3.4 Environmental responses

Environmental responses to climate and sea level changes are manifested through hydrological, hydrodynamic, geomorphological and ecological processes. Development of the coastal plains also rests on a balance between these processes such that the coast progrades when sea levels are lowering, rainfall is high and fluvial forces prevail. Conversely, the shoreline retreats and tidal creeks extend landwards when sea level is rising, rainfall is low and coastal processes prevail. There is a wide range of interactions and responses between these extreme conditions. Hence, an understanding of the coastal hydrodynamics, and particularly the hydrology of streams and wetlands, is a fundamental requirement for understanding the biological and chemical processes that characterise stream and wetland ecosystems. The complexities of the hydrological cycle for the ARR are not thoroughly understood, especially in relation to groundwater interactions with the aquatic and wetland ecosystems. Effective management practices for such aquatic ecosystems are often limited by an inadequate understanding of the underlying hydrological processes.

Although the Kakadu wetlands have undergone major ecological change over the past few decades (Finlayson et al 1991; Finlayson et al 1988) and controversy still surrounds plans by mining companies in the region to release excess runoff water to the aquatic ecosystem (Johnston 1991), this has not provided sufficient impetus to thoroughly investigate the complex hydrology of the region.

Adjacent to the ARR, pastoralists have registered concerns over increasing encroachment of saline waters into freshwater wetlands that are used for seasonal pastures (Knighton et al 1991, 1992; Woodroffe & Mulrennan 1993). Remedial measures to deal with this problem have included emplacement of open mesh rubble mattresses and earth bunds to impede tide water penetration. The porosity of the mattresses and inherent instability of the bund walls brings these mitigation measures into question. More successful approaches to the problem will require an increased understanding of coastal and floodplain hydrodynamics and geomorphology that is based on rigorous, scientific research (Sessional Committee on the Environment 1995).

Ecological process affected by environmental change include the expansion and contraction of plant communities with consequent effects on animal habitats. Again, insufficient knowledge of the interaction between wetland plant communities and changes in hydrological and depositional conditions makes prediction of the long-term effects difficult. Wetland plant communities are viewed as being widespread in the region and highly dynamic in terms of variability in species composition, structure of the community and geographic spatial extent. The plant species are widespread at pan-regional and regional scales and no communities or individual species of rare or endangered species have been recorded. Similarly, animal species are widespread and no rare and endangered species are known from areas that could be affected by environmental change.

4.0 Processes of change and resources affected

The biophysical environment is dynamic, continually changing in response to variations in weather and climate. In order to better understand the processes of change the interactions between physical and biological processes are perceived in relation to the resources affected. Likewise, the cultural and social components of the environment are dynamic and also respond to the biophysical changes. These complex sets of process and resource interactions are discussed in the context of environmental changes in the ARR.

4.1 Physical processes

4.1.1 Weather and climate

Weather conditions in the ARR determine the intensity of climatic factors that affect river flow, sediment transport by streams, and plant growth in the freshwater meadows of the coastal plains. Additionally, the weather conditions and river discharges interact with the high tides of Van Diemen Gulf to determine shoreline processes along the coast as well as cause saltwater intrusion of coastal swamps and lowlands. In this respect, the variability of climatic factors, such as barometric pressure, temperature, storminess, winds and rainfall, over the historical period provides a baseline from which future variability may be assessed and long-term trends identified. The historical record of recent climate change and its biophysical effects are at least as significant as the broad picture of environmental change afforded by investigation of Holocene landform evolution. The two lines of investigation need to be drawn together. In the first instance, the natural variability of biophysical processes along the coast of the ARR should be established as a necessary precursor to identification of any long-term trends and any other environmental changes that might be due to predicted future climate change and other factors. The broader geological interpretations then provide an important context for interpretation of the historical changes.

Climatic conditions for the ARR have been described by the Australian Bureau of Meteorology (1961), McAlpine (1969), Christian and Aldrick (1977), Woodroffe et al (1986), Nanson et al (1990), Riley (1991), Wasson (1992) and Butterworth (1995). Although the climatic records for the region are relatively short—50 years for Gunbalunya (Oenpelli) and 20 years for Jabiru—longer-term records are available for Darwin. The description below is drawn from the available literature.

The climate of the ARR is defined as wet-dry tropical with a Wet season duration of 4.5 to 7 months (Nanson et al 1990). The mean annual rainfall is approximately 1500 mm and pan evaporation averages 2600 mm per year. As elsewhere in the ARR, at Jabiru the rainfall is strongly seasonal with annual rainfall varying between 1129 mm in 1971/72 to 2223 mm in 1975/76. The Dry season extends from May to September when little or no rain falls on the coast (Wasson 1992). The Wet season extends from October through April and is characterised by over 90% of the annual rainfall. However, what is less evident is the cyclic nature of the Wet season. Butterworth (1995) describes three phases: pre- and post- monsoon periods, which are transition periods characterised by isolated thunderstorm activity; active monsoon periods characterised by widespread and often heavy rain; and the monsoon break/inactive periods, characterised by a return to scattered thunderstorms and squalls.

Tropical cyclones are likely to occur during the monsoon periods. Carter (1990) has demonstrated (fig 3) that there is high interannual variation in rainfall at Darwin, with markedly different trends over periods of 5 to 30 years. The drier periods have annual average rainfalls of around 1380 mm and the wetter periods have average annual rainfalls of about 1660 mm; most of these periods have annual rainfall that is significantly different from the long-term average.

The CSIRO (1994) has indicated that there is some evidence from its modelling that:

> monsoonal circulation strengthens under enhanced greenhouse with a concomitant increase in rainfall. The CSIRO 9 2XCO_2 simulation shows a 20% increase in summer (December, January and February) rainfall over the Australian tropics for a doubling of carbon dioxide, but this increase is not uniform across the region.

Although there is potential for a large increase in rainfall during the monsoon periods, there is no current prediction for significant change in either incidence or intensity of tropical cyclones in the Northern Territory under global warming (Garden pers comm). Investigation of the future number, intensity and potential tracks of tropical cyclones remains a priority for research.

Temperatures are high throughout the year with a lowest mean monthly maximum of 31.3°C in June and July, and a highest of 37.1°C in October (Nanson et al 1990). Extremes typically are as much as 10°C higher and more than 10°C lower than the means (Woodroffe et al 1986). An analysis of extreme temperatures (CSIRO 1994) indicates that the frequency of summer days over 35°C would increase by at least 50% at Jabiru by the year 2030. Moffatt (1992) has expressed this in terms of there being an increase of 8 to 12 days over 35°C for each 1°C rise in temperature due to greenhouse warming.

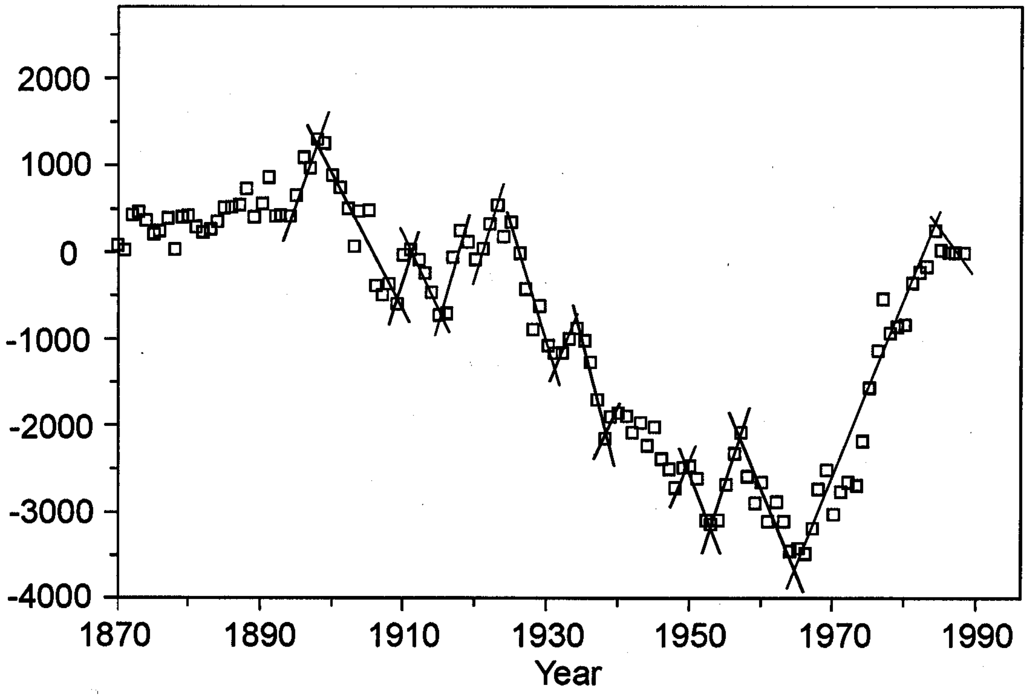


Figure 3 Cusum plot of Darwin rainfall (from Carter 1990)

4.1.2 Sea level fluctuation, water circulation and littoral transport in Van Diemen Gulf

Very little information describing either water circulation or littoral transport in Van Diemen Gulf is available, and systematic observations of sea level variation in the ARR are lacking. Patterns of water and sediment movement shown on satellite images indicate that these are highly complex (Plate 3).

The hydrodynamics of the Gulf are considered to be the primary driving force underlying contemporary shoreline and estuarine processes. The importance of tidal and sea level fluctuation has been acknowledged and examined for fluvial systems (Woodroffe et al 1986; Woodroffe & Mulrennan 1993). How these relate to storm surge activity, seasonal variation in sea level and interannual variation in Gulf water levels is unknown.

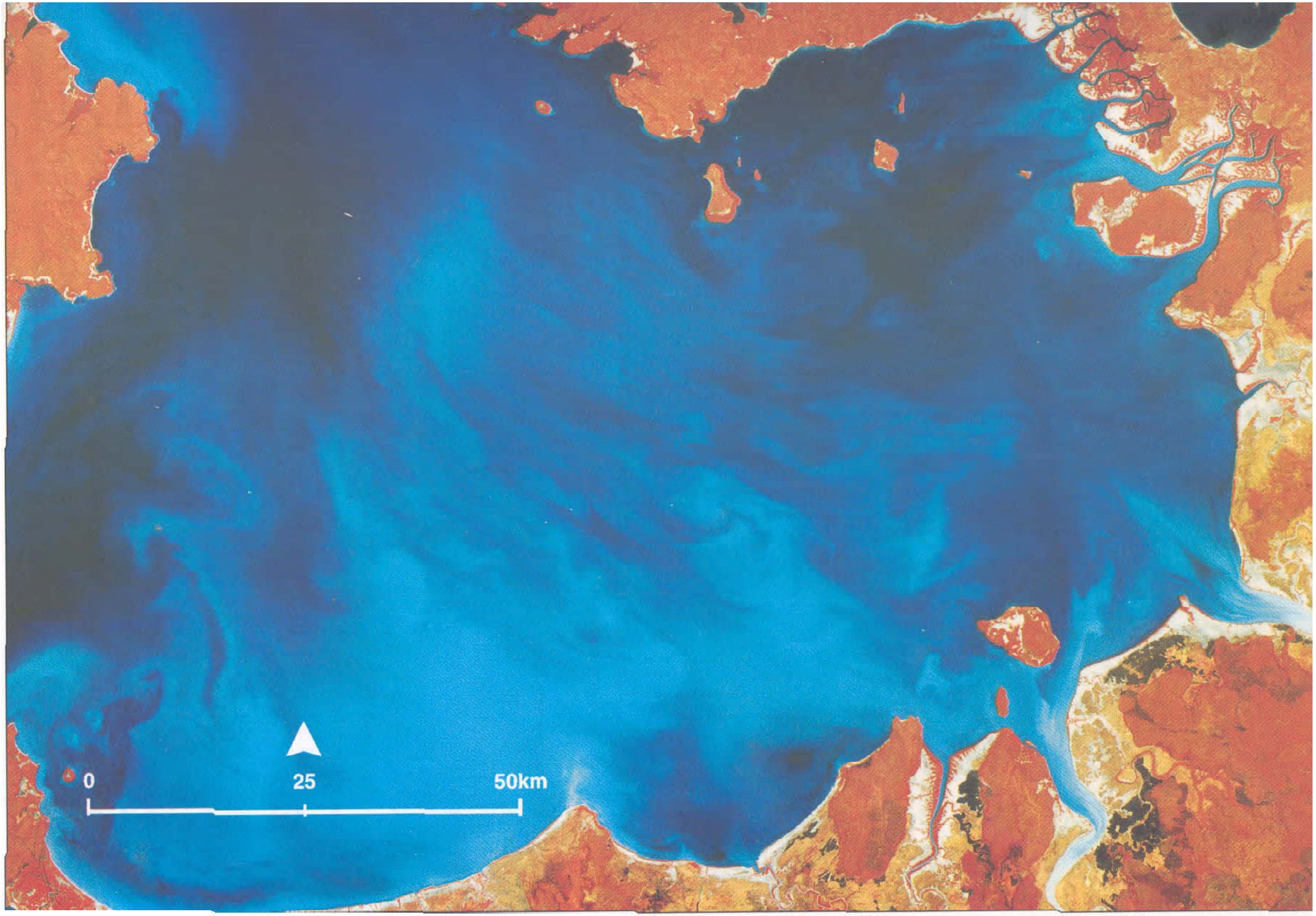


Plate 3 Satellite imagery of Van Diemen Gulf, Landsat 5 MSS 11-Jun-1994 (data supplied by ACRES and used with permission of Parks Australia)

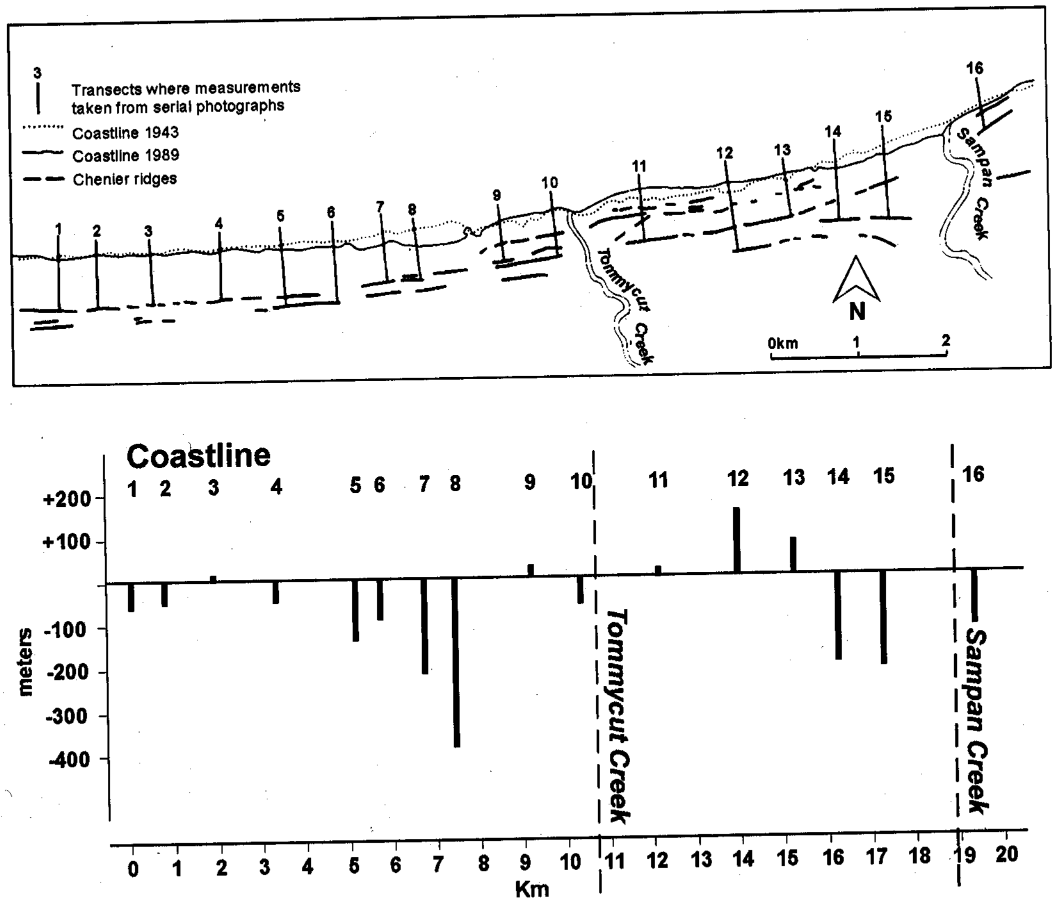


Figure 4 Changes to the coastline where the Mary River enters Van Diemen Gulf via Sampan and Tommycut Creeks (from Woodroffe & Mulrennan 1993)

4.1.3 Shoreline retreat

Patterns of shoreline movement occurring between 1943 and 1989, in the vicinity of Tommycut Creek and Sampan Creek on the Lower Mary River plains, have been reported by Knighton et al (1992) and Woodroffe and Mulrennan (1993). Also, it is anticipated from field observation that the alternating patterns of erosion, deposition and relative stability recorded in the vicinity of the Mary River (fig 4) will occur along the shoreline of the wider region and Kakadu National Park. Such variation is due to local differences in coastal orientation, nearshore wave and water circulation processes, and sediment supply to the coast.

Further work is necessary to establish the geographic extent and direction of shoreline movement in much of the ARR. However, it is apparent that the proportion of coast currently undergoing recession exceeds that which is prograding or stable. The photogrammetric analysis reports by Woodroffe and Mulrennan (1993) indicate shoreline retreat of up to 400 m west of Tommycut Creek and over 200 m in the vicinity of Sampan Creek, with erosion rates of approximately 4 to 8 m per year. Although Woodroffe and Mulrennan (1993) argue otherwise, coastal erosion has apparently reduced the distribution of mangroves along the coast. It is anticipated that shoreline retreat has markedly contributed to saltwater intrusion into the freshwater meadows of the coastal plains through the erosion of cheniers and levees. It is difficult to envisage a situation where over 200 m of shoreline retreat along several kilometres of coast, as has occurred in the vicinity of the mouth of the Mary River over the past decade, is likely to have less effect on the intrusion of tidally-driven, saltwater into low-lying freshwater meadows than grazing buffalo or fisherfolk dynamiting channels. However, further work is needed to clarify the causes and rates of saltwater intrusion, including its relationship to coastal erosion, and to determine the geographic extent of its effects on the coastal wetlands.

Cursory observation of coastline landforms in the vicinity of the Mary River and along the Carmor Plain indicates that the shoreline retreat occurs in several ways. First, steady retreat of the profile with shelly chenier sediments being rolled landward through localised washover. Under such circumstances, the mangrove distribution is characterised by eroded stumps in the nearshore waters, a thin fringe of mature mangroves along the coast, with apparent regeneration of mangroves taking place on the landward side of the chenier. Second, in places where the mangrove fringe is thin it may be breached by storm surge that washes flotsam and jetsam across the salt flats and against landward cheniers. Mangrove colonisation occurs along the debris lines marking the landward limit to storm surge. Third, where the mangrove fringe is widest, the shoreline retreats by undercutting, cliff formation and surface reduction by runoff erosion. The areas undergoing the different types of retreat and the relative significance of each is not known.

Depositional processes occur on the eastern flanks of the streams and at Point Stuart. The preferential location of the depositional zones may be indicative of net littoral transport in an easterly direction, although this requires confirmation through field measurement and survey.

Over a shorter, more recent period, investigations of the chenier sequence at Point Stuart are significant because they may provide a broad record of major storm activity in the region during the past 1500 years. Lees (1987) argued that a variation in the type of sediments comprising the cheniers from mainly sandy to shelly sediments indicated change in their mode of development. The landward most cheniers were thought to be a result of delta switching, a change from more arid to pluvial conditions, or some combination of these. Lees (1987) pointed out that the five seaward chenier ridges appear to have formed within the past 1270 + 100 years in response to major storm activity and shell deposition, with the most recent phase of chenier formation at approximately 300 to 700 years ago.

4.1.4 Saltwater intrusion

The processes and extent of saltwater intrusion into freshwater meadows of the low-lying floodplains present the major coastal management problem in the ARR and adjacent areas. The problem has been described for the Mary River (Stocker 1970; Woodroffe et al 1991; Knighton et al 1992) the East Alligator River–Magela Creek system (O'Neil 1983; Williams 1984; Finlayson & Woodroffe 1996), and for the South Alligator River (Woodroffe et al 1986). Their observations are summarised below.

In areas of low tidal range, freshwater wetlands may be lost through gradual disintegration. This is observed where there is accelerated relative sea level rise, largely as a result of local subsidence. However, in areas of large tidal range, rapid tidal-creek extension is likely to pose a major threat, representing an additional mechanism of saltwater intrusion. Such an extension has occurred in the past 50 years over the coastal plains, particularly the catchment of the Mary River and on Carmor Plains.

For example (Knighton et al 1992), the coastal fringe of the Mary River catchment is drained by many tidal creeks, most of which are limited in their inland extent by chenier ridges running sub-parallel to the coastline. Since the late 1930s–early 1940s, two of those creeks (Sampan and Tommycut) have breached the chenier barrier and have extended more than 30 km inland. The tidal creeks have invaded freshwater wetlands and destroyed the associated vegetation and allowing mangroves to expand along the new creek systems. The most remarkable feature is the rapidity with which the saltwater network has developed (fig 5).

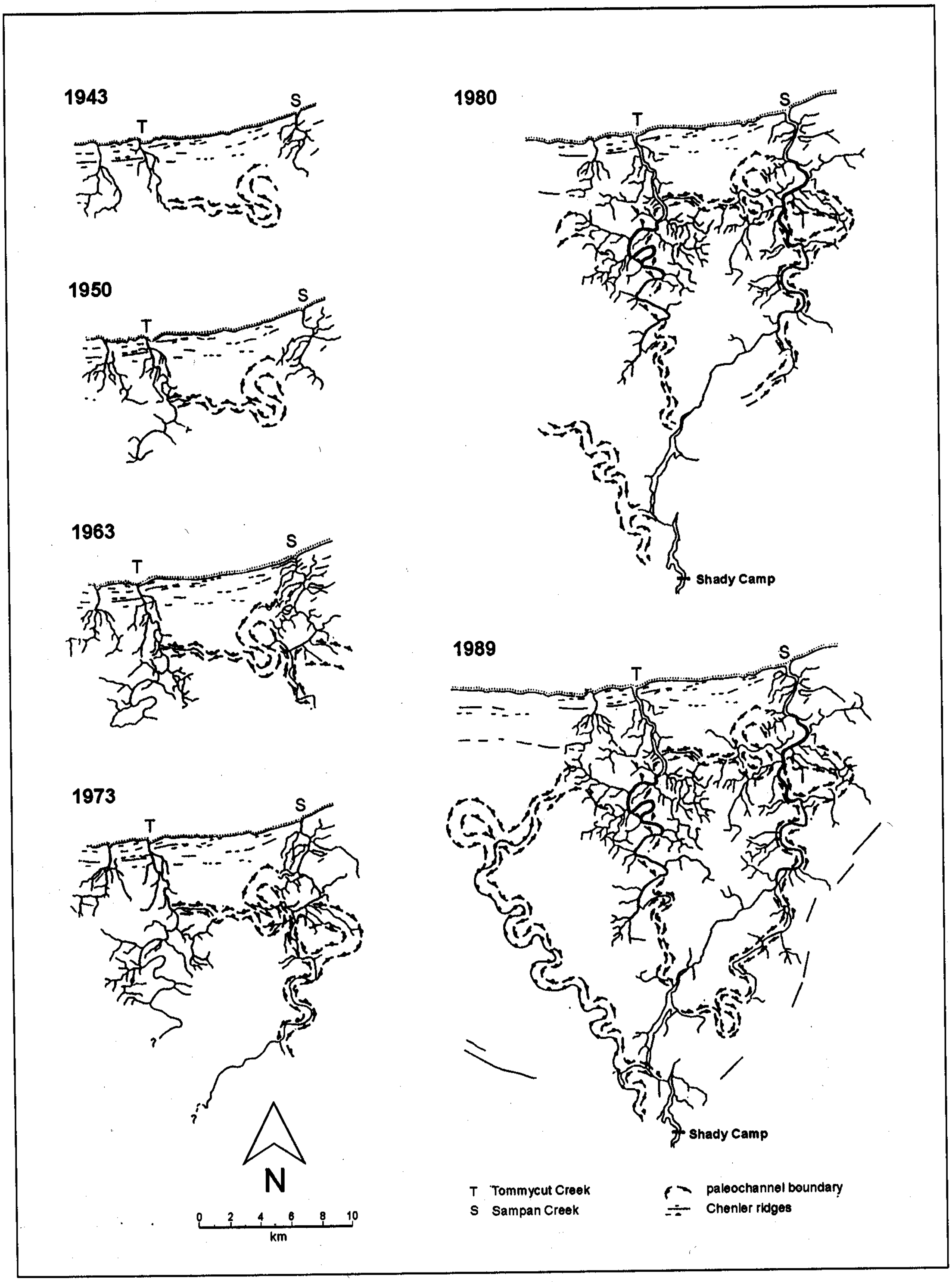


Figure 5 Expansion of Sampan and Tommycut Creeks, 1943–1989
(from Knighton et al 1992)

The tidal networks have developed through a combination of extension and widening of the main channels and tributary growth. Expansion of the system, measured by the magnitude of the network has been exponential. The process of tidal-channel formation begins with the surface invasion of saltwater during exceptionally high tides along lines of slightly lower elevation, resulting in a seepage zone. At this stage any channel is indistinct or very shallow with a high width to depth ratio. Tidal action scours the central part of a zone, and an initially diffuse flow becomes increasingly concentrated and results in more efficient drainage through channels. Subsequent incision is rapid, especially in those channels that drain directly into major creeks, presumably because of their proximity to large semidiurnal fluctuations in base level. Wet season floods operating at a longer time scale may accentuate the scour. Rates of extension in excess of 0.5 km/yr have been measured.

The tidal networks are still expanding and only in their lower reaches does a later phase of maximum extension seem to have been reached. The smallest tributaries are being eliminated by abstraction as mangrove trees (*Avicennia* spp.) spread along creek boundaries and trap the large quantities of fine sediment released by extension and incision.

According to Knighton et al (1992), several factors have contributed to the rapidity of network expansion. The large tidal range of 5–6 m in Van Diemen Gulf ensures that there are bi-directional currents with high velocities, and hence a high potential for channel cutting. Since there are only very small elevation differences over the Mary River plains the low lying land can quickly be exploited by invading saltwater channels. Additionally, many of the remote backwater plains lie at or below the elevation achieved by the highest tides. They are only protected from immediate inundation by levee-like features adjacent to the river channels. Former channel courses are often incompletely infilled. These lower lying surfaces are particularly prone to invasion by the tide, and have concentrated much of the more vigorous tributary activity. In addition, uncontrolled feral buffalo have formed swim channels in the Wet season. Some of the swim channels have subsequently been preferentially occupied by tidal creeks.

The trends of saltwater intrusion are well known from the published research. However, this is patchy and the maps from studies of the different areas are not directly comparable. The geographic extent of the problem, spatial variation in rates of change, and the area of freshwater wetlands affected by saltwater intrusion are unknown. Spatial information management tools are available to document changes that have occurred over the past 50 years. It is an essential task for management to document the processes and rates of saltwater intrusion because of the potential threat to freshwater habitat areas that attract high levels of tourist visitation, such as that at Yellow Water in Kakadu National Park

4.1.5 Hydrology of streams and wetlands

Fluvial processes of the major rivers of the broader region have been well described in the literature (Chappell et al 1995). References to more specific areas have been published for the Mary River (Woodroffe et al 1991; Knighton et al 1991, 1992) East Alligator River-Magela Creek system (Vardavas 1989a & b; Nanson et al 1990; Wasson 1992; Finlayson & Woodroffe 1996), and for the South Alligator River (Woodroffe et al 1986). The principle problems they address that are related to climate and associated environmental changes include:

- headward erosion of freshwater creeks;
- sedimentation of stream beds;
- overwash deposition and levee development;
- breakdown and erosion of mine waste and tailings dam.

Understanding the hydrology of streams and wetlands is a fundamental requirement for understanding the biological and chemical processes that characterise stream and wetland ecosystems. Stream flow interacts with tidal processes and apparently overwhelms them during the Wet season. The hydrological cycle for the ARR is complex and not fully understood, especially in relation to groundwater. Effective management practices for such aquatic ecosystems are often limited by inadequate understanding of the underlying hydrological processes.

The drainage network system of the region is not considered dense, reflecting the absence of impermeable soils (Chapman 1988); in general, a dense drainage network has a preponderance of impermeable soils. Kingston (1991) estimated the lag between rainfall and runoff as around 2 months, which supports the conclusions of Chapman (1988) that the drainage network is not dense.

The spring tidal range in Van Diemen Gulf is 5–6 m, affecting the river flow up to 105 km inland (Woodroffe et al 1989). During the Wet season, water in the estuaries is predominantly fresh, becoming more saline in the Dry season when rainfall runoff from the catchments declines and eventually ceases. Discharges from the rivers have not been measured because the tidal influence makes hydraulic rating extremely difficult. Average flows between 400–700 m^3/s for the South Alligator River were estimated from a comparison with the nearby Daly River (Woodroffe et al 1986). However, more direct monitoring of all major rivers in the area needs to be established for modelling and management purposes.

In Magela Creek variations in discharge are a direct response to the seasonal variations in climate with discharge peaks occurring late in the Wet season when the floodplain and billabongs are full with water. Peak discharges of more than 200 m^3/s are not uncommon, although most are less than 100 m^3/s. The relationship between rainfall and creek flow in Magela Creek, shown by the comparison of flow rate with water depth in the creek and rainfall in Jabiru, was carried out by Finlayson (1991) for the period October 1983 to February 1985. Though an empirical relationship is evident in this comparison, it has not been quantified.

The water of the rivers and creeks typically follows a quasi-cyclic pattern in direct response to the seasonal cycle, with the ionic concentrations gradually increasing during the Dry season (Hart & McGregor 1980, Brown et al 1985, Walker & Tyler 1984). This cyclic effect is more pronounced for water bodies with no groundwater inflow. Baseline monitoring will need to take into account possible hydrologic and hydrogeologic changes to the Magela floodplain due to saltwater intrusion. The program must also take into account the high interannual variability in rainfall of the region.

4.2 Biological processes

4.2.1 Mangroves

The sub-coastal floodplain and intertidal wetlands of Kakadu National Park occupy around 217 450 ha. Of this area, mangroves account for 3.3% (7200 ha), samphire 7.5% (16 400 ha), and freshwater wetlands 89.1% (193 850 ha). At numerous scattered locations at the margins of these primary wetland types patches of monsoon forest occur.

Flora

Mangrove communities form relatively narrow bands along the coast and on tidally influenced creek and river banks. Thirty-eight species of mangrove plants have been recorded from the region (Wightman 1989) and this represents about 81% of the total mangrove plant taxa known to occur in the whole of the Australasian biogeographic region (Duke 1992).

However, the mangrove plant communities of the ARR are not characterised by high levels of regional or local endemism. Most of the mangrove plant species in the ARR are widespread both around the coast in Australia and throughout the Indo-Malesian biogeographic region which includes the coasts of Indonesia, South East Asia and India (Duke 1992).

Mangrove plant communities along the coast in the ARR may be strongly zoned along the intertidal topographic gradient (Specht 1958b; Hegerl et al 1979). Zonation suggests that the conditions for propagule recruitment and/or the competitive abilities of different species are highly sensitive to relatively small changes in the tidal flooding regime. A common pattern of mangrove zonation along the ARR coast is *Sonneratia alba* (at the seaward edge) →*Rhizophora stylosa*→*Ceriops tagal*→*Avicennia marina* (at the landward margin) (Hegerl et al 1979).

Tidally influenced estuarine mangroves in the region can extend to large distances upstream from the sea. In the South Alligator River, estuarine mangroves occur over 100 km upstream from the mouth (Messel et al 1979). Mangrove zonation has also been documented for estuarine mangroves (Davie 1985; Hegerl et al 1979). Along upstream gradients, however, estuarine mangroves show the various species tolerances to a range of regimes of exposure to freshwater (Messel et al 1979, Duke 1992; Ball 1988; Davie 1985). For example, *Sonneratia alba* is restricted to near coastal locations while *Sonneratia lanceolata* (as *S. caseolaris*) occurs in extreme upstream situations of having high seasonal freshwater input. The patchy distribution of *Xylocarpus* probably reflects the infrequent occurrence of areas along the river having perennial (usually spring-fed) freshwater input (Wightman 1989).

Davie (1985) highlights the instability of the estuarine environment and shows that mangrove communities along the South Alligator River exist in a variety of stages of colonisation and degradation reflecting a history of responses to everchanging stream channel dynamics. His conclusion is highly relevant:

> The vegetation patterns described…illustrate an environment dominated by physical change driven by powerful physical and climatic forces which characterise the macrotidal monsoonal environment. Vegetation change is taking place over several scales in time and space.

Although no studies have been conducted in the ARR, information concerning the effects of storm damage to coastal mangrove stands have been conducted elsewhere in the Northern Territory. Bardsley (1985) showed that following cyclone impact many mangrove species, despite sustaining extensive damage resprouted vigorously. However, species in the family Rhizophoraceae were a notable exception: if the small branches were stripped they did not regenerate.

No mangrove productivity studies have been done in the ARR. Woodroffe et al (1988a) determined the production rates of litter from an estuarine mangrove stand in Darwin. They demonstrated a Wet season peak in litter production and that different mangrove zones had very different litter production rates. In the second year of the two year study litter production was consistently lower than the first but the percentage reduction was not consistent across all sites.

The flora of the tidal hypersaline salt flats is very simple, comprising only 7 species. No studies have been done on any aspect of this apparently barren, but possibly important environment in the ARR.

Fauna

A pilot survey and review of the literature concerning mangrove and estuarine fauna in the ARR was completed by Hegerl et al (1979, 1982). Very little work has been done since then:

for example, fish (Davis & May 1989; Bishop et al 1990), wading birds (Bamford 1988) and crocodiles (Jenkins & Forbes 1985; Lindner 1994). Not surprisingly, nearly all of the data concerning fauna in coastal mangrove and estuarine habitats of the region consist of species lists with limited reference to spatial and temporal distribution patterns or general biology. Similarly, the conservation status of most groups of mangrove and estuarine fauna in the region is uncertain at both regional and national levels due to the poor survey coverage around the north Australian coast. Indeed the lack of comprehensive data concerning faunistic elements of coastal and estuarine environments in the Northern Territory is such that predominantly physical data sets were used by Northern Territory government agencies to construct the recent biogeographic regionalisation map of the Northern Territory coastline (Ferns & Billyard 1995).

The comments below are purposely restricted to taxa or species groups in coastal and estuarine environments of the ARR that:

- have been identified as rare or endangered *(Commonwealth Endangered Species Protection Act 1992*) or notable (Roeger & Russell-Smith 1995);
- are supported by enough extra-regional distribution data to assess their significance of occurrence in the ARR;
- have been monitored in the ARR to show temporal or spatial trends; or
- are of recreational or commercial significance.

The lists of mangrove and estuarine fauna in the ARR are contained in the references provided.

The vertebrate fauna of mangroves, intertidal mudflats and near shore waters in the ARR comprises 16 species of reptiles and amphibians (Braithwaite et al 1991) and about 75 bird species (Morton & Brennan 1983). There are few records of mammals from mangrove habitats in the ARR. Hegerl et al (1979, 1982) recorded (mostly indirectly) evidence of about 8 species (including feral stock) while the list of Hutchins and Recher (1982), for Australia, includes others that might occur. Each of the above mangrove mammal lists suffers from lack of data concerning small insectivorous bats. The fish fauna is probably also under-represented. Two studies (Davis & May 1989; Bishop et al 1990), both in the East Alligator River, returned a total of 85 fish species.

Seven species of vertebrate fauna known from Kakadu National Park are listed in Schedule 1 of the *Endangered Species Protection Act 1992*. Three of these, all marine turtles, are the loggerhead, green, and olive ridley. Only the olive ridley turtle has been recorded breeding in Kakadu National Park but the ARR coast is not considered prime habitat for any of these species. Another marine turtle, however, the flatback, not currently listed on Schedule 1, is regarded by Parks Australia as notable (Roeger & Russell-Smith 1995). Of six major Australian breeding populations the ARR lies within one. Three bird species that commonly associate with mangroves, the great-billed heron, large-tailed nightjar and collared kingfisher, are listed as notable by Parks Australia (Roeger & Russell-Smith 1995). Two rodents on schedule 1 of the same Act, the golden-backed tree-rat and false water-rat, have not yet been recorded from mangrove habitats in the ARR, but could be present.

The avifauna of intertidal wetlands and mangroves is one of the few fauna groups having both well established taxonomy and a reasonable spread of distributional data from across northern Australia. The ARR includes several mangrove-specialised species with distinctive endemic north western Australian subspecies (Schodde et al 1982; Ford 1982). All of these though have extended distributions outside the ARR. Most of the passerine bird species recorded from mangrove habitats are not specialised to this habitat and probably only appear in response to seasonally abundant food resources (a similar comment may be made of the bat fauna). Seasonal populations of migratory waders on intertidal mudflats are not large (Bamford 1988).

Saltwater crocodile populations in estuarine environments were first surveyed in the ARR in the late 1970s (Messel et al 1979). Monitoring since then has been continued by Parks Australia staff (Jenkins & Forbes 1985; Lindner 1994) and results suggested that populations had been increasing annually by 6% in the period 1977−1988. Additional studies concerning breeding areas (Grigg & Taylor 1980) and seasonal movement patterns (Jenkins & Forbes 1985) have been completed.

The invertebrate fauna of the intertidal wetlands in the ARR is currently known to include 36 crustaceans, 59 molluscs, 60 species of spider and 83 insect species (Hegerl et al 1982). No mangrove invertebrate studies to understand aspects of community organisation or spatial and temporal dynamics have been done in the ARR.

The mangrove fauna includes several species of commercial or recreational significance. These include catfish, mangrove jack, thread-fin salmon, barramundi, prawns and mudcrabs as well as a range of mud-dwelling mollusc species utilised as food by Binninj. Barramundi are known to spawn in inshore waters adjacent mangroves, while banana prawns and mudcrabs spawn at sea (Griffin 1985). For each of these species, however, mangroves and tidal swamps provide important nursery areas to which juvenile stages migrate. It has been demonstrated that the barramundi and banana prawn fisheries are enhanced during years of above average rainfall (Griffin 1986, Staples 1980). Young barramundi may spend their first 3 or 4 years in freshwater environments, then return to the estuary as breeding adults.

Introduced flora and fauna in mangroves

There are no alien plants in the mangroves of the Northern Territory. Hegerl et al (1979, 1982) noted buffalo, cattle and pig damage to mangroves at the mouth of the East Alligator River. Since those reports feral populations of buffalo and cattle have been almost eliminated from Kakadu National Park and a pig control program is being developed. Feral cats appear to attain high densities in mangroves adjoining freshwater wetlands (pers obs K Brennan).

Process of change in mangrove flora

The various components of climate change and how they are expected to influence mangrove communities globally have been dealt with extensively (Pernetta 1993; UNEP 1994; Ellison 1994). The text that follows reiterates these findings in a more local context.

There is no doubt that relative sea level rise and coastal retreat will affect mangrove communities. However, the amount of the rise is not as important as the rate at which it occurs. Ellison and Stoddart (1991) showed that island mangrove stands, generally constrained by a steeply rising hinterland and with negligible input of allochthonous sediment, cannot keep pace when the rate of sea level rise exceeds around 12 cm/100 years. In the ARR though, where substrates are derived primarily from allochthonous input, and where mangroves are generally backed by an extensive low gradient hinterland, the critical rate of sea level rise at which mangrove communities begin to disintegrate is probably considerably higher; determined by the rate of vertical accretion of sediment. Accretion rates of 60 cm/100 years have been associated with previous sea level rises (in the period 8000−6000 years before present) in the ARR (Woodroffe 1990) so that mangroves in this region could well hold their own or contract only slightly at the coast (UNEP 1994) if the predicted rate of sea level rise of 25−80 cm/100 years eventuates.

In the event of a slight rise in relative sea level in the ARR, the coastal mangrove communities may enter a period of continuous self-adjustment to the receding shoreline. Successive generations of mangroves will, relative to their parent populations, be recruited at more landward positions. Parental mangrove populations will be eliminated at the seaward edge of their zone of tolerance. Coastal mangrove trees subject to rising sea levels may not achieve the heights of those present today. Overall plant stature may be inversely related to the rate of relative sea level rise because plants may not be able to attain their full potential height before changes to the tidal flooding regime cause their demise.

Rising relative sea level will cause sub-coastal flats to be flooded more extensively by tides possibly resulting in rapid inland development of tidal channel networks (Knighton et al 1991). Because of the low gradient of the coastal plains small rises in relative sea level may result in relatively large areas becoming affected by saltwater intrusion.

Any expansion of the estuarine wetland system will be at the expense of present-day freshwater-dominated wetlands. The process will be driven initially by episodic intrusions of saltwater during spring tides in the Dry season when the amount of surface freshwater is much reduced and, with subsequent evaporation, hypersaline conditions can develop. Initial impacts on captured freshwater wetlands could be visually dramatic; especially where areas of *Melaleuca* woodland are affected (Woodroffe & Mulrennan 1993). Present-day freshwater billabongs associated with old, incompletely filled palaeochannels could be particularly susceptible to capture by inland-penetrating estuarine channels. Estuarine capture of shallow basins and groundwater-fed systems may well produce a range of saline marsh and mangrove plant communities either not currently found or poorly represented in the region. Overall, a general inland expansion of tidally influenced terrain will provide the basis of a more extensive and possibly more diverse estuarine mangrove system than is seen today.

Mangrove plants utilise C_3 photosynthetic pathways and some species may respond to elevated CO_2 levels through greater productivity from increased water use efficiency (Ball 1986; UNEP 1994). It is not possible to predict which species will respond or by how much.

An increase in rainfall, especially where any extension to the Wet season occurs, will enhance both mangrove spread and mangrove productivity. Mangrove spread would be most evident where the landward margins of estuarine communities back onto saltflats. Increased inputs of freshwater to saltflats would favour mangrove establishment. Conversely, decreased rainfall and a longer Dry season would favour more extensive salt flat development and narrow strips of mangrove along tidal channels. Increased rainfall may also enhance the rate of sediment accretion against rising sea level.

It is expected that increased mean temperature will lead to an overall increase in primary productivity and that some changes in phenology and growth will result. How individual species will respond is unknown.

Finally, increased storminess along the coast will inflict some damage to some coastal mangrove communities, but it is not known whether the time lapse between successive storm events will be less than the time it takes for the mangroves to recover.

The overall conclusion is that if, as has happened in the past, the rate of sea level rise is more or less nullified by the sediment accretion rate, then the prognosis for mangrove communities in the ARR is one of expansion. Furthermore, most of the climatic factors associated with the projected climate change will enhance that expansion. Only increased storminess, that will inflict direct physical damage to mangrove populations seems likely to have a negative impact. Whether or not the present-day patterns of association and dominance between the various mangrove species will be maintained is not predictable.

Changes to mangrove and intertidal fauna

On the basis of observations and experience it is expected that the changes to the mangroves and intertidal fauna could be as follows.

- Any expansion of mangrove plant communities and intertidal habitat would be soon followed by an expansion of the range of fauna associated with them. If not mobile as adults, most mangrove fauna have mobile juvenile forms that are spread efficiently by tidal oscillations.
- The overall increase in the productivity of mangrove plants is likely to flow on through the food chain though the species that will benefit most cannot be predicted.
- Many mangrove soft-bodied fauna may be affected by an increase in environmental temperature. The species occupying unshaded intertidal mudflats could show the largest responses (either positively or negatively).
- An increase in mangrove extent coupled with higher rainfall is likely to advantage the barramundi fishery and some prawns.
- The creation of areas of shallow saline swamps as part of the inland extension of estuarine habitat may attract larger populations of migratory wading birds to the region and could provide late Dry season feeding habitat for a range of waterbirds disaffected by loss of freshwater wetland.

4.2.2 Freshwater wetland communities

Flora

The number of plant taxa recorded from freshwater coastal wetland environments in the ARR currently stands at 346 species (Brennan unpub data) This includes some 78 entirely aquatic species, 37 species having extended aquatic and dry land growth phases and 231 species that only flourish in the absence of surface water on damp substrates. Taylor and Dunlop (1985) concluded that the wetland flora in the region is primarily cosmopolitan. There are no species restricted to the region but 11 are listed as Northern Territory endemics (Leach et al 1992). Four of these are fully aquatic floodplain plants: the floating grass *Hygrochloa aquatica* and the waterlilies *Nymphaea hastifolia, Nymphoides spongiosa* and *Nymphoides subacuta* while the others, *Mimulus uvedaliae*, *Goodenia neglecta*, *Goodenia porphyra*, *Dentella dioeca*, *Urena lobata*, *Lindernia plantaginea* and *Phyllanthus leaii*, are herbs found on damp ground without surface water. None of this latter group are restricted to coastal floodplain situations in the ARR. There are no plants species considered endangered on freshwater floodplains in the ARR, but several are considered rare: eg *Fimbristylis dipsacea*, *Lemna tenera*, *Tenagocharis latifolia*, *Najas malesiana* and *Utricularia tubulata*.

Plant communities on the freshwater wetlands are known to form complex spatial mosaics within any season. These represent a continuum of vegetation responses to topographic position, period and depth of inundation, flow regime, salinity and prior vegetation history (Specht 1958b; Frith & Davies 1961; Williams 1979; Sanderson et al 1983; Bowman & Wilson 1986; Finlayson et al 1990a; Whitehead et al 1990). Most of the freshwater floodplain environment in the ARR becomes seasonally dry and plant communities are characterised by suites of aquatic species attaining high biomass during the Wet season which subsequently senesce and are replaced by lower biomass suites of predominantly terrestrial species as water diminishes during the Dry season (Sanderson et al 1983; Finlayson et al 1989; Finlayson

1991). Superimposed upon all of this are year-to-year fluxes in dominance caused by differential responses of species to the subtle uniqueness of every Wet season (Sanderson et al 1983; Finlayson et al 1990a; Taylor & Tulloch 1985). Some of the dominant species on flooded freshwater floodplain habitat in the ARR are the grasses *Oryza rufipogon*, *Hymenachne acutigluma*, *Leesia hexandra* and *Pseudoraphis spinescens*; the sedges *Eleocharis* spp.; waterlilies *Nymphaea* spp., *Nymphoides indica* and *Nelumbo nucifera*; other herbaceous species *Ludwigia adscendens*, *Najas tenuiflolia*, *Maidenia rubra* and *Vallisneria caulescens*; and the trees *Melaleuca* spp., *Barringtonia acutangula* and *Pandanus spiralis*.

Fauna

The avifauna of the ARR region consists of over 100 species of birds (Morton & Brennan 1991). None are endemic to the region or listed under the Endangered Species Protection Act. Most species have widespread distributions throughout Australia although a few including magpie goose, green pygmy goose and pied heron are more or less confined to the north. The magpie goose, wandering whistling duck, yellow chat, little curlew, grass owl and Burdekin duck are listed as 'notable' (likely candidates for listing in the ESP Act) by Parks Australia (Roeger & Russell-Smith 1995).

The seasonal use of freshwater wetlands of the region by waterbirds has been documented (Morton et al 1990a, 1990b, 1991, 1993a, 1993b; Bayliss & Yeomans 1990). The region is an important refuge area for waterbirds during the Dry season. Dry season congregations of magpie geese, of over 1 million birds, represent 60–70% of the total Northern Territory population. The feeding ecology of most of the waterbirds in the region is well known (Frith 1967; Recher & Holmes 1982; Dostine & Morton 1988, 1989a, 1989b, 1989c). Most of the Dry season movement patterns are driven by the need for the various species to locate specific types of foraging habitat under a regime of diminishing water availability. The green pygmy goose and jacana are among the most aquatic of all the wetland birds, requiring perennial availability of open freshwater habitat. Most other species can forage in a variety of shallow fresh or brackish to saline waters. Detailed studies of reproduction of waterbirds in the ARR are limited (Frith & Davies 1961), although, in general terms, the situations in which species breed are well known. The ARR does not appear to be a major breeding area for many species. The magpie goose is one of the only species that nests exclusively in flooded macrophyte vegetation during the Wet season. Most others nest either in dry sites at the margins of wetlands or in trees. Magpie goose nesting areas in the ARR and elsewhere along the coast are usually associated with stands of *Oryza rufipogon* and *Eleocharis* spp. (Tulloch et al 1988; Frith & Davies 1961; Bayliss & Yeomans 1990). In some years the breeding effort of magpie geese is destroyed by late season flooding caused by storms. Long-term monitoring of magpie goose population has shown that the total population size has been characterised by lengthy periods of decline, recovery and stability over the last 40 years (Tulloch & McKean 1983; Bayliss & Yeomans 1990).

Freshwater fish diversity in the ARR (41 species, not including marine vagrants) is high nationally as well as compared with other floodplain systems overseas. This following account is primarily taken from Bishop and Forbes (1991). There are no fish species endemic to the region (Larson & Martin 1990), although for four, the Magela hardyhead, exquisite rainbow fish, Midgley grunter and sharp-nosed grunter, listed as notable by Parks Australia (Roeger & Russell-Smith 1995), the ARR is a core area. Each of these species, however, are primarily distributed in upstream water bodies associated with sandstone escarpments. Only the sharp-nosed grunter regularly occurs on coastal floodplains. Twenty per cent of the freshwater fish in the region are catadromous, ie breed in marine or estuarine situations. Many freshwater-breeding fish use floodplains to breed (during the Wet season) but none breed exclusively in it. Backflow billabongs along rivers and creeks upstream of floodplains are important breeding areas with some species breeding only in them. Many wholly freshwater fish undertake seasonal migration from permanent upstream refugia near escarpments to downstream backflow billabongs and floodplains during the early part of the Wet season. At the end of the Wet season migrations back to upstream refuges occur. The water quality of Dry season refugia in permanent billabongs on floodplains in the region can deteriorate markedly toward the end of the Dry season and coupled with a range of factors associated with early Wet season rains may result in dramatic 'natural' fish kills. The fish monitoring program centred on the Magela Creek catchment (Bishop et al 1995) is one of the few long-term monitoring studies in the ARR.

Twenty-two species of aquatic or semi-aquatic reptiles are known from the region (Braithwaite et al 1991). Two species, the saltwater crocodile and pig-nosed turtle, are listed as notable by Parks Australia (Roeger & Russell-Smith 1995), but neither is restricted to the region and both occur in estuarine as well as in upstream situations in rivers away from freshwater floodplains. The pig-nosed turtle nests in sand adjacent to permanent billabongs in upland locations (Georges & Kennett 1989) while the saltwater crocodile nests on floodplains usually adjacent to tidal waterways (Grigg & Taylor 1980). Of the two other floodplain turtles *Emydura australis* appears to be associated with permanent floodplain billabongs while *Chelodina rugosa* is widespread along whole river systems and frequently aestivates in burrows on floodplains during the Dry season when water levels recede (Legler 1982). Studies of the Arafura file snake in the Magela Creek floodplain (Shine & Lambeck 1985) showed that they are primarily nocturnal, occupy permanent billabongs during the Dry season but forage extensively in the shallow water margins of floodplains during the Wet season. This species is not entirely restricted to floodplains but is known to range from estuarine environments to upland escarpment pools. Diet and abundances of some of the aquatic/semi-aquatic fauna in the region were studied by Shine (1986a).

The frog fauna inhabiting freshwater wetlands of the ARR consists of 18 species (Tyler & Cappo 1983; Braithwaite et al 1991). There are no endemics (Tyler & Davies 1986) or notable species (Roeger & Russell-Smith 1995) and only one species, *Litoria dahlii*, is a specialised swamp dweller. The others are variously semi-aquatic or terrestrial with widespread occurrence in a range of habitat types throughout the region. Studies of the frog fauna in the ARR include diet and feeding habits (Tyler & Cappo 1983) and reproductive biology (Tyler et al 1983).

The diversity of macro-invertebrate fauna of freshwater environments in the region is considered high (Outridge 1987) at a national level, but no assessment of its conservation significance is possible. Most studies of the macro-invertebrate fauna have focused on the fauna of Magela Creek in upstream escarpment pools, backflow billabongs and creek channel habitats. However, the macro-invertebrates collected from a floodplain billabong by Outridge (1987) contained only one species that was not subsequently collected at another upstream site. The ecology of the fresh water mussel (Humphrey & Simpson 1985) in the region shows that this species is highly sensitive to warmer temperatures and depleted levels of O_2 in floodplain billabongs during the late Dry season.

The freshwater wetland fauna and flora include a number of recreationally and economically important species. The barramundi forms the basis of an important recreational fishery on floodplain billabongs (Duff 1989). Similarly, the presence of highly visible wild crocodile populations, spectacular waterbird congregations and extensive 'undisturbed' wetland macrophyte plant communities on floodplains form the basis of several highly successful tourist enterprises.

Introduced flora and fauna

Five species of introduced animals—Asian water buffalo, European cattle, pigs, horses and domestic cats—are found on or around freshwater wetland environments in the ARR.

Buffalo numbers at Kapalga on the South Alligator River floodplain were at densities of about 340/10km^2 in 1981 (Ridpath 1991). Indeed, it was from concern for the wetlands and the visible impact that buffalo were having on them that the CSIRO Wildlife and Ecology research station at Kapalga was initially established (Braithwaite et al 1995). Subsequent establishment of Kakadu National Park in the region coupled with concerns by the Australian meat industry about the disease threat to controlled stock posed by feral populations eventually resulted in funding for an eradication program. Buffalo are rarely seen in the region today and continue to be removed if sighted. While a small number of papers reported the effects of buffalo on the wetlands (Stocker 1971, 1977; Byrnes 1977; Corbett 1988; Friend & Taylor 1984; Taylor & Friend 1984; Williams & Ridpath 1982; Hill & Webb 1982), it may in hindsight prove to be more unfortunate that no research was ever undertaken to study the effects of their removal. At least two consequences of buffalo removal appear to be an increase in floodplain fires and an explosion of aggressive weeds.

Feral cattle were mostly eradicated from the region at the same time as buffalo but these never achieved the densities of the latter. The impact of pig damage to the margins of floodplains has never been evaluated. Pig eradication has always been a much more difficult prospect due to their nocturnal feeding habits and secretive behaviour during the day. However, a pig control program is currently being developed by Parks Australia. Cat populations appear to attain relatively high densities along tidal rivers adjacent to floodplains. Their impact on the native wildlife in these situations is unknown.

In the near future the cane toad is expected to invade the ARR. The freshwater wetland environments in the region will provide ideal habitat and its impact on native fauna is likely to have severe implications.

Three major weed species currently affect freshwater wetlands in the ARR: *Mimosa pigra*, *Salvinia molesta* and *Brachiaria mutica*. Management authorities in Kakadu are committed to an ongoing program of control and surveillance to prevent *Mimosa*, a highly aggressive woody shrub, from getting more than a toe-hold in the park. The structural change it causes to wetland plant communities is devastating to wildlife. The *Mimosa* control effort inside the Park is set against an expanding *Mimosa* population outside its borders where property owners do not have sufficient funding to be able to be so vigilant.

The floating fern *Salvinia* has established throughout freshwater floodplains along the East Alligator River, including the Magela Creek floodplain, and on some sections of the floodplain of the South Alligator River. It is expected that it will eventually colonise all freshwater basins along the South Alligator. No chemical control measures used against it have been successful at eradication. Current control is exercised through releases of a weevil, *Cyrtobagus salviniae*. Although now proclaimed effective, at some times of the year (especially early in the Wet season) *Salvinia* can form dense mats across the surfaces of floodplain billabongs in some years. The ecological impact of *Salvinia* has not been determined.

Brachiaria mutica is an invasive rambling wetland grass. It has had a long history of establishment in the ARR, east of the East Alligator River, just outside Kakadu National Park around Oenpelli (Specht 1958b). Somewhat like *Salvinia*, *Brachiaria* only started to be seen as a problem in Kakadu National Park in the years following removal of feral buffalo. It forms a dense thick cover that appears to displace native species in its path. Major areas of infestation and spread include sections of the floodplain of the East Alligator River around Cannon Hill and parts of the Magela Creek floodplain. The challenge is to find a control method that won't threaten native grass species. The ecological impact of *Brachiara* on the freshwater wetlands in the ARR has not been determined.

Process of change in freshwater flora

It is clear that the area of freshwater wetland in the ARR will diminish as a result of relative sea level rise and inland penetration of seawater. The amount of the reduction will be determined by the height at which the sea stops rising. A relative sea level rise of 1−2 m (over any period of time) could see a return to the 'big swamp' conditions of 2000−3000 years before present when most of the present day freshwater wetlands in the ARR were saline and supported mangrove communities (Woodroffe et al 1986).

Finlayson et al (1989) in describing mapping units for the Magela Creek floodplain referred to a range of species with high dominance across the floodplain during the latter part of the Wet season when plant biomass was highest. This suite of dominant species from the Magela floodplain (a wholly freshwater system) is listed below with the species' maximum percentage frequency of occurrence (in parentheses) at a range of saline/semi-saline floodplain sites across the north west of the Northern Territory (Wilson & Brocklehurst 1990): *Melaleuca viridiflora* (0%), *M. leucadendra* (0%), *Hymenochaeta grossa* (0%), *Leesia hexandra* (0%), *Hydrilla verticillata* (0%), *Hymenachne acutigluma* (0%), *M. cajaputi* (1−5%), *Nelumbo nucifera* (1−5%), *Nymphoides indica* (1−5%), *Ludwigia adscendens* (1−5%), *Najas tenuiflora* (1−5%), *Maidenia rubra* (1−5%), *Ceratophyllum demersum* (1−5%), *Pseudoraphis spinescens* (1−5%), *Nymphaea macrosperma* (1−5%), *Nymphaea pubescens* (1−5%), *Utricularia* spp. (*aurea* 1−5%, *gibba* 1−5%, *muelleri* 1%), *Eleocharis* spp. (*dulcis* 75−100%, *sphacelata* 0%, *spiralis* 50−75%, *sundiaca* 1−5%) and *Oryza rufipogon* (as *O. meridionalis*) (50−75%). This example shows not only that many of the dominant plants in freshwater situations may succumb to saltwater intrusion, but also that community collapse may not necessarily be total; species responses will not necessarily be uniform and some, eg *Oryza rufipogon, Eleocharis dulcis* and *Eleocharis spiralis*, may continue to flourish.

Inland expanding tidal channel networks may also have a direct impact on freshwater wetland communities by accelerating drainage during the Dry season This may be especially evident where shallow freshwater basins are penetrated. Affected sites will dry out earlier in the Dry season and may take longer to flood in the Wet season; shifts in community composition at such sites may occur.

On areas not affected by salt intrusion, elevated temperatures could cause freshwater floodplains to dry out faster during the Dry season; or to dry out more extensively and thereby diminish the number or size of communities in present-day permanent swamps. It is possible that this effect would be offset by anticipated higher rainfalls, especially if the season was slightly extended.

Increased storminess, and consequently, more short-duration high-intensity flood events may increase flow rates along floodplain drainage corridors. This could alter species dominance patterns in some flow corridor communities (eg less *Hymenachne actigluma*).

Elevated CO_2 levels may increase the productivity of the C_3 tree species such as the paperbarks (*Melaleuca* spp.). Warmer temperatures and higher rainfall would facilitate this. An overall increase in the area of paperbark forest could be predicted, but, if the plains dry out more quickly during the Dry season then the frequency of fire may increase. Given the sensitivity of paperbarks to fire an increase in exposure could lead to an overall contraction of paperbark forest.

Some of the emergent aquatic macrophytes could also respond to elevated CO_2. Some grasses could be C_3 species (Hattersley 1983) as could some sedges, and these may gain competitive advantage within their communities.

Processes of change in freshwater fauna

Under a regime of diminishing area the capacity of the freshwater wetlands of the ARR to support present-day abundances of wetland-dependent fauna must also diminish. The impact of loss of refuge habitat will probably be species specific and may only become apparent at the end of the Dry season when the size of the refuge area is most reduced.

Waterbird populations may be able to respond to initial reductions to Dry season refuge by increasing their efficiency at exploiting them. How efficiently waterbirds utilise present-day Dry season refuges is not known. The carrying capacity of Dry season refuge areas may eventually be determined by how well they are able to supply the various waterbird species with adequate feeding opportunities. A disproportionate reduction of late Dry season, shallow-water environments will impact populations of wading and dabbling species such as egrets, herons, ibis, the small migratory waders and some ducks. Reduction of deep water environments will impact on some ducks, cormorants and the darter. It is unlikely that any waterbird species will be threatened by a complete loss of Dry season refuge habitat. Regional populations may become greatly reduced, but even if all of the freshwater floodplain environment was lost to estuarine capture, pockets of suitable late Dry season refuge habitat would still persist in more upland situations, in billabong systems associated with rivers and creeks. The future Dry season status of any waterbird species in the region will be difficult to predict. The abundance of many species may be determined by the relative extent of favourable refuge habitat outside the ARR. Many bird species may respond to a reduction in freshwater habitat availability by turning to the expanded saline and brackish water habitat complex. The spectacular Dry season congregations of Magpie Geese, however, could decline rapidly with loss, through saltwater intrusion, of the relatively small-area high-productivity ‘goose camps’.

The size of future freshwater wetland fish populations will be determined in the first instance by how many permanent freshwater basins escape estuarine capture. Significant losses of permanent bodies of freshwater on the floodplains may cause dramatic declines in fish population sizes, but will probably not threaten the overall survival of any species in the region. No freshwater-dependent fish species is entirely dependent on floodplain Dry season refuges; annual upstream migration ensures that a part of the population returns to permanent freshwaters in upland situations.

Reductions to the amount of permanent freshwater on floodplains will also affect the total population sizes of a range of other ‘fish bowl’ fauna species. These would include file snakes, some frogs, turtles and freshwater mussels and a range of invertebrate species. Partial or complete losses of these groups on the floodplains would be unlikely to threaten their overall survival in the region. They would each be survived by smaller populations in permanent waterbodies in upland situations.

4.2.3 Monsoon forests

Monsoon forest communities

The monsoon forest communities associated with coastal and subcoastal wetland systems in the ARR occur typically in two Holocene landscape settings: coastal and seasonally dry floodplain margins These monsoon forests equate to the Group 9 monsoon forest type of Russell-Smith (1991). A very small number of monsoon forest communities in the ARR are also found in lowland settings around perennial springs—Group 2 monsoon forests (Russell-Smith 1991).

Flora

The distribution patterns of 248 species of monsoon forest plants listed from Holocene landforms in the Northern Territory (Russell-Smith & Dunlop 1987) reveal that 75% of species have extra-Australian distributions and a further 20% are confined to Australia but widespread across the north (Liddle et al 1994). Of the small group of species regarded as endemic to the Northern Territory, only 4 (*Flacourtia territorialis, Carpentaria acuminata, Bambusa arnhemica* and *Canthium schultzii)* occur in coastal monsoon forest in the ARR (Leach et al 1992). None of these species is restricted to coastal monsoon forest situations in the region. There are no plant species listed as rare or endangered (*Endangered Species Protection Act 1992*) or notable (Roeger & Russell-Smith 1995).

Russell-Smith and Dunlop (1987) described the coastal monsoon forest patches as 'composed of highly vagile and widespread species'. Sixty-six per cent of the monsoon forest plant species on Holocene landforms have bird or bat dispersed fruit, 17% are wind dispersed, 4% have sticky or barbed seeds and 3% have buoyant water-dispersed seeds. Only 10% of species produce seeds apparently unspecialised for dispersal by an obvious biotic or abiotic vector. Russell-Smith and Dunlop (1987) cite the colonisation by monsoon forest of an abandoned early coastal settlement as an example of the effectiveness of monsoon forest propagule vagility. Bowman et al (1990) identified actively expanding monsoon forest patches on the coast just outside the ARR. They proposed a model for the process which is initiated by the facilitative woody species, *Acacia auricularformis*. It provides the nucleus beneath which seedlings of monsoon forest species can establish. The timing and frequency of fire variously encourages or retards the process.

The distribution of patches of coastal monsoon forest in the ARR is associated with localised sites having slightly higher soil moisture status than surrounding upslope or cross-slope areas (Specht 1958b; Bowman & Wightman 1985; Bowman & Dunlop 1986). Typical sites include the swales of coastal dunes and sites where breaks or faults in impervious lateritic strata occur. Although many monsoon forest species can tolerate burning (Bowman & Wilson 1988; Russell-Smith & Dunlop 1987), most monsoon forest sites also offer some protection from fire (Bowman 1992; Bowman & Dunlop 1986; Bowman & Wightman 1985). The present-day distribution in the ARR of floodplain edge monsoon forest primarily on the western margins of floodplains, attests to this. Compared with eastern margins, the western sides of floodplains are relatively protected by north-flowing rivers and their residual swamps from grass fires originating in eucalypt woodlands and driven by south east trade winds during the Dry season.

The size of individual patches of coastal monsoon forest in the ARR is small (mean 3.1 ha from 28 seasonally dry, sub-coastal and coastal sites of Russell-Smith, 1984). The species richness per patch can vary enormously. A large patch of >25 ha supported 109 species yet one of 2 ha contained 101, but another of 2 ha only 36 species. From the sites of Russell-Smith used above, each patch supported a mean of 58 species and on average almost two-thirds of these were represented by fewer than 50 individuals. The coastal and subcoastal floodplain margin monsoon forests are floristically similar, however, coastal forests support small suites of species restricted to the coastal fringe. Widespread common species include

Canarium australianum, *Sterculia quadrifida*, *Drypetes lasiogyna*, *Abrus precatorius*, *Pouteria sericea* and *Aidia racemosa*. Species restricted to coastal locations include *Diospyros maritima*, *Pongamia pinnata*, *Peltophorum pterocarpum* and *Paramignya trimera*. Patches are dominated by trees species with many deciduous during the Dry season.

All monsoon forest tree species in the ARR utilise C_3 photosynthetic pathways and are thus expected to respond to future elevated CO_2 levels by increasing productivity (Eamus & Duff 1992). Berryman et al (1993) investigated the response of seedlings of the monsoon forest tree *Maranthes corymbosa* to elevated CO_2 levels. Compared with seedlings grown under ambient CO_2 conditions, those grown under elevated CO_2 conditions had greater biomass, height and total leaf area. Foliar levels of nitrogen were decreased and a significant decline in the leaf area to total root dry weight ratio was shown. It was concluded that *Maranthes* seedlings would have greater capacity to survive drought in an elevated CO_2 climate.

Fauna

Braithwaite et al (1991) recorded 42 species of reptiles and amphibians from lowland monsoon forests in the ARR and concluded that they did not support a distinctive reptile and amphibian fauna. All species occurred in adjacent communities (eucalypt woodland and open forest or wetlands), although Woinarski and Gambold (1992) identified 7 species—*Morelia spilota*, *Carlia gracilis*, *C.rufilatus*, *Glaphyromorphus* (ex *Sphenomorphus*) *douglasi*, *G. darwiniensis*, *Boiga irregularis* and *Denrolaphis punctuata*—that attain their highest abundances in monsoon forest. None of these species are listed as rare, endangered or notable in the region *(Endangered Species Protection Act*; Roeger & Russell-Smith 1995).

Of birds, Woinarski (1988) recorded 118 species from 88 monsoon forest sites which included all types of monsoon forest (including those in the sandstone escarpment) in Kakadu National Park. Kikkawa and Monteith (1980) recorded 65 species from 4 sites in subcoastal monsoon forest. The results of both studies show that for the majority of bird species seen in it, monsoon forest is not the primary habitat; only about 20 bird species have monsoon forest as their primary habitat. From Woinarski (1988) it was also noted that only 5 species (orange-footed scrubfowl, rose-crowned fruit-dove, rainbow pitta, white-browed robin and little shrikethrush) were restricted to monsoon forest. Three of these, orange-footed scrub-fowl, rainbow pitta and white-browed robin, are listed as notable by Parks Australia (Roeger & Russell-Smith 1995). The white-browed robin is the only species restricted to subcoastal monsoon forest.

Woinarski (1988) found that the number of bird species in monsoon forests was related to patch size, with smaller patches having fewer species. The presence and abundance of orange-footed scrubfowl and rainbow pittas were related to patch size. He found that the abundance of fruit and nectar were important variables determining both the overall abundance of birds at a site and the distribution of some species, ie rose-crowned fruit-dove, Torres Strait pigeon, varied triller, ie many monsoon forest dependent birds are highly mobile and respond quickly to flowering and fruiting events when and where they occur. This result is not particularly surprising given that the vagility of monsoon forest plants is, to a large extent, underpinned the need of mobile frugivorous birds. Orange-footed scrubfowl abundance was negatively related to the abundance of weeds at a site. Overall, large subcoastal/coastal monsoon forest patches had the highest conservation value in the region.

Menkhorst and Woinarski (1992) analysed the distribution of mammals in monsoon forests in the Northern Territory. They concluded that no mammal species are restricted to monsoon forests but that many species use them at some times of the year. *Melomys burtoni*, a rodent, appeared to have the highest dependency on monsoon forest while another four species, all bats, *Macroglossus minimus*, *Pteropus scapulatus*, *Hipposideros ater* and *Nyctophilus arnhemensis*, had greater abundance inside monsoon forest than in adjacent habitats. Of these, *Macroglossus minimus* is listed as notable by Parks Australia (Roeger & Russell-Smith 1995).

There is very little information available concerning the invertebrate fauna of subcoastal and coastal monsoon forest in the region. Kikkawa and Monteith (1980) collected 325 invertebrate species from 4 subcoastal monsoon forest sites in the ARR. These included 120 species of spider, 36 butterfly species, 81 beetles (Coleoptera), 32 bugs (Hemitera), 17 flies (Diptera), 15 Psocoptera and 24 species of Proctotrupoidea. Friend (1985) added 29 species of grasshoppers. Kikkawa and Monteith (1980) noted dense aggregations of several invertebrate species normally regarded as solitary. They also noted in overall summary that the monsoon forests throughout the region had a common core assemblage of obligate species to which were added suites of facultative monsoon forest species originating from adjacent habitats.

Introduced flora and fauna

Populations of feral livestock such as buffalo, cattle and pigs are attracted to patches of coastal and subcoastal monsoon forest for shelter, food, and at some sites, water.

Impacts due to buffalo in monsoon forest are primarily related to trampling and wallowing which cause soil compaction, alteration to site hydrology and physical destruction of vegetation. Buffalo activity is known to be able to cause death to large trees which then results in an increased light penetration regime which, coupled with physical disturbance to the soil and native seedlings, promotes subsequent weed infestation. (Braithwaite et al 1984; Russell-Smith & Bowman 1992).

Pigs appear to cause less structural damage to monsoon forest, but may inhibit species recruitment (Russell-Smith & Bowman 1992). Bowman and McDonough (1991) found instances where pig infestations caused minimal damage to monsoon forest. It was believed that the forest was being used primarily as shelter, with feeding taking place in adjacent communities where food availability was high.

There are no highly aggressive weeds in coastal and subcoastal monsoon forest in the region. This, however, does not imply that monsoon forests are weed-free—quite the contrary. Weed infestation is widespread and is believed to proceed by opportunistic colonisation in a setting of active disturbance rather than by aggressive invasion and displacement in undisturbed settings (Russell-Smith & Bowman 1992). The types of disturbance that enhance weed infestation include damage by fire, introduced animals and storms. Weed infestation is usually most prevalent around the margins of patches. Some of the common weed species associated with monsoon forests are *Hyptis suaveolens*, *Senna obtusifolia*, *Senna occidentalis*, *Sida acuta*, *Sida cordifolia* and *Passiflora foetida* (Cowie & Werner 1987). Apart from *Passiflora*, a vine, the others are each shrubs or sub-shrubs that grow to about 1.5 m in height.

Process of change in monsoon forest flora

Monsoon forest patches along the coast could be affected by both rising sea level and increased storm frequency. If a rising relative sea level penetrates the coastal foredunes and floods the swales, then the monsoon forest patches situated in them would be destroyed. Mangrove communities may develop in their wake. The drier monsoon vine thickets that grow on shelly chenier ridges at the rear of mangroves, just above high water mark, may also succumb to rises in sea level. However, losses at the seaward edge may be countered by recruitment at the rear of the stands and this would allow these communities to persist for as long as suitable elevated substrate existed. Ultimately if an entire present-day coastal dune system were swamped, the coastal monsoon forests would still be survived by communities in refugia on laterite around the shores of 'islands' such as West Alligator Head, Mount Hooper and wherever else new opportunities for establishment became available along the redefined coast. Patch survival may be enhanced by wetter Wet seasons.

An increase in storminess along the coast would probably hasten any collapse of coastal monsoon forest initiated by rising relative sea level. Alternatively if the coastline were to remain stable against a rising sea level then increased storminess could have both negative and positive impacts. Physical damage sustained by forest patches in foredune situations, coupled with subsequent weed invasion, could lead to long-term degradation. On the other hand, Fensham (1993) suggests that sea water driven by storms across dune systems, in the presence of high rainfall, can enhance the nutrient status of rear dune soils and that these sites are favourable for monsoon forest colonisation.

Seasonally dry subcoastal monsoon forest patches around the edges of floodplains will be killed by exposure to saltwater intrusion. However, because these patches tend to occur on sites more elevated than the floodplains, saltwater intrusion effects will probably be minimal—confined to down-slope margins. The extent of incremental loss at the margins will be determined by the height at which the sea stops rising and the gradient of the site.

Prediction of the future status of subcoastal monsoon forest in the region is difficult. A number of factors suggest an improved future status. Higher rainfall and greater aquifer recharge may allow some existing patches to expand, and as well, provide new sites with high potential for colonisation. Monsoon forest expansion would also be aided by warmer Wet seasons and elevated atmospheric CO_2 levels; the seedlings of some species will be able to establish faster and develop more robust root systems. However, any favour gained in this quarter could be lost by the effects of the future fire regime under a drier, warmer Dry season. Dry season fires may become more frequent and more intense earlier in the year and this would act to diminish patch sizes. Some sites, though, may be afforded a higher level of insulation from fire as a result of inland expansion of estuarine mangrove communities. These communities, frequently irrigated and difficult to burn, are likely to provide a greater level of protection to monsoon forests on the western margins of floodplains than the present-day actively burnt, seasonally dry, freshwater floodplains.

How elevated CO_2 levels, better soil water relations and higher temperature will change internal dynamics and the overall community structure of monsoon forest patches cannot be predicted. The responses of individual species will not be uniform (Eamus & Duff 1992). For some species (like *Maranthes corymbosa*) enhanced productivity under elevated CO_2 will be maintained, while for others an initial increase in productivity rate may decrease through time. Phenological patterns may also be affected but again these are not predictable.

Overall, monsoon forest patches along the coast may enter a period of active re-adjustment to a retreating coastline. Communities around floodplain margins, close to the coast and on the western sides of coastal plains, could expand due to increased protection from fire afforded by inland-expanding estuary networks. Upstream monsoon forest patches, adjoining seasonally dry freshwater floodplains, could diminish as a result of increased fire exposure.

Process of change in monsoon forest fauna

With no clear picture of the nett effect of climate change on subcoastal and coastal monsoon forest the overall impact of climate change on its fauna is also vague. Some effects may be local. If particular patches expand or contract their suitability to some species may change—for example, orange-footed scrubfowl and rainbow pittas may colonise some patches that expand, and cease to inhabit larger patches that diminish in size.

More general effects concerning climate change will be impossible to predict. These will be related to the effect of increased temperature on overall community metabolism and the response of fauna, particularly invertebrates, to wetter Wet seasons and greater plant productivity from elevated CO_2. The CO_2 effect on fauna will not be simple; confounded by the fact that the overall productivity gain in each monsoon forest plant community will not be uniform for all plant species and that while productivity may increase the availability of foliar nitrogen will actually decrease.

4.2.4 Beach communities

Beach habitats in the region are restricted and supported by only narrow, low elevation dunes. A loss to the coastal foredune system through sea level rise may invoke concerns for the loss of specialist 'beach' flora and fauna in the ARR. In many respects the beach-specialised flora along the ARR coast could be considered depauperate. Widespread Northern Territory beach shrubs such as *Messerschmidia argentea* and *Suriana maritima* are not known from the ARR while others like the tree, *Casuarina equisetifolia*, and shrub, *Scaevola taccada*, are only known from single records of juvenile plants. This poor representation of specialised beach flora may reflect either a long history of continuous instability of coastal beach environments in the region or the presence of unfavourable near-shore tidal currents that do not efficiently disperse propagules from adjacent populations.

Though little is known of the ARR beach fauna, losses of beach habitat will cause loss of marine turtle nesting habitat.

4.2.5 Riparian communities

Plant communities along the lower reaches of rivers will be affected by upstream penetration of saltwater. Patches of gallery forest on floodplain river levees may be eliminated where levees are overtopped by saline water in the Dry season. River and creek systems upstream of potential inland tidal penetration may be affected by the predicted increase in frequency of extreme rainfall events during the Wet season. A greater frequency of extreme rainfall events and subsequent flash flooding could result in destabilisation of banks and increased stream channel scouring along lowland rivers and creeks. A long-term consequence could be overall 'thinning' of lowland riparian woodland and forest communities. In escarpment areas the effects of more frequent high intensity flash flood events will be similar to those in lowland streams, however, the population sizes of several plant species, mostly restricted to creek banks in escarpment gorges, and uncommon or endemic, could be reduced. These species include *Lophopetalum arnhemicum* (Northern Territory endemic), *Syzygium minutuliflorum* (Northern Territory endemic), *Ternstroemia cherryii* (only found ARR in Northern Territory), *Polyscias australianum* (uncommon in Northern Territory) and *Mackinlaya macrosciadea* (only found on ARR in Northern Territory).

4.3 Cultural processes

The Binninj of the Alligator Rivers Region (ARR) have experienced considerable changes in their environment and lifestyles. In the 60 000 years that they are believed to have inhabited the region (Roberts et al 1990) sea level has varied between -150 m and +1 m to that of the present (Woodroffe et al 1987).

The regional freshwater floodplain systems are understood to have developed after current sea levels were attained ca 6000 years before present, and possibly mostly within the past 1500 years (Clark & Guppy 1988; Hope et al 1985; Wasson 1992; Woodroffe et al 1986, 1988b). Lucas and Russell-Smith (1993) consider that concurrent with the development of this wetland resource, precontact human populations in the region probably increased substantially over the past few thousand years. Associated with changing patterns of human population, distribution and density, evolution of floodplain wetland systems would have been subject to marked changes and developments in burning/fire management practices, such that these systems could appropriately be considered 'anthropogenic or managed landscapes'.

In the 200 years of Balanda (non-Aboriginal) settlement in the region, Binninj have adapted to further significant changes in their environment. Balanda brought changes to many levels of Binninj life: the establishment of church missions, introduction of feral animal and plant species, including buffalo which provided the basis for a whole associated industry and infrastructure and more recently, mining, tourism and the construction of permanent Balanda towns.

The changes introduced by Balanda have impacted upon the diets and foraging patterns of Binninj:

- availability of Balanda foods has displaced many of the traditional sources;
- introduction of Balanda technology; guns, and vehicles in particular have greatly influenced the pattern range and extent of foraging. Faunal species once considered difficult to hunt are now more accessible. Less time is required in the pursuit and capture of certain species;
- feral animals and plants have been responsible for significant changes in wetland habitats leading to a reduction or at least shift in availability of traditional food sources.

Maintenance of knowledge of the subtleties and cycles of foraging plays a significant role in the reaffirmation of cultural ties to the land (Meehan 1988). Consequently, beyond diet itself, changes in traditional resource utilisation have had implications for the cultural integrity of the Binninj people.

4.3.1 Current status of information

A considerable body of literature exists on Binninj utilisation of bush foods and other resources. However, most of this literature is now over ten years old and in part relates to the experience of older people under circumstances that have now changed. Previously, much of the research within the ARR on Binninj diet was directed at toxicological issues arising from the impact of uranium mining, (eg Beck 1986; McLaughlin 1982; Meehan & McLaughlin 1983). It may be the case that the types of questions that arose from this approach had an influence on the response from Binninj and the type of information given.

Most recently, Lucas and Russell-Smith (1993) have documented the traditional resources of the South Alligator floodplain, their utilisation and management in northern Kakadu. Particular reference is made to the middle reaches of the South Alligator River and the experience of various traditional owners and their perceptions of major environmental changes within this region during their lifetime. There is still very little information concerning traditional resources and their utilisation for the far northern estuarine mangrove regions of the ARR.

Food resources

Floodplain/riverine habitats and billabongs represent the richest environments for hunting and foraging (Layton 1981; Lucas & Russell-Smith 1993). In particular, most animal and plant foods traditionally used as staple items were and still are associated with these habitats. Lucas and Russell-Smith (1993) found that of 12 plant species and 19 animal species considered to be staples, 8 plant and 13 animal species were associated with floodplain/riverine habitats and billabongs (table 1).

Table 1 Native animal and plant species in the Binninj diet (compiled from Lucas & Russell-Smith 1993)

Binninj (Gundjeyhmi) name	Scientific name	Habitat	Balanda name	Seasons available (6 season calendar)*
PLANT SPECIES				
Fruit and seeds				
Maardjakalang	*Nymphaea macrosperma*	floodplain	water lily	4
Yalgei	*Nymphaea pubescens*	floodplain	water lily	4
Andem	*Nymphaea violacea*	floodplain	water lily	4
Yams				
Gaamain	*Amorphophallus paeonifolius*	lowland jungle		2
Anbidjoh/Angodjbang	*Aponogeton elongatus*	creeks/springs		1
Angindjek	*Dioscorea bulbifer*	jungle	round yam	4
Angaiyawol/Gorrbada	*Diocorea transversa*	jungle	long yam	6
Angulaidj	*Eleocharis dulcis*	floodplain	spike rush	3
Galaarum	*Eleocharis* sp.	floodplain	spike rush	4
Anburrei	*Ipomea* sp.	sandstone		5
Wurrumaning	*Nelumbo nucifera*	floodplain	lotus/red lily	2
Maardjakalang	*Nymphaea macrosperma*	floodplain	water lily	5
Yalgei	*Nymphaea pubescens*	floodplain	water lily	5
Andem	*Nymphaea violacea*	floodplain	water lily	5
Anbuled/Buldeer/gukbam	*Triglochin procerum*	floodplain		4
ANIMAL SPECIES				
Fish				
Anmakawarri	*Arius leptaspis*	billabong	salmon catfish	6
Dunbukmang	*Hephaestus fuliginosus*	billabong	black bream	6
Gulobirr	*Sclerpages jardini*	billabong	saratoga	6
Namanggorl	*Lates calcarifer*	billabong	barramundi	6
Reptiles				
Crocodiles				
Ginga	*Crocodylus porosus*	billabong/river	saltwater crocodile	1 (eggs)
Gumugen	*Crocodylus johnstoni*	billabong	freshwater crocodile	1 (eggs)
Lizards				
Birrnining	*Varanus indicus*	floodplain/mang	mangrove monitor	2
Djanai/Dalag	*Varanus panoptes*	floodplain	sand monitor	3
Galawan	*Varanus gouldii*	woodland	Gould's goanna	3
Snakes				
Bolorgoh	*Lialis fuscus*	floodplain	water python	1
Nauwandak	*Acrochordus arafurae*	billabong	Arafura file snake	3

Table 1 continued

Turtles				
Almangiyi	*Chelodina rugosa*	floodplain	long necked turtle	2
Ngardehwoh	*Elseya dentata*	billabong	short necked/ snapping turtle	3
Warradjang	*Carettochelys insculpta*	billabong	pig-nosed/pitted shell turtle	2
Birds				
Bamurru	*Grus rubicundus*	floodplain	magpie goose	3 (meat) 2 (eggs)
Marsupials				
Gornobolo	*Macropus agilis*	woodland	agile wallaby (male)	2
Merlbe	*Macropus agilis*	woodland	agile wallaby (female)	2
Mammals				
Nangamor	*Pteropus scapulatus*	creeks, springs, jungle	little red flying fox	4
Nagaiyalak	*Pteropus alecto*	creeks, springs, jungle	black flying fox	4

Gundjeyhmi seasonal calendar: *Yegge*—cooler but still humid; *Wurreng*— cold weather season; *Gurrung*—hot dry weather season; *Gunumeleng*—pre-monsoon storm season; *Gudjewg*—monsoon season; *Banggereng*—knock 'em down storm season

4.3.2 Flora

In general, it appears that fauna constitute a proportionately greater bulk component of the Binninj bush diet than flora (Layton 1981; Meehan 1988; Altman 1984). European carbohydrates, eg flour and sugar, have largely displaced bush sources. Beck (1986) noted that of the vegetable species identified as being edible many were only collected at her request or 'to show' and were not subsequently consumed. Altman (1984) indicated that gathering of bush carbohydrates represented a highly labour intensive and time consuming exercise.

Although in terms of energy and protein the flora may not constitute a major part of the bush diet, it probably represents a valuable source of supplementary nutrition in a diet notoriously unbalanced when dominated by typically consumed European foods. Altman (1984) makes the point that while flora may not contribute significantly to the diet in kilocalorie or protein terms, their vitamin contribution may be important. He cites the example of the billygoat plum, *Terminalia ferdinandiana*, being consumed by the Gunwinggu in Arnhem Land, which contains some of the highest known concentrations of vitamin C in fruit. In addition to dietary issues the cultural value associated with knowledge of the native flora cannot be underestimated. Plants also have an important function as indicators of stages in seasonal and faunal life cycles representing optimum times for hunting and foraging.

Many of the staple plant species are associated with freshwater habitats. Lucas and Russell-Smith (1993) identified the floodplain water lilies, *Nymphaea violacea*, *Nymphaea macrosperma* and *Nymphaea pubescens*, as of particular importance to traditional regional economy during the Dry season for the starchy seed heads. These species as well as the red lily, *Nelumbo nucifera*, and spike rushes, *Eleocharis*, also provide edible yams as traditional dietary staples.

4.3.3 Fauna

Fish

It is notable that the larger fish species such as barramundi, saratoga and salmon catfish are characteristic staples. Barramundi and catfish have broad dispersals and high abundances making them ideal food items. Of the fish species listed by Larson and Martin (1990) and Pidgeon and Humphrey (1991) seven species are either marine vagrants into freshwater or diadromous (returning to sea or estuaries to spawn). These species may benefit from increased estuarine spawning habitat. Grey (1988) states that in the case of barramundi, although increased sea levels will result in the inundation of some coastal swamps, the landward progression of the coastal environment could maintain the nursery environment in most of the barramundi habitats at the mouths of the major rivers and along the adjacent coast. However, another factor to consider would be the restriction of population size through contraction of habitats associated with this species' rapid growth phase in coastal freshwater swamps before migrating further upstream at the end of their first Wet season.

Salmon catfish are usually found living in pure freshwater in a wide variety of habitats, although they may also be found well downstream in the tidal reaches of rivers and creeks (Larson & Martin 1990). In addition there are marine catfish species associated with estuarine habitats. Saratoga are of particular concern in relation to sea level rise as they do not inhabit areas subject to tidal influence. It is one of Australia's few primary (evolved completely in freshwater) freshwater fish and is the only primary freshwater fish in the Northern Territory (Larson & Martin 1990).

Reptiles

File snakes are entirely aquatic (Shine & Lambeck 1985) and feed exclusively on fish including carrion (Shine 1986c). Of the three species of *Acrochordus*, *A. javanicus* and *A. granulatus* are predominantly marine while *A. arafurae,* found in the ARR, is the only 'freshwater' acrochordid. Little is known about the ecology of acrochordids (Shine 1986c), so it is possible that the distribution of *A. arafurae* is greater than is presently known, eg there are undocumented accounts of their capture in brackish water (Gordon Grigg via Rick Shine pers. comm.). File snakes have greater abundances in the floodplain and downstream billabongs (Shine 1986b) and are harvested by Binninj as far downstream as Cannon Hill Lagoon where marine vagrant fish species such as the bull shark, river sawfish and brown river stingray are known to frequent.

Of the goannas (Varanids), five species in the ARR are utilised by the Binninj as food: sand goannas, *Varanus panoptes* and *V. gouldii*, the mangrove monitor, *Varanus indicus*, and water goannas, *V. mertensi* and *V. mitchelli*. The larger sand goannas are predominantly terrestrial and commonly seen in riparian (particularly *V. panoptes*) and woodland habitats in the Magela Creek system. The diets of sand monitors are diverse, typically comprising many small invertebrates and occasional large vertebrate prey. Most prey items (70% in *V. panoptes*, > 98% in *V. gouldii*) are of terrestrial rather than aquatic origin (Shine 1986a). Given these data and their relatively high mobility it might be surmised that degradation of the existing wetlands would be unlikely to affect these species.

Varanus indicus has been documented in Lucas and Russell-Smith (1993) as a staple species associated with several lower billabongs of the South Alligator floodplain. According to general accounts of distribution by Cogger (1979) its range includes tidal mangrove habitats and is therefore unlikely to be adversely affected by sea level rise.

The other two Varanids are classified as water goannas and are generally associated with smaller water bodies and shallow water areas such as small creeks and overflow zones between billabongs upstream of the floodplain. A high proportion of their diet consists of aquatic prey, especially crabs (in *V. mertensi*) and fishes (in *V. mitchelli*). Water goannas are relatively unimportant as a traditional food source in the ARR due to their scarcity, small size and elusive nature. The same is true of the small terrestrial Varanids (eg *V. timorensis* and *V. tristis*) (Shine 1986a).

All turtle species are eaten by the Binninj except for perhaps the saw shell turtle *Elseya latisturnum* which is smaller and has a relatively unknown and possibly limited distribution (Legler 1980). The pig-nosed or pitted-shell turtle *Carettochelys insculpta* is favoured by some for its size and flavour (Georges & Kennett 1989). Pig-nosed turtles are more common in the upper reaches of the South Alligator River system and only one record exists from the East Alligator River. It occupies permanent water from lowland billabongs in the black soil plains to plunge pools in the escarpment. There are no records from marine or estuarine waters in the ARR, although it occupies saline estuarine environments in Papua New Guinea (Groombridge 1982). It is an opportunistic omnivore depending on what food sources are available at a given location (Georges & Kennett 1989).

Of the other species, the long-necked turtle *Chelodina rugosa* appears to be the more abundant food source (Beck 1986; Legler 1980), although Lucas and Russell-Smith (1993) include the long-neck turtle and pig-nosed turtle as staple species. The long-necked turtle is characteristically harvested in greater numbers using baited hooks; it is also found under dry or semi-dry mud at the edges of receding waterbodies by probing with long metal rods or wooden sticks. The literature on the distribution of turtles in the ARR is limited. Undocumented observations (D Walden pers. comm.) suggest that larger numbers of long-necked turtles are found in the black soil areas, with sizeable populations of snapping and to a lesser extent northern short-necked turtles occurring in upper Dry season refuge areas.

Birds

There are many references to birds in the context of the Binninj diet, particularly the larger waterbirds such as geese, ducks and waders (Meehan 1977, 1988; Beck 1986; Layton 1981; Jones 1980; Altman 1984). Magpie geese occur in large numbers in the Dry season in the ARR. The major Dry season refuge in the Northern Territory comprises the Boggy Plain–Nourlangie Creek swamps in the South Alligator River floodplain where between 60–70% of the total population of magpie geese seek refuge towards the end of the late Dry season. The floodplains of the Adelaide and Mary Rivers encompass the most important nesting habitat in the Northern Territory for magpie geese (Bayliss & Yeomans 1990).

Lucas and Russell-Smith (1993) identify magpie geese as one of the most important avifaunal staples in traditional diet. Vulnerability of this species to habitat loss has been demonstrated at a local scale through effects of buffalo activity. Verbal accounts from traditional owners highlight the disappearance of magpie geese from wetland areas in which vegetation has been decimated by buffalo. Bayliss and Yeomans (1990) indicate that Dry season densities are highest where roosting and feeding areas occur together, ie shallow freshwater and short grass lawns or extensive patches of *Eleocharis* respectively. Wet season densities are highest in areas that provide a broad range of nest and food plants. The effect of saline intrusion on such vegetation could, therefore, have implications for magpie geese populations. Also of note in reference to effects of climate change, is that seasonal rainfall appears to be a major determinant of geese population dynamics. However, Bayliss and Yeomans (1990) indicate this relationship is complex, involving the timing and cumulative effect of previous rainfall events.

Eggs

Frequent references are made to the consumption of eggs (Meehan 1977, 1988; Layton 1981; Beck 1986; McLaughlin 1982). Geese and duck eggs seem to be the most frequently consumed due to their numbers and relative ease of collection. Eggs of crocodiles, goannas, freshwater and saltwater turtles are also eaten and greatly prized (Meehan 1977). Disturbance of nesting habitats would most likely affect egg production and availability as a Binninj food resource.

Mammals

Of the seven species of macropods in Kakadu National Park, four are usually found around the escarpment either on the plateaux, scree slopes or around escarpment outliers. Of the other three, the northern nail-tail wallaby has been recorded infrequently in Kakadu National Park where sightings have generally been associated with paperbark forests of the lowlands. The remaining two, the Antilopine kangaroo (*Macropus antilopinus*) and the agile wallaby (*Macropus agilis*), are the most common in Kakadu National Park and inhabit the lowlands in open forest and woodland. The latter two species are eaten by the Binninj living close to the escarpment areas. Macropods form an important component of the traditional diet, but would probably not be particularly dependent on the floodplain to be considered vulnerable to any changes in this habitat.

The dusky rat (*Rattus colletti*) inhabits floodplain areas, retreating to shallow margins or higher levees during the Wet season. Lucas and Russell-Smith (1993) record its use as an occasional opportunistic food item but not as a significant species in Binninj diet.

Both the little red flying fox (*Pteropus scapulatus*) and the black flying fox (*Pteropus alecto*) are the main native mammals associated with the floodplain/riverine habitats to be hunted with any regularity. Both species are broad ranging, feeding largely on fruits and nectar, particularly of *Eucalyptus* and *Melaleuca* trees. The black flying fox can form large camps of several thousand individuals in *Melaleuca* and mangrove swamps as well as adjacent monsoon forest patches. Being a highly mobile and ubiquitous species with a wide variety of food sources it is most likely to be adaptable to habitat changes in the floodplain.

4.4 Social and economic factors

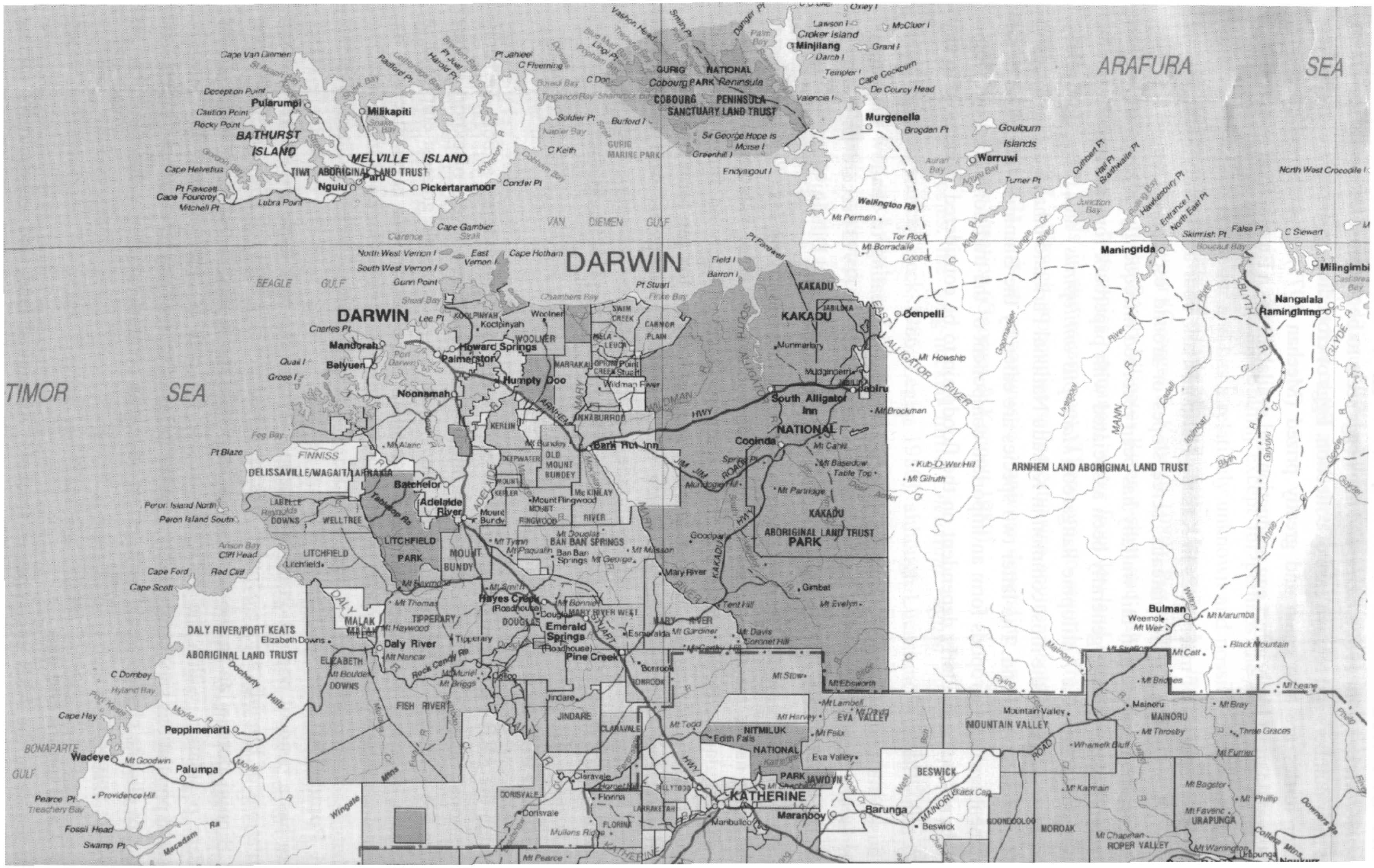
Although the ARR has a low population it is of high economic importance at both Territory and National Scales. Tourism and uranium mining earn significant levels of export money and are the mainstay of the resident populations. Tourism is the single greatest employer in the region, followed by conservation and recreation. Some pastoralism is practised on the floodplains to the west of the ARR.

4.4.1 Population

Jabiru has a resident population of 1500 people. Within the park there are several resident populations of Binninj, whose population is estimated as being between 250 and 300 people. The Binninj population in the park varies as people move in and out of the region. The resident population within the ARR but outside the park is approximately 1000 people. Seasonal populations vary considerably with the influx of tourists and recreational visitors. One impact of climate change would be its effect on human comfort, which may have implications for visitor numbers.

4.4.2 Land tenure and use

Land tenure in the ARR encompasses freehold, Aboriginal land, and leasehold for mining and residential purposes. In nearby areas there are pastoral leases, Northern Territory conservation reserves and Aboriginal land (map 7).



Map 7 Land tenure and use map (from Pastoral and General Tenure Map, NT of Australia)

Residential land within Jabiru is managed by local government within provisions of the *Jabiru Town Development Act 1978* (ANPWS 1991), as delegated by the Jabiru Town Development Authority. The land is vested in the Director of National Parks and Wildlife and leased to the Jabiru Town Development Authority, which in turn subleases to industry in the town area. Special leases and agreements cover other properties within the park boundaries.

Land uses within Kakadu National Park are controlled through zoning provisions contained in the plan of management (ANPWS 1991). The plan of management prescribes the type of activities that may be undertaken within the zones delineated in map 8. Commercial operations and the activities of the traditional owners are accommodated through the plan. The plan (ANPWS 1991) is currently being revised, and will take into account management issues arising from environmental change in accordance with the Commonwealth Coastal Policy (DEST 1995).

Uranium is mined and milled within the boundaries of Kakadu National Park. The mining lease areas have been excised from the park. Operations for the recovery of minerals are carried out persuant to Section 3A(2) of the *National Parks and Wildlife Conservation Act 1975*. Under the Act the only operations permitted are those currently being carried out by ERA-Ranger uranium mines. An extensive monitoring program is in place for the mining operations and this includes gathering of climatic, hydrologic, biological and other environmental information for the catchment of Magela Creek.

ERA-Ranger Mines currently holds the mining leases to the north of the existing operations at Jabiru. Other mining leases exist within the Park boundaries but the recovery of minerals from these areas has not occurred.

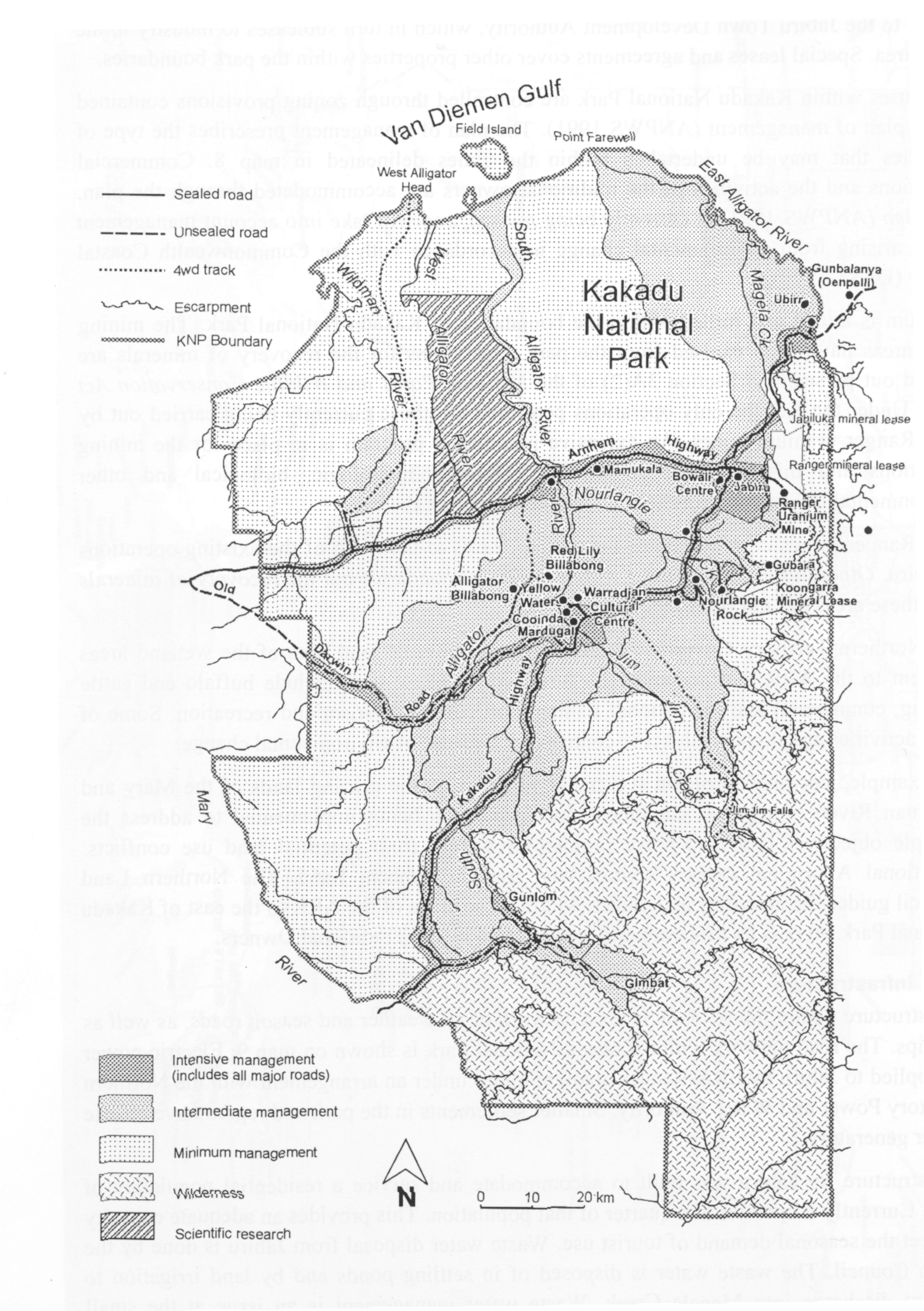
The Northern Territory Government seeks to have multiple land uses of the wetland areas adjacent to the ARR that are under its jurisdiction. These uses include buffalo and cattle grazing, commercial and recreational fishing, horticulture, tourism and recreation. Some of these activities are already subject to controversy because of environmental change.

For example, saltwater intrusion is a major problem on the grazing lands of the Mary and Wildman Rivers. Integrated catchment management is being implemented to address the multiple objectives and help solve problems resulting from potential land use conflicts. Traditional Aboriginal owners control land uses in Arnhem Land. The Northern Land Council guides the activities undertaken within those areas of the ARR to the east of Kakadu National Park. Access to Arnhem Land is controlled by the Traditional Owners.

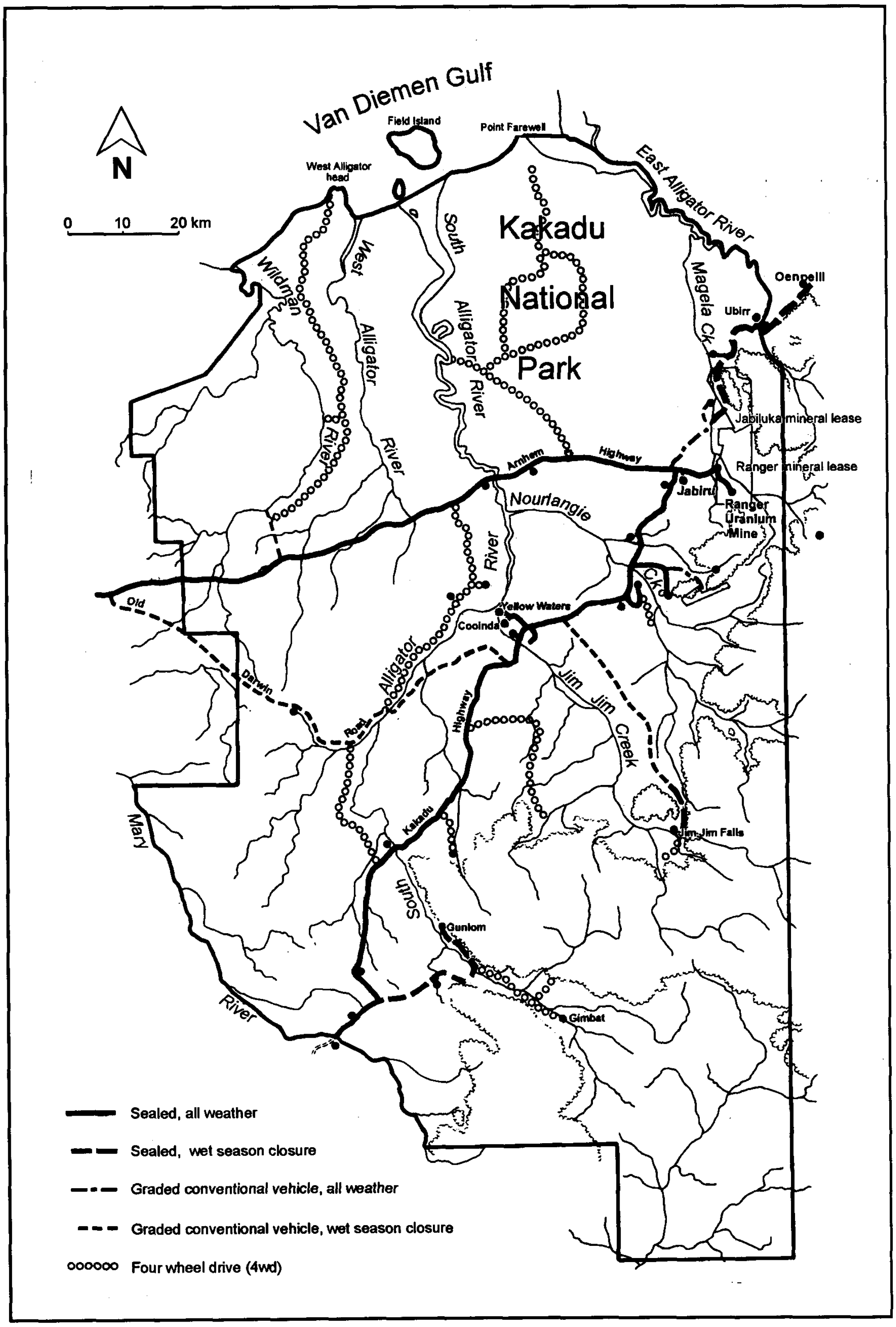
4.4.3 Infrastructure

Infrastructure within the ARR includes a network of all weather and season roads, as well as airstrips. The road network within Kakadu National Park is shown on map 9. Electric power is supplied to Jabiru by ERA-Ranger uranium mines under an arrangement with the Northern Territory Power and Water Authority. Smaller settlements in the park and region have on-site power generators.

Infrastructure for Jabiru was built to accommodate and service a residential population of 6000. Currently it operates at a quarter of that population. This provides an adequate capacity to meet the seasonal demand of tourist use. Waste water disposal from Jabiru is done by the Town Council. The waste water is disposed of in settling ponds and by land irrigation to prevent discharge into Magela Creek. Waste water management is an issue at the small settlements outside Jabiru, largely due to the large fluctuation in demand during Wet and Dry seasons.



Map 8 Land use (and access) in Kakadu National Park
(from ANPWS 1991)



Map 9 Kakadu National Park: Road network
(from ANPWS 1991)

Storm water runoff from town roads is retained in Lake Jabiru, in the town lease area. This pond operates seasonally as a wetland retention area thus reducing discharge of urban runoff into Magela Creek. It is the policy of the Jabiru Town Council not to fertilise parklands abutting the lake.

Water is supplied from town bores approximately 20 km from Jabiru along the Arnhem Highway, outside the catchment of Magela Creek. Additionally, there are bores within the townsite that are used for non-domestic purposes.

4.4.4 Tourism and recreation

Jabiru provides the focal point for servicing the tourism industry in Kakadu National Park, providing essential facilities and services. Tourist visitor numbers to Kakadu National Park have increased significantly since the park was declared—150 000 in 1985, and averaging 230 000 in the 1990s (Kakadu Board of Management & ANCA 1996).

Tourist resources provided within the park include hotels, chalet accommodation and camping grounds. Tourist access is controlled through the plan of management. Nevertheless, numbers are expected to increase in future and will increase the pressure for access to be provided to areas not currently used for tourist and recreational purposes, as well as for increased levels of accommodation.

The Jabiru Tourism Development Plan (Market Equity 1995) has been prepared by the Jabiru Town Council and submitted to Parks Australia for consideration in preparing the fourth Kakadu Plan of Management. This Development Plan recommends formation of a Tourism Task Force to devise action plans for funding, promotion and monitoring of tourism in the park. The plan has as its theme Jabiru as the Heart of Kakadu, thus making it the acknowledged destination area for tourists within the ARR. It is noted, however, that the main Parks Australia visitor facilities are not located within the Jabiru townsite.

5.0 Issues

Six broad issues were identified through the issue scoping process outlined in Section 2.1. Measures to be taken towards resolving each issue are indicated. The areas of issue and their implications are summarised below.

5.1 Perceptions and values

Societal perceptions and values are manifest in both the level of awareness of the possible effects of climatic and associated changes as well as in the attitudes held with regard to the hazards and threats to the environment resulting from climate change. Although closely interrelated, these issues need to be considered separately.

5.1.1 Awareness

Awareness of possible responses to the expected changes is an important factor to be considered when determining how governments and communities perceive the range of responses that could be necessary to manage the change process. Awareness of change is a difficult concept to come to grips with when dealing with climate related matters because there are few benchmarks from which governments, communities or individuals can measure change. Time series data are usually not generated and few people have access to the available information. Likewise, there are few examples available of GIS or other forms of spatial documentation that show how shorelines have moved or areas of specific habitat have expanded or contracted in response to climate or any other factor. This is specialist