reasonably good indicators of sea level because they are almost exclusively intertidal, and so occur at predictable elevations relative to mean tide level. However, fine detail in the South Alligator record is obscured by the broad elevational range of living mangroves, a total of 4.7 metres throughout the estuary (Woodroffe et al., 1987), reflecting the high local tidal amplitude. Most of the samples in the data set derive from the mid Holocene 'big swamp' mangrove phase. Younger data points are fewer because of the rapid retreat of mangroves as infilling of the estuary proceeded. In Figure 8.2 radiocarbon ages greater than 6800 years B.P. are from samples recovered below the
Figure 8.2 Comparison of sea level data from the South Alligator River (Woodroffe et al., 1987) with results from other Australian studies. Dotted lines indicate sea level envelope by Thom and Roy (1983) for eastern Australia. Dashed lines indicate sea level envelope by Grindrod and Rhodes (1984) for Missionary Bay. Karumba and Great Barrier Reef curves after Chappell et al. (1982, 1983).
present range of mangrove growth, while those less than 5800 years B.P. fall within the present elevational range of living mangroves. The data therefore define the final stages of the Post Glacial Marine Transgression and the subsequent period of relative sea level stability. In essence the results suggest rapid sea level rise between 8000 and 5800 radiocarbon years B.P., and no change in sea level between 5800 years B.P. and present.

Figure 8.2 also shows transgressive sea level envelopes for eastern Australia by Thom and Roy (1983, 1985), and northeastern Queensland (Grindrod and Rhodes, 1984), as well as post 6000 years B.P. sea level curves for Karumba in the southern Gulf of Carpentaria, and the inner islands of the northern Great Barrier Reef Province (Chappell et al., 1983; Chappell, 1982). The transgressional data from the South Alligator River fall to the right of those provided by the first two studies, suggesting that sea level rise relative to Van Diemen Gulf lagged slightly behind that of eastern Australia. Further, as all samples younger than 5800 years B.P. fall within the modern range of mangrove growth, there is no evidence of mid Holocene higher sea level, such as is defined by the Karumba and Great Barrier Reef curves.

It is possible that the younger ages for transgressive sea level data relative to results from eastern Australian localities, and the lack of evidence for mid Holocene higher sea levels in mangrove sediments of the South Alligator River are related to either slight tectonic sinking of the Van Diemen Gulf region or sediment compaction, or a combination of these factors. Although tectonics cannot be dismissed, no independent geological evidence for regional subsidence has been reported. The problem of sediment compaction, however, can be more readily addressed. At Princess Charlotte Bay in northeastern
Queensland, evidence for a higher mid Holocene sea level from raised fringing coral reefs is not reflected in nearby fossil mangrove horizons beneath a prograded chenier plain (Chappell and Grindrod, 1984). This is explained in terms of sediment compaction, as indicated by local depression of sedimentary horizons beneath chenier overburden, and by increasing bulk densities in older sediments. In the sea level reconstruction for the South Alligator River area, Woodroffe et al. (1987) argue against significant sediment compaction on the grounds that there is generally good agreement in elevation between samples recovered directly above consolidated basal strata, and those overlying deep, unconsolidated Holocene sediments. However, in the stratigraphic section along transect 1 described in Chapter 4 (see Figure 4.4) mangrove sedimentary horizons of a consistent age become progressively lower from south to north. Hence the 6000 B.P. isochron, for example, falls through approximately 6.5 metres vertical range, which is greater than the present total elevational range for mangrove growth throughout the entire estuary, and approximately double the elevational range for living mangroves on the coastal plain. Lowest elevations for the isochron appear where mangrove sediments directly overly marine mud as opposed to consolidated basal strata, and underly the greatest thicknesses of sediment overburden; that is, where the sedimentary layer is most vulnerable to deflection by compaction.

The detailed sedimentary and palynological analyses from the South Alligator estuary also invite comment on reconstruction of former tidal range. The sedimentary model employed by Klein (1971) to gauge palaeotidal range from sediment size distribution through intertidal sequences can theoretically be applied to pollen core sequences which provide markers of lower and upper levels of mangrove growth. However, the model is difficult to apply in the Holocene context of the South
Alligator River estuary because it relies on stable sea level, and requires the confident identification of elevational limits to mangrove growth at a single point in time. It cannot be applied to transgressional sequences which, by definition, were deposited during the time of relative sea level rise, and is difficult to apply to post 6000 year sequences because the transition from transgressive to regressive environments is not clearly marked in the pollen record, nor well defined by radiocarbon in appropriate core sequences.

High tide limits in the past are more readily identified from pollen analysis of cores where supratidal sedimentation has taken place over mangrove. In this event the mangrove to non-mangrove transition may be clearly recorded by pollen. Thus Woodroffe et al. (1986) cite palynological evidence for lower high tide levels upstream in the former sinuous South Alligator River approximately 5000 years B.P. The transition from mangrove to floodplain environments in pollen cores is taken to represent the former high spring tide level. Accurate survey data show these transitions to lie approximately 1 metre below the present upper level of mangrove growth at equivalent points along the river (Figure 8.3), suggesting a rise in the upper tidal limit in the period since 5000 years B.P. However, this evidence is compromised by more recent palynological data described in this thesis. The upper limit to mangrove growth indicated in the pollen sequences from cores SAH 29 and SAH 31 on the coastal plain adjacent to the river mouth is also well below the present upper level of mangrove growth (Figure 8.3). The mangrove to non-mangrove transition occurred less than 2000 years ago in SAH 29, and around 5000 years ago in SAH 31. If the upper mangrove limit delineated by pollen can be taken as a reliable indicator of the former level of high tide, then it follows that this level was uniformly lower throughout the length of the tidal estuary approximately
Figure 8.3  Elevation of the present upper limit to mangrove growth in the South Alligator River (after Woodroffe et al., 1986), and elevational range of upper mangrove limit in pollen cores, relative to distance from the river mouth.
5000 years ago, and tidal range was not merely subdued in the upper estuary due to the sinuous form of the river channel. Furthermore, the sequence from SAH 29 would suggest that the lower than present tidal range persisted later than 2000 B.P. In reality, these results are difficult to explain in terms of tidal range or sea level changes. It is considered more likely that the uniformly lower levels for upper mangrove growth suggested in the pollen cores are the result of relatively consistent sediment compaction throughout the river estuary.

The foregoing suggests that there are a number of direct and indirect lines of evidence suggesting that sediment compaction has had a significant effect on the elevation of mangrove and related sedimentary horizons. Direct lines of evidence are: 1. Mangrove sediments of consistent age appear at greater depth beneath the coastal plain, where they overlie unconsolidated sediments, and underly the greatest thicknesses of overburden. 2. Palynologically-defined upper limits to mangrove growth, from less than 2000 to approximately 5000 B.P., from points throughout the estuary are uniformly lower than the present upper level of mangrove growth.

In the light of these considerations it must be concluded that there is no necessity to invoke a lag in sea level rise for the Van Diemen Gulf relative to eastern Australia, as suggested by Woodroffe et al. (1987), and it cannot be assumed from the South Alligator relative sea level curve that mid Holocene higher sea levels, as recorded elsewhere in eastern and northern Australia, did not also occur in Van Diemen Gulf. Further, the palynological evidence for tidal changes in the mid to upper reaches of the South Alligator River estuary invoked by Woodroffe et al. (1986) is questionable. Indeed, if sediment compaction has accounted for 1.0 to 1.5 metres vertical displacement of upper
pollen horizons the pollen evidence would suggest no detectable change in the upper tidal limit over the past 5000 years.

Clearly, there is a need for independent sea level data, not derived from deep, unconsolidated sediments, for the Van Diemen Gulf region. Although preliminary observations have not been encouraging, evidence for post 6000 year sea levels relative to Coburg Peninsula (northern Van Diemen Gulf) may be recovered from former fringing coral reefs (Woodroffe, pers. comm.).

Climatic Versus Geomorphological Effects on Mangrove and Wetland Vegetation

Stratigraphic evidence for former extensive mangrove forests has been reported for a number of localities in tropical Australia; for instance, in Western Australia at the Fitzroy River (Jennings, 1975), the Ord River (Thom et al., 1975), and King Sound (Semeniuk, 1980, 1982), and in the Northern Territory at the Daly and South Alligator rivers (Hope et al., 1985; Woodroffe et al., 1985c, 1986). Dating of organic horizons associated with the former extensive mangroves generally indicates their presence between 7500 and 5500 radiocarbon years B.P. (Jennings, 1975; Thom et al., 1975; Woodroffe et al., 1985c, 1986).

Jennings (1975) attributes the former extensive mangroves of the Fitzroy River to a wetter than present climate in the river's catchment, resulting in increased and seasonally prolonged freshwater discharge at the coast. Apart from the greater than present areal extent of mangrove communities, the interpretation is based on inferred high mangrove vigour as gauged by fossil tree stumps of *Avicennia marina*, with diameters exceeding those of living trees in the region today. By
contrast, Woodroffe et al. (1985c, 1986) link the existence of former widespread mangroves in the South Alligator River estuary to sedimentary infill in response to sea level stabilisation following the Post Glacial Marine Transgression, and see no reason to invoke climatically-induced changes in river hydrology.

The pollen record from the South Alligator River estuary provides no clear evidence of climatic variation over the past 8000 radiocarbon years. There is no evidence for the former luxuriance of mangrove taxa, such as Acanthus, Diospyros, Xylocarpus and Nypa, which might suggest more humid conditions than present, although it is clear that the pollen representation of at least the first 3 taxa may be unreliable. As Woodroffe et al. (1985c, 1986) have pointed out, the great expanse of mangrove during mid Holocene times can be attributed to broad areas made suitable to mangrove habitation within the shallowing, muddy estuary. It is also possible that, under extensive mangrove conditions, plant vigour was also enhanced. Thus Jennings' conclusion that out-sized fossil tree stumps of Avicennia marina indicate a "significantly longer and heavier rainy season than now" (Jennings, 1975, 252) may be inappropriate, because it is possible that widespread, deep organic sediments bound by mangrove vegetation trapped wet season floodwater and retained it for extended periods into the dry season, thereby enhancing growth conditions and effectively lengthening the growing season. It is interesting that the large fossil tree stumps identified by Jennings (1975) are from Avicennia marina, which has an extremely variable growth form according to suitability of site, ranging from tall and stately trees in low salinity mangroves, to gnarled, dwarfed shrubs in high salinity environments. Along much of the South Alligator River today large trees of Avicennia marina (and other mangroves) are rare because supra-tidal sedimentation has displaced the mangrove habitat.
(see Chapter 2). By contrast, large Avicennia marina trees are common in the West Alligator River, which retains prime intertidal habitat for extensive mangroves. As these rivers feed from adjacent headwaters in Western Arnhem Land, it is unlikely that climatically-induced differences exist between them; indeed the smaller West Alligator River has moderate freshwater discharge relative to its large neighbour.

The fossil pollen record from the South Alligator coastal plain indicates the former presence of Selaginella swamps and the possibility of Pandanus swamps adjacent to mangrove communities on the former land surface prior to the final stages of the marine transgression approximately 7000 to 6000 years ago. Coastal swamps of this nature are not recorded in the region today, and are generally a feature of more humid or less seasonally arid environments. In addition, the freshwater aquatic shrub Aeschynomene, which is not prolific in the area today, was an important component of the mangrove to non-mangrove transitions throughout the estuary approximately 5000 years ago. Conversely, well developed saltmarsh communities were apparently absent during the period 7000 to 5000 years B.P., but have subsequently formed a broad zone in the coastal plain littoral fringe. It could be argued that the combination of these various vegetation changes indicate wetter than present conditions 7000 to 5000 years ago when freshwater swamp elements Selaginella, Aeschynomene and perhaps Pandanus were more prolific than at present in the study area, followed by a shift to less humid conditions marked by the development of saltmarsh communities characteristic of more arid or seasonally arid coasts. However, as outlined above, the former presence, or more recent establishment, of habitat settings suitable to the respective plant taxa in question, can be largely explained by geomorphological and ground water responses to sea level change and do not require explanation in climatic terms.


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Ecology and distribution of plants represented in the pollen diagrams and selected plants mentioned in the text. Information compiled from field observation and with the generous assistance of Marilyn Ball of the A.N.U., Glen Wightman and Clyde Dunlop of the Conservation Commission of the N.T., and with reference to Taylor and Dunlop (1985) and Wells (1982).

**Acacia** (Mimosaceae). Evergreen shrubs and trees; sclerophyll shrublands, Eucalyptus open forests and woodlands; infrequent in monsoon forests and Melaleuca swamp forests. A common, widespread genus, including at least 24 species in the Alligator rivers region.

**Acanthus ilicifolius** (Acanthaceae). The "holly-leaved mangrove". Gangling evergreen shrub to 2 m tall, in low salinity riverine mangrove communities. Occasionally forms dense, low thickets to the exclusion of other plants. Maximum growth where ground water salinities are about 5% sea water concentration, but persists where dry season salinities reach 100% sea water. Flowers year round, but most seed is set in the early wet season. The conspicuous blue flowers are attractive to insects. Not common in the Alligator rivers region.

**Aegialitis annulata** (Plumbaginaceae). Shrub or small tree to 4 m tall; in landward, high salinity mangrove habitats. Often associated with Avicennia marina and saltmarsh plants. May also form low dense meadows seaward of coastal mangrove forests where tidal inundation is deep and protracted. Secretes large quantities of salt from the leaves. Slow
growing with a broad salinity tolerance range. Flowers appear late dry season, seed shed towards the end of the wet season. Common and widespread in coastal and riparian mangrove communities of the Alligator rivers region, and throughout northern Australian coasts generally.

*Aegiceras corniculatum* (Myrsinaceae). Shrub or small tree to 5 m tall; well-drained coastal and riparian mangrove communities subject to frequent tidal inundation. May form dense understorey in low salinity environments; shade tolerance decreases with increasing salinity. Tolerates extended periods of inundation by fresh water. Maximum growth rate at 5% sea water salinity. In northern Australia, flowers appear late in the dry season, propagules shed during the wet season. Common and widespread along northern and eastern Australian coasts. Common in the Alligator rivers region.

*Aeschynomene indica* (Fabaceae). Annual shrub on river floodplains, in seasonal freshwater swamps and coastal plains adjacent to mangroves. Pantropical; common in the Alligator rivers region.

*Amyema mackayense* (Loranthaceae). The "mangrove mistletoe". Woody parasite of mangrove trees, particularly *Avicennia marina* and *Camptostemon schultzii*. Occurs sporadically throughout coastal and riverine mangroves of the Alligator rivers region.

*Antidesma ghaesembilla* (Euphorbiaceae). Large deciduous shrub or small tree to 5 m tall. In Eucalyptus open forest and woodland, lowland monsoon forest and forest margins, and in Melaleuca swamp forest. Pantropical; widespread in the Alligator rivers region.
Avicennia marina (Avicenniaceae). "The grey mangrove". Varies from low, almost prostrate shrub to large tree to 20 m tall. A. marina displays a very wide tolerance range to ground water salinities, from 0 to 200% sea water concentration. Greatest tree size is attained in salinities approximately 5% sea water. Occurs in a great variety of mangrove habitats from well drained, deeply inundated tidal forests, to low shrubs fringing infrequently flooded hypersaline flats. In northern Australia flowering occurs late in the dry season; tidally-distributed propagules are mostly shed in the mid wet season, and remain viable after many months afloat. Pantropical; common and widespread in mangrove environments in all mainland Australian states. Very common in the Alligator rivers region.

A. officinalis. Large evergreen shrub or small tree to 7 m tall, with conspicuous adventitious roots. Prolific along tidal rivers on well drained, perennially moist soils. Propagules are shed early in the wet season, and may remain viable for months before taking root. Seedlings are not persistent where salinities exceed 75% sea water concentration. In Australia, A. officinalis is only recorded in a few rivers between Darwin and eastern Arnhem Land in the N.T.

Azolla filiculoides (Azollaceae). Small, free-floating aquatic fern forming continuous cover on ephemeral and permanent freshwater swamps. Widespread in all Australian states; common throughout the Alligator rivers region.
**Banksia** (Proteaceae). Includes one species only in the N.T.; *B. dentata*, shrub or small tree to 5 m tall; on poorly drained soils and in seasonal swamps. An isolated population occurs on quartzitic beach ridge sands adjacent to the mouth of the South Alligator River. Widespread in the far north of the N.T., Cape York Peninsula in Queensland and southern Papua New Guinea; infrequent in the Alligator rivers region.

**Barringtonia acutangula** (Lecythidaceae). Deciduous tree to 15 m tall; lowland swamps, swamp margins and along ephemeral and permanent river courses. Conspicuous, pendulous flowers are attractive to insects. Pantropical; common in the Alligator rivers region.

**Batis argillicola** (Bataceae). Succulent, perennial shrub to 70 cm tall; in mangroves, saltmarshes and saline grasslands. Sometimes forms narrow monospecific vegetation belt near the upper limit of tidal penetration, landward of mangroves. Generally on fine muddy clay soils; occasionally on calcareous and quartzitic sands. Highly salt tolerant. Widespread throughout coastal saltmarshes of tropical Australia; common in the Alligator rivers region.

**Boerhavia dominii** (Nyctaginaceae). Spreading herb with perennial root stock; on varied soil types throughout Eucalyptus open forests and woodlands, and in coastal beach ridge communities. Widespread and common in the Alligator rivers region.

**Bombax ceiba** (Bombacaceae). A large, spreading, deciduous tree to 18 m tall. Conspicuous in northern Australian coastal areas on calcareous or quartzitic beach ridges, along river levees, and
on moist, well drained hillslopes in monsoon forest. Flowering occurs in the dry season when tree is defoliated. Large flowers contain moisture and are visited by a range of insects. Widespread throughout tropical coastal Australia, common within restricted habitats in the Alligator rivers region.

**Borreria australiana** (Rubiaceae). Spreading, terrestrial herb to 30 cm tall; **Eucalyptus** open woodlands, seasonally flooded river plains, sclerophyll shrublands and grasslands. Flowers attractive to ants and bees. Common throughout the Alligator rivers region.

**B. breviflora.** Annual, spreading herb to 30 cm tall; **Eucalyptus** open forests and woodlands of lateritic and sandstone environments; less frequent in upland monsoon forests. Pantropical; common and widespread in the Alligator rivers region.

**B. exserta.** Herb to 1 m tall; **Eucalyptus** and **Callitris** open forests and grasslands of the sandstone uplands, coastal dunes and calcareous soils. Common in the Alligator rivers region.

**B. leptoloba.** Annual herb to 30 cm tall; **Eucalyptus** open forests and woodlands. Common in the Alligator rivers region.

**B. membranacea.** Herb to 40 cm tall; sandy soils of the sandstone uplands. A species of restricted range in the Alligator rivers region.

**Breynia cernua** (Euphorbiaceae). Evergreen shrub or small tree to 5 m tall; coastal monsoon thickets, sand dune communities, gallery forests, **Melaleuca** swamps, and on river levees and
calcareous sands adjacent to mangroves. Also in Eucalyptus open forests and woodlands and monsoon forests of the sandstone uplands. Pantropical; widespread in the Alligator rivers region.

Bruguiera exaristata (Rhizophoraceae). Evergreen shrub or tree to 10 m tall; coastal and riverine mangrove habitats, landward of Rhizophora forest. Broad salinity range; prefers well drained sites regularly inundated by tides. Propagules are shed late in the dry season. Common and widespread along northern Australian coasts, including the Alligator rivers region.

B. gymnorrhiza. Evergreen shrub or tree to 15 m tall; coastal and riverine mangrove habitats. Most prolific where soil water salinities are moderate; typically a sub-canopy shrub at higher salinity. Flowers all year round, but most strongly in the dry season. Most propagules are shed in the late wet season. Widespread throughout the tropical west Pacific and Indian Oceans. Recorded in Australia along the northern coast of the N.T. including Van Diemen Gulf, northeastern shores of the Gulf of Carpentaria, and Queensland's east coast.

B. parviflora. Evergreen shrub or tree to 10 m tall; on boggy, poorly drained sites in mangrove habitats. Typically in fringing mangrove forests along tidal rivers. Groundwater salinities in preferred sites range from 50 to 100% seawater concentration. Sometimes forms monospecific stands on sites infrequently inundated by seawater. Propagules are shed early to mid wet season. Widespread in the west Pacific region and throughout tropical Australian shores. Common in mangrove habitats of the Alligator rivers region.
Callitris intratropica (Cupressaceae). Moderate to large tree to 10 m tall; in Eucalyptus open forests and woodlands of the sandstone uplands and on shallow lateritic soils. Occasionally dominant or co-dominant canopy tree. Pollen is dispersed long distances by wind. Common and widespread in the Alligator rivers region.

Camptostemon schultzii (Bombacaceae). The "kapok mangrove". Tall tree to 18 m high; typical of seaward mangrove forests of the open coast subject to deep, regular inundation by tides, often in association with Sonneratia alba. Also common throughout fringing mangrove forests of tidal rivers. Does not occur where ground water salinities exceed sea water concentrations. Seeds are released in the early wet season and germinate quickly. Widespread on far north coasts of Australia; common in the Alligator rivers region.

Capparis sepiaria (Capparaceae). Perennial, deciduous shrub or climber to 2 m tall; calcareous and quartzitic beach ridges, adjacent to mangroves, lowland monsoon forests and forest margins. Conspicuous flowers probably attractive to insects and birds. Pantropical, common in restricted habitats in the Alligator rivers region.

Cardiospermum halicacabum (Sapindaceae).Introduced erect herb to 30 cm tall or prostrate herbaceous vine; on river floodplains, and in riparian forests. Widespread, but not very common in the Alligator rivers region.

Cassia obtusifolia (Caesalpineaceae). Exotic, annual herb or small
shrub to 2 m tall. Aggressive weed of river floodplains, lowland monsoon forests and the margins of freshwater swamps. Common and widespread throughout the Alligator rivers region.

*C. occidentalis.* Exotic, annual shrub to 2 m tall. Weed of black soil plains, swamp margins, damp soils in *Eucalyptus* open forests and woodlands. Common and widespread throughout the Alligator rivers region.

*Casuarina cunninghamiana* (Casuarinaceae). Tree to 20 m tall; conspicuous along rocky, freshwater river channels. Widespread throughout eastern mainland Australia and the far north of the N.T. Infrequent within the Alligator rivers region, and confined to freshwater sections of major river beds.

*C. equisetifolia.* ssp *equisetifolia.* Small tree to 7 m tall. Apparently restricted to coastal environments, particularly on quartzitic dunes. Pollen dispersed long distances by wind. Widespread in eastern Australia and the far north of the N.T. Infrequent in the Alligator rivers region.

*Cathormion umbellatum* (Mimosaceae). Deciduous, shrub or small tree to 5 m tall; margins of river floodplains and drainage channels, lowland monsoon forests, beach ridge communities and adjacent to mangroves. Fragrant, profuse flowers probably visited by insects and birds. Pantropical; common and widespread in the Alligator rivers region.

*Celtis philippinensis* (Ulmaceae). Evergreen tree to 5 m tall; lowland and coastal monsoon forests, occasionally in *Eucalyptus* open woodlands, commonly on sandy soils. Pantropical; widespread
in northern Australia, moderately common in the Alligator rivers region.

**Centrolepis exserta** (Centrolepidaceae). Tufted, annual herb about 8 cm tall. On sandy, clayey and peaty soils on seasonally flooded plains, in *Melaleuca* swamps, jungle creeks, seepage areas of sandstone uplands and adjacent to mangroves. Widespread but not very common in the Alligator rivers region.

**Ceratopteris thalictroides** (Parkeriaceae). Erect, semi-aquatic, annual fern to 30 cm tall; ephemeral and permanent fresh water swamps, floating grass mats, seasonally inundated grasslands and sedgelands. Often on black, cracking clay soils of the river floodplains. Pantropical; widespread in northern Australia, infrequent in the Alligator rivers region.

**Ceriops decandra** (Rhizophoraceae). Evergreen shrub or gangling tree to 5 m tall; generally providing an understorey in mixed *Bruguiera* and *Rhizophora* mangrove forests fringing tidal rivers. Rarely an important canopy tree. Established plants display considerable shade-tolerance, and only moderate salinity tolerance. Propagules shed late in the dry season. Widespread in the western Pacific and Indian Ocean regions; including N.T. and Queensland coasts. Common in the mangroves of the Alligator rivers region.

**C. tagal** var. **australis**. Evergreen shrub or small tree to 10 m tall; mangrove habitats. Greatest size in low salinity environments. May become the dominant canopy species in either low salinity dry, or high salinity wet, mangrove environments. Inundation by fresh water inhibits seedling
growth. Flowers appear late in the dry season; propagules
are shed late in the wet season. Widespread throughout tidal
waterways of northern Australia; common in mangroves of the
Alligator rivers region.

**Choriceras tricorne** (Euphorbiaceae). Shrub or small tree to 5 m tall;
**Eucalyptus** open woodlands and forests, monsoon forest margins
and adjacent to mangroves; on organic sandy loams and
gravelly lateritic soils. Widespread in the Alligator rivers
region.

**Cordia dichotoma** (Boraginaceae). Spreading shrub or tree to 10 m tall
with fleshy fruits and aromatic stems and leaves; lowland
monsoon forests, gallery forests, coastal vine thickets,
fringing river floodplains and swamps; on lateritic and
alluvial soils. Pantropical, common in the Alligator rivers
region.

**Cressa cretica** (Convolvulaceae). Small annual herb to 15 cm tall;
seasonally flooded grassland margins, river floodplains,
**Eleocharis** sedgelands, river verges and adjacent to mangrove
and coastal salt mudflats. Pantropical; common and
widespread in the Alligator rivers region.

**Crinum angustifolium** (Liliaceae). Herb to 60 cm tall with perennial
bulb. Stems and foliage usually die off in the dry season.
Seasonally inundated grasslands and sedgelands on river
floodplains, **Melaleuca** swamp forests, coastal plains adjacent
to mangroves. Conspicuous, fragrant flowers visited by
insects. Widespread but infrequent in the Alligator rivers
region.
C. uniflorum. Herb to 30 cm tall with perennial bulb. Stems and foliage die off during the dry season. On lateritic soils and waterlogged sands; Eucalyptus open forests and woodlands, margins of river floodplains. Widespread but infrequent in the Alligator rivers region.

Cyperaceae. "The sedges". Low graminoids generally less than 0.5 m tall. Most common in freshwater swamps and on seasonally flooded terrain but also scattered through open forests and woodlands. A few species grow at margins of salt mudflats. This family includes many species in the study area.

Denhamia obscura (Celastraceae). Evergreen tree of Eucalyptus open forests and woodlands, coastal dunes and lowland monsoon forests. Fragrant flowers probably attractive to insects. Australian endemic; widespread in the Alligator rivers region.

Derris uliginosa (Fabaceae). Scrambling, perennial vine of mangrove habitats. Prolific in low salinity, well-drained riverine mangrove communities subject to frequent tidal inundation by brackish water. Widespread along far northern coasts of Australia; common in the Alligator rivers region.

Diospyros ferrea (Ebenaceae). Evergreen, dioecious tree, up to 15 metres tall. Diverse habitat range from low salinity mangroves to montane rainforest. Occurs throughout the Asian tropics, Polynesia and northern Australia (Tomlinson, 1986); common in mangroves of the sinuous section of the Adelaide River, not recorded in the Alligator rivers region.

Dodonaea lanceolata (Sapindaceae). Shrub to 2 m tall; Eucalyptus open
forests and woodlands, gallery forests and creek bank communities. Widespread shrub of the N.T. hinterland, common in the southern (inland) section of the Alligator rivers region.

**D. platyptera.** Spreading, shrub or small tree to 3 m tall; in coastal monsoon forests and beach ridge communities, river and creek verges. Infrequent in the Alligator rivers region.

**Drynaria quercifolia** (Polypodiaceae). Terrestrial or epiphytic fern with fronds 40 to 100 cm long; moist rainforests, shaded sandstone gorges, coastal vine thickets, *Barringtonia* and *Melaleuca* swamps. Widespread in northern Australia; infrequent in the Alligator rivers region.

**Erythrina variegata** (Fabaceae). Deciduous, spreading tree to 8 m tall; *Eucalyptus* open woodlands, monsoon forests, beach ridge communities. Conspicuous red flowers appear mid to late dry season as new leaves develop. Flowers visited by birds and insects. Pantropical; widespread but infrequent in the Alligator rivers region.

**Eucalyptus** (Myrtaceae). Canopy trees of open forests and woodlands characteristic of lateritic and sandstone upland environments in the Alligator rivers region, where at least 22 species are recorded.

**E. bleeseri.** Evergreen, canopy tree 15 to 20 m tall; *Eucalyptus* open forests and woodlands, particularly on drier sites and in shallow, rocky soils. Confined to a small area of northern W.A. and far northern N.T. Common and widespread in the Alligator rivers region.
E. miniata. Evergreen, canopy tree to 20 m tall; Eucalyptus open forests and woodlands on well drained soils. Conspicuous orange flowers are attractive to birds, bats and insects. Disjunct distribution across northern Australia, mainly north of latitude 17°S. Widespread and very common in the Alligator rivers region.

E. papuana. Evergreen canopy tree to 20 m tall in diverse habitats including damp soils of floodplain and swamp margins, mixed Eucalyptus open forests and woodlands and lowland monsoon forests. Also in semi arid and arid environments of the hinterland. Throughout coastal and inland tropical Australia and southern Papua New Guinea; common in the Alligator rivers region.

E. tetrodonta. Evergreen, canopy tree to 20 m tall; Eucalyptus open forests and woodlands. Conspicuous, white flowers attractive to bats and probably other animal pollination vectors. Widely distributed across northern Australia, north of latitude 17°S. Common and widespread in the Alligator rivers region.

Excoecaria agallocha (Euphorbiaceae). "The milky mangrove". Deciduous shrub or small tree to 4 m tall; at landward edge of coastal and riverine mangrove communities. In northern Australia flowers appear during the late dry season, seeds are shed during the wet season. Low salinities required for seed germination and optimum growth. Minimal leaf growth when salinities exceed seawater concentrations. Deciduous under very dry conditions. Widespread in the western pacific, along northern and eastern Australian coasts. Common in the Alligator rivers region.
Exocarpos latifolius (Santalaceae). Parasitic, evergreen shrub or small tree to 5 m tall; Eucalyptus open forests and woodlands, coastal monsoon forests, river frontages and swamps. Pantropical; widespread but infrequent in the Alligator rivers region.

Ficus opposita (Moraceae). Spreading, deciduous tree to 10 m tall; Eucalyptus open forests and woodlands of lateritic and sandstone environments, non-eucalypt beach ridge communities. Pollination probably achieved through symbiotic association with wasps as with other figs. Pantropical; common and widespread throughout the Alligator rivers region.

Gardenia (Rubiaceae). Prostrate and erect shrubs and small trees; widespread and common understorey plants in Eucalyptus open forests and woodlands of the Alligator rivers region, where at least five species are recorded (G. edulis, G. fucata, G. keartlandii, G. megasperma, G. pyriformis).

Gonocarpus leptothecus (Haloragaceae). Perennial, evergreen shrub; Eucalyptus open woodlands, particularly on sandstone uplands. Pantropical; widespread in the Alligator rivers region.

Gymnanthera nitida (Asclepidaeae). Gangling perennial, deciduous shrub or climber, generally less than 2 m tall. On riverine floodplains; in monsoon forests and low salinity mangrove environments. Pantropical, widespread in the Alligator rivers region.

Halosarcia halocnemoides (Chenopodiaceae). Perennial, halophytic, succulent herb or small shrub to 50 cm tall. In landward mangrove communities and on adjacent high-tide salt mudflats.
Highly salt tolerant. Predominantly wind-pollinated. Widespread throughout coastal northern Australia; common in the Alligator rivers region.


*Heliotropium* (Boraginaceae). Includes at least four pantropic species (*H. carpentariae, H. paniculatum, H. tenuifolium, H. ventricosum*) native to the Alligator rivers region. Small annual herbs, widespread throughout Eucalyptus open forest and woodlands of the sandstone uplands and lateritic soils.

*H. indicum.* Introduced annual herb to 40 cm tall; at woodland margins, along river banks and on black soil plains. Common and widespread weed of the pastoral industry in the Alligator rivers region and the N.T. generally.

*Helminthostachys zeylanica* (Ophioglossaceae). Perennial fern to 40 cm tall, with spreading rhizome; *Melaleuca* and *Barringtonia* swamp forests, moist rock crevices and creek beds in the sandstone uplands, understorey in monsoon forests. Pantropical; throughout northern Australia; widespread but not common in the Alligator rivers region.

*Ipomoea aquatica* (Convolvulaceae). Prostrate, scrambling vine to 3 m length. Permanent and ephemeral freshwater swamps, swamp margins, seasonally flooded river plains, swamp grasslands and sedgelands. Large, conspicuous flowers attractive to insects. Pantropical; common and widespread in the Alligator rivers region.
Jasminum molle (Oleaceae). Evergreen, scrambling vine or low spreading shrub to 1 m tall; Eucalyptus open woodland and monsoon forests, and on river floodplains. Fragrant flowers probably attractive to insects. Pantropical; widespread but not common in the Alligator rivers region.

Leptocarpus elatior (Restionaceae). Sedge-like, erect, perennial herb to 50 cm tall; on sites of impeded drainage and saturated sandy soils of stream and swamp margins, river floodplains and adjacent to coastal mangroves. Widespread, but infrequent in the Alligator rivers region.

L. ramosus. Sedge-like, erect, perennial herb to 40 cm tall; drainage depressions, seasonally flooded soils, and along stream banks. Throughout the Alligator rivers region but not common.

L. spathaceus. Sedge-like perennial herb to 80 cm tall; in and adjacent to freshwater swamps, streams and drainage depressions and on seasonally flooded river plains. Forms dense clumps to the exclusion of other plants. Infrequent on drier soils in Eucalyptus open woodland. Widespread in the Alligator rivers region; common only in specific habitats.

Lomandra tropica (Xanthorrhoeaceae). Perennial, sedge-like tussock to 30 cm tall; monsoon forests, Eucalyptus open forests and woodlands and swamp margins. Widespread and common in the Alligator rivers region.

Lophopetalum arnhemicum (Celastraceae). Small tree to 5 m tall; in creek beds, riverine forests and deep sands beside permanent
water in sandstone uplands, and *Eucalyptus* open forests. Pantropical; widespread in the Alligator rivers region.

*Lumnitzera racemosa* (Combretaceae). Shrub or small tree to 5 m tall; in low salinity, dry mangrove environments. Optimum growth at 5% seawater salinity; leaf growth ceases when ground water salinities exceed seawater concentration. Fruits are shed late in the wet season. This species is deciduous under very dry conditions. Widespread and common throughout coastal and riverine mangroves of northern Australia. Common in specific environments in the Alligator rivers region.

*Lygodium flexuosum* (Schizaeaceae). Perennial, climbing fern to 1 m tall; along permanent and ephemeral watercourses, in monsoon forests and wetter open woodlands, sheltered sandstone gorges. Pantropical; widespread in the humid Australian tropics. Common only in restricted habitats in the Alligator rivers region.

*L. microphyllum*. Perennial, climbing fern to 1.5 m tall; moist sandstone gorges, monsoon forests, gallery forests, *Pandanus* and *Melaleuca* swamps. Pantropical; widespread throughout tropical Australia, common in the Alligator rivers region.

*Malachra fasciata* (Malvaceae). Exotic, annual herb or small shrub to 50 cm tall. Common weed of river floodplains, lowland monsoon forest, swamp and woodland margins. Pantropical; widespread and common throughout the Alligator rivers region.

*Mallotus nesophilus* (Euphorbiaceae). Evergreen tree 4 to 8 m tall; lowland monsoon forests and rainforests, riverine gallery forests, adjacent to *Melaleuca* swamp forests and on sandy
coastal soils adjacent to mangroves. Fragrant green and white flowers are attractive to insects. Pantropical; widespread and common in the Alligator rivers region.

Maytenus ferdinandi (Celastraceae). Slender tree to 7 m tall; sandstone monsoon forests, Eucalyptus open forests and woodlands. Infrequent in the Alligator rivers region.

Melaleuca acacioides (Myrtaceae). Medium-sized tree 8 to 10 m tall; infrequent on seasonally inundated river plains. Not common in the Alligator rivers region.

M. cajuputi. Evergreen, canopy tree to 20 m tall; sparsely distributed or in dense stands in permanent and ephemeral freshwater swamps, especially on or marginal to river floodplains.

M. symphyocarpa. Evergreen tree to 10 m tall; fringing permanent swamps on lateritic uplands. Common in specific habitats in the Alligator rivers region.

Melastoma denticulatum (Melastomataceae). Evergreen shrub or small tree; Eucalyptus open woodlands and monsoon forests of the sandstone uplands. Pantropical; infrequent in the Alligator rivers region.

M. polyanthum. Evergreen shrub to 2 m tall; creek banks and moist locations in Eucalyptus open forests and Melaleuca swamp forests. Conspicuous purple flowers attractive to insects. Widespread in tropical Australia; not very common in the Alligator rivers region.

Microsorium scolopendria (Polypodiaceae). Erect terrestrial or epiphytic fern to 30 cm tall; rainforests, closed swamp
forests, and on floating mats in perennial freshwater swamps. Throughout coastal regions of northern Australia; infrequent in the Alligator rivers region.

*Mitracarpus hirtus* (Rubiaceae). Exotic herb to 50 cm tall; Eucalyptus woodlands and dry monsoon forests on lateritic and sandy soils, particularly along roadsides and in disturbed areas. Common only in restricted areas of the Alligator rivers region.

*Myoporum acuminatum* (Myoporaceae). Shrub to 2 m tall; sandy coastal soils, often adjacent to mangroves and saltmarshes. Widespread throughout coastal regions of northern Australia, not recorded in the Alligator rivers region.

*Myriophyllum* spp. (Haloragaceae). Submerged and emergent fresh freshwater aquatic herbs. Flowers sub-aerial. Species common in freshwater swamps and slow flowing rivers throughout the Alligator rivers region include *M. callitrichoides*, *M. dicoccum* and *M. filliforme*.

*Ophioglossum costatum* (Ophioglossaceae). Small, perennial fern to 20 cm tall with spreading rhizome; boggy soils at rainforest edges, in open forest and seepage zones in the sandstone uplands. Not common in the Alligator rivers region.

*O. intermedium*. Small, erect fern to 10 cm tall; deep shade at rainforest floor, perennially wet jungles, coastal palm swamps. Not common in the Alligator rivers region.

*O. lineare*. Terrestrial fern to 10 cm tall; shady, moist localities. Infrequent in the Alligator rivers region; apparently confined to sandstone uplands in the south.
Osbornia octodonta (Myrtaceae). Evergreen shrub or small tree to 5 m tall; coastal and estuarine mangrove communities, beach ridge and salt mudflat margins. Flowers appear late in the wet season, seeds drop early dry season. Widespread along northern and north eastern coasts of Australia; infrequent in the mangroves of the Alligator rivers region.

Pandanus aquaticus (Pandanaceae). Palm-like, branching tree to 3 m tall; in, and marginal to, freshwater creeks, rivers and swamps. Common in specific habitats in the Alligator rivers region.

P. arnhemensis. Palm-like, branching tree to 4 m tall; sandstone uplands, quartzitic coastal dunes and Eucalyptus open forests and woodlands. Widespread and common in the Alligator rivers region.

P. spiralis. Palm-like, branching tree to 10 m tall with prominent, adventitious roots arising from the trunk. In upland and lowland monsoon forests, and throughout Eucalyptus open forests and woodlands. Ubiquitous in terrestrial habitats in the Alligator rivers region.

Passiflora foetida (Passifloraceae). Exotic, aggressive, scrambling vine in lowland monsoon forests, Pandanus fringing forests,
river floodplain communities and coastal beach ridges. Common throughout the Alligator rivers region.

**P. pterocarpum.** Spreading, deciduous tree to 10 m tall. On calcareous and quartzitic beach ridges, along floodplain margins, and in coastal monsoon thickets. Conspicuous yellow flowers attractive to insects. Pantropical; common in coastal and near-coastal habitats in the Alligator rivers region.

**Petalostigma pubescens** (Euphorbiaceae). Small evergreen tree to 5 m tall; *Eucalyptus* open forests and woodlands. Australian endemic, widespread in the Alligator rivers region.

**P. quadriloculare.** Perennial, dioecious, evergreen shrub to 3 m tall; *Eucalyptus* open forests and woodlands on lateritic soils and the sandstone uplands. Australian endemic; common in the Alligator rivers region.

**Phyllanthus flagellaris** (Euphorbiaceae). Perennial, prostrate herb; *Eucalyptus* open forests and woodlands; on lateritic soils and in crevices in the sandstone uplands. Widespread in the Alligator rivers region.

**P. grandisepalus.** Erect, evergreen shrub to 1 m tall; *Eucalyptus* open woodlands, rainforest margins. Widespread but not common in the Alligator rivers region.

**P. minutiflorus.** Spreading, procumbent, annual herb to 15 cm length; mixed open woodlands, margins of *Melaleuca* swamps and river floodplains; on humic, sandy and lateritic soils. Pantropical; widespread but infrequent in the Alligator rivers region.
**P. reticulatus.** Shrub or slender tree to 3 m tall or scrambling climber; in gallery forests, limestone outcrops, on river levees and floodplains. Widespread but infrequent in the Alligator rivers region.

**P. simplex.** Perennial, evergreen herb to 30 cm tall; *Eucalyptus* woodlands, *Melaleuca* swamps and swamp margins, on alluvium and grey loam soils. Often prominent on disturbed sites. Pantropical; widespread in the Alligator rivers region.

**P. urinaria.** Perennial, evergreen herb to 60 cm tall; lowland monsoon forests, swamp forest margins, permanent and ephemeral swamps. Pantropical; common in the Alligator rivers region.

**Poaceae.** Widespread, terrestrial, perennial and annual herbs (grasses). At least 100 genera and 450 species recorded in the N.T.

**Polygonum attenuatum** (Polygonaceae). Tall, emergent, aquatic herb in flooded depressions, at swamp margins and on seasonally inundated floodplains. Widespread in freshwater wetlands of the Alligator rivers region.

**P. barbatum.** Spreading, freshwater aquatic, perennial herb to 1 m tall; in swampy creeks and rivers, on floating grass mats; less frequent in *Pandanus*, *Melaleuca* and *Barringtonia* swamp forests. Widespread in the Alligator rivers region.

**P. orientale.** Exotic, annual, aquatic, trailing herb to 2 m; freshwater swamp margins, seasonally flooded plains, and on floating grass mats. Widespread in the Alligator rivers region.

**Premna serratifolia** (Verbenaceae). Spreading tree to 4 m tall in
Eucalyptus open forests and woodlands, and at monsoon forest margins. Members of this genus are commonly pollinated by ants. Pantropical; widespread in northern Australia; widespread but not very common in the Alligator rivers region.

Restionaceae - Sedge-like perennial herbs common on ill-drained soils throughout the Alligator rivers region. See also Leptocarpus.

Rhizophora apiculata (Rhizophoraceae). Evergreen shrub or tree to 10 m tall with conspicuous, looping prop roots. Mangrove habitats; usually on perennially wet, boggy sites where tidal inundation is frequent. Occurs as stunted bush at higher salinities near salt mudflat margins. Optimum growth where ground water salinities are approximately 30% sea water concentration. Tolerates long periods of inundation by fresh water. R. apiculata generally establishes landward of R. stylosa forests. Flowers appear late in the dry season; copious pollen is predominantly wind-dispersed. Propagules are shed in the wet season. Widespread in the western Pacific including the northeast coast of Queensland. Recorded at a few sites only on the N.T. coast east of Melville Island. Present but not common in the Alligator rivers region.

R. stylosa. Tall, evergreen tree to 15 m high with conspicuous prop roots; forms dense mangrove forests on well drained, frequently inundated sites of the open coast and along tidal rivers. Persistent on drier sites in stunted form. Wind-pollinated flowers appear early in the wet season; most propagules drop in the mid dry season when salinities are moderate to high. Common throughout the western Pacific region; along northern and eastern Australian shores from
northern N.S.W. to northern W.A. Common in mangroves of the Alligator rivers region, particularly along open coasts where it forms tall, dense continuous forests, behind a seaward fringe of *Sonneratia alba* and *Camptostemon schultzii*.

*Rumex* (Polygonaceae). Native and introduced aquatic and sub-aquatic herbs, on ill-drained soils. Not listed for the South Alligator River region.

*Salsola kali* (Chenopodiaceae). Low, spreading, perennial, succulent herb of varied habitats on sandstone uplands, coastal dunes, river floodplains, and hypersaline flats adjacent to mangroves. Widespread but not common in the N.T.

*Selaginella ciliaris* (Selaginellaceae). Tiny, tufted fern ally to 5 cm tall; *Eucalyptus* open forests and woodlands, *Melaleuca* swamp forests, river floodplains, drainage depressions and moist sandstone gullies. Throughout northern Australia; common in the Alligator rivers region.

*S. uliginosa*. Tufted, herbaceous fern ally to 30 cm tall with perennial rhizome; moist soils along drainage channels, lowland and coastal freshwater swamps, wet grasslands and coastal heathlands. Common in specific habitats in northern Australia. This species is rare or absent in the Alligator rivers region, but is profuse in coastal swamps on Melville Island, N.T.

*Sonneratia alba* (Sonneratiaceae). Tall, spreading mangrove tree to 10 m high; in mangrove forests subject to deep, regular tidal inundation. Co-dominant with *Camptostemon schultzii* at seaward mangrove edge along open coasts. Occurs sporadically
within estuaries but is not common very far inland along tidal rivers with substantial freshwater discharge. Maximum growth at approximately 50% sea water salinity. Fruit are shed late in the dry season or early wet season. Widespread in the western Pacific and Indian Ocean regions; along northern Queensland and N.T. coasts coast excluding the Gulf of Carpentaria. Common on open coasts of the Alligator rivers region.

*S. lanceolata.* Evergreen shrub or small tree to 6 m tall; mainly in mangrove habitats of moderate salinity along tidal rivers, where tidal inundation is frequent. Maximum growth where groundwater salinities are approximately 10% seawater concentration. Copious seedling growth on bare, accreting mud banks. Seedlings may be intolerant of shade. Fruit are shed during the mid to late wet season when salinities are lowest. Throughout the west Pacific; northeastern Queensland and far northern coasts of the N.T. Common along tidal rivers of the Alligator rivers region.

*Sporobolus virginicus* (Poaceae). Low, perennial, salt-tolerant grass of coastal plains and marshes adjacent to mangrove and saltmarsh environments. Widespread and common in specific environments in the Alligator rivers region, and throughout northern Australia generally.

*Sterculia quadrifida* (Sterculiaceae). Deciduous tree to 8 m tall; dry monsoon forests, coastal vine thickets and beach ridge communities. Flowers appear in dry season before new foliage appears. Small, conspicuous flowers are probably attractive to insects and birds. Pantropical; common and widespread in the Alligator rivers region.
Suaeda arbusculoides (Chenopodiaceae). Perennial, halophytic, succulent herb to 30 cm tall, high-tide saltmarshes and mangrove margins. Widespread in coastal N.T.; common in the Alligator rivers region.

Syzigium suborbiculare (Myrtaceae). The "bush apple". Medium to large evergreen tree to 10 m tall; coastal sand ridge communities, moister sites in Eucalyptus open forests and woodlands, monsoon forests. Conspicuous flowers attractive to birds and insects. Pantropical; common and widespread in the Alligator rivers region.

Tecticornia australasica (Chenopodiaceae). Perennial, halophytic, succulent herb to 50 cm tall; landward mangrove communities, high-tide saltmarshes and Sporobolus grasslands.

Terminalia grandiflora (Combretaceae). Narrow-leaved, evergreen tree to 10 m tall. Widespread in Eucalyptus open forests and woodlands; sandy beach ridge soils adjacent to the South Alligator River mouth. Pantropical; widespread but not very common in the Alligator rivers region.

Tinospora smilacina (Menispermaceae). Robust, deciduous vine; Eucalyptus open forests and woodlands, monsoon forests, floodplain margins and in non-eucalypt beach ridge communities. Pantropical; widespread in the Alligator rivers region, but not common.

Trema aspera (Ulmaceae). Evergreen shrub or small tree to 4 m tall; Eucalyptus open woodlands and monsoon forests. Pantropical;
widespread in northern Australia, including the Alligator rivers region.

*Typha domingensis* (Typhaceae). Erect, rhizomatous, perennial "bull rush" to 3 m tall; river floodplains, freshwater swamps and swamp forests, occasionally adjacent to mangroves. Throughout mainland Australia, infrequent in the Alligator rivers region.

*T. orientalis*. Erect, perennial "bull rush" to 2.5 m tall; in and marginal to freshwater swamps. Pantropical; throughout the Australian mainland; infrequent in the Alligator rivers region.

*Wrightia pubescens* (Apocynaceae). Small, deciduous tree to 4 m tall; in *Eucalyptus* open forests and woodlands and lowland monsoon forests. On lateritic and sandy soils. Conspicuous large white flowers are probably attractive to animal pollinating vectors. Pantropical; infrequent in the Alligator rivers region.

*Xylocarpus australasicus* (Meliaceae). Deciduous mangrove shrub or tree to 20 m tall; low salinity, riparian mangrove communities subject to reliable tidal inundation by brackish water. Ground water salinities may range from 0 to 100% sea water. Can withstand long periods of inundation by fresh water. Flowers appear during the dry season and are attractive to insects. Seeds drop early in the wet season, and remain viable after extended periods afloat (up to 6 months). This species may be confined to northern Australian coasts and southern Papua New Guinea. Moderately common in the Alligator rivers region.
X. granatum. Deciduous shrub or small tree to 10 m tall; in low salinity, moist, riparian mangroves. Tolerant of long periods of inundation by fresh water. Widespread in the west Pacific, this species is not common in the N.T.; not recorded in the Alligator rivers region.