A Preliminary Study of the Mangroves of the Dampier Archipelago, Western Australia

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Index

1. INTRODUCTION

This report is an account of a preliminary study of the mangals of the Dampier Archipelago, Western Australia, conducted over March and April 1983. It is beyond the scope of this work to include a review of the literature available on mangroves of the Australian coastline for which reference can be made to the detailed work of Thom *et al.* (1975), Semeniuk *et al.* (1978), Semeniuk (1980) for the Western Australian coastline, and the recently published comprehensive study of Australian mangrove ecosystems edited by Clough (1982). A recent overview of the Dampier Archipelago environment (Semeniuk *et al.* 1982) provides useful information about this part of the coastline.

The objectives of the present study were to provide quantitative information on the extent of mangal cover in the Archipelago using maps already prepared for this area by Thorman (1983), and to document those mangals which now show obvious symptoms of stress either through natural processes or human interference.

Natural environmental pressures may be considerable, particularly since the mangals are growing in a tropical-arid climate. Any natural stress is likely to be aggravated by increased industrial development along this section of coast (see Nicholson 1980), raising the question as to whether such pressures may be sufficient to 'tip-the-balance' on the continuing viability of mangals in the Archipelago.

For the initial stage of this study the approach taken has been one of observation and comment supplemented with limited quantitative measurements. These were made from on-site visits to a number of problem areas, particularly those where mangroves are either dead or appear to be very stressed. These are seen as the most obvious sites for immediate attention in terms of providing background information for a future study of the stress in mangroves of this region. Some comment on the accessibility of the more important sites visited is included here (see Appendix).

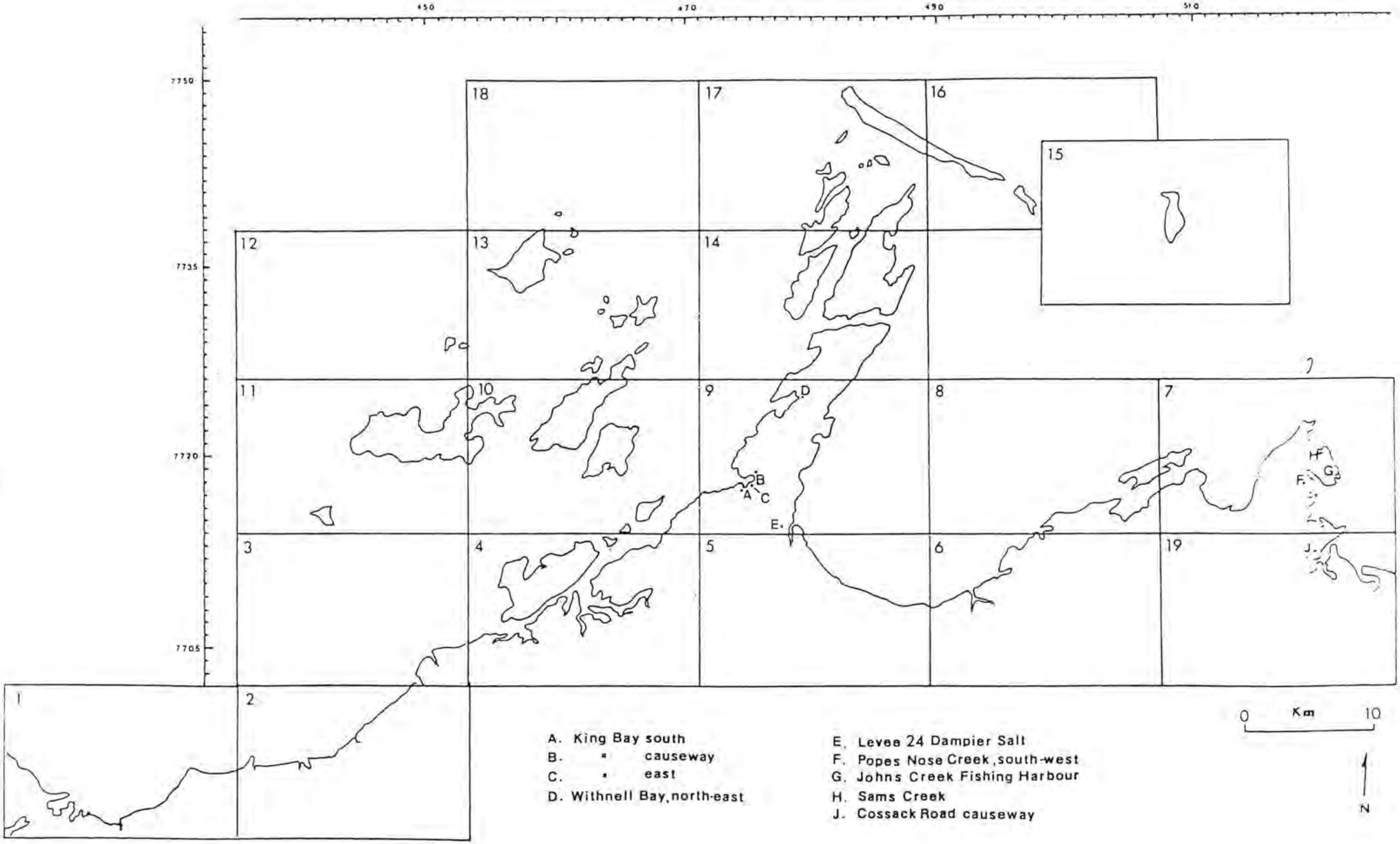

Figure 1. Principal Study Sites and Map Numbers, Dampier Archipelago, Western Australia.

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2. METHODS

2.1 Study Area

The study area, described here as the Dampier Archipelago, includes the coastline and islands immediately east of Cape Preston and east to Cossack, including the mangal on the east shore of Butcher Inlet. Mangal cover was assessed using maps prepared for this area, including islands (see Fig. 1). For logistical reasons on-site visits to mangals were confined to land-based locations only.

2.2 Mapping

Maps used to determine mangal cover were prepared from colour and false-colour infra-red aerial photographs (May 1980; July 1981) verified by ground-truthing (Thorman 1983), for the Department of Conservation and Environment. Photographic details appear below.

2.3 Aerial Photographs

Mangals were visually assessed from stereoscopic scanning of the following aerial photographic sets.

1 Colour, Dampier Archipelago, 1:25,000 (12,500' A.S.L.), 7th-8th May, Kevron Aerial Runs (10 per set) for the Department of Conservation and Environment (DCE).

2 False-colour infra-red, Dampier Archipelago, 1:25,000 (12,500' A.S.L.), 7th-8th May, Kevron Aerial Runs (10 per set) for DCE.

3 Colour, Dampier Archipelago, 1:25,000 (25,500' A.S.L.), 14th July 1981.

4 Colour, Nickol Bay, Dampier Archipelago (6800' A.S.L.) 28th January 1982, Run 2, 0026-0033, Aerial Surveys of Australia, Perth, WA, for DCE.

5 Colour, Nickol Bay, Dampier Archipelago (5000' A.S.L.) 17th March 1982, Run 1, 0779-0789, Aerial Surveys of Australia, Perth, WA for DCE.

6 A number of selected low altitude aerial photographs of Woodside Spoil Area No 4, Withnell Bay and King Bay were made available by Woodside offshore Petroleum Pty Ltd for this study.

2.4 Assessment of Mangal Cover

Areas of mangal were calculated by planimetry using an electronic digitizer (Summagraphics Corp., Fairfield, Connecticut, USA). At the elevation of the aerial photographs clear differentiation between zones of *Avicennia marina* and *Rhizophora stylosa* was possible as these zones were very clear on the photographs.

Some other species in the mangal (notably *Ceriops tagal* and *Bruguiera exaristata*) have similar leaf colour to *Rhizophora* and, at the elevation of the survey photographs, are difficult to separate from the latter mangroves. This introduces a source of error into the

Rhizophora area estimates, but this is likely to be small considering (i) the predominance of *Avicennia* and *Rhizophora* in the mangals along this section of the coast, and (ii) the loss of some mapping sensitivity at the elevation of the surveys used for preparation of the maps. Mangals have therefore been broadly divided here into either zones of *Avicennia* or *Rhizophora*.

2.5 Location and Coding

The mangals in the Archipelago were fitted to the 1000 m grid intervals of the Australian Map Grid, Zone 50. These were used to label specific sites by prefixing the grid reference with the appropriate map number. For example, the mangal to the south of King Bay appearing on map 9 becomes identified as 9/474/7718, the grid number referring to the upper left corner of this particular area. Because of the difficulty in defining realistic boundaries between adjacent mangals, especially where there are well-developed creeks, this method provides a useful approach to labelling and identifying specific sites of interest down to areas of 1 km^2.

2.6 Salinity

Samples for groundwater (sub-surface) salinity were obtained by excavating the soils both on the salt-flats and within the mangals, to reach 'free' water. Salinities were measured using a portable, temperature-compensated refractometer (American Optical Company, USA) calibrated with standard seawater.

3. RESULTS

3.1 Assessment of mangal cover

The total area of living mangal (km^2) in the Archipelago (within the limits of the maps surveyed) is given in Table 1. The data are divided into areas designated as either zones of 'Avicennia' or 'Rhizophora'. The data were compiled from 19 maps each covering 216km (Figure 1). The percentage of mangal within the limits of each map is included in Table 1 along with areas of cover for each. Of the total area of living mangroves (59km^2), Avicennia makes up nearly 87% and Rhizophora the remaining 13%.

Table 2 shows the area of dead mangal, which includes both Rhizophora and Avicennia. Much of the dead mangal is associated with the salt evaporation ponds of Dampier Salt Ltd. Of the 71km^2 of mangal calculated for the entire Archipelago, over 16%, corresponding to an area of nearly 12km^2, is now dead. This figure is conservative and could be added to, somewhat, by including localized dead mangals in particular areas eg. landward of Pope's Nose Creek and west of the Cossack Road Causeway, where there are large tracts of now-dead mangroves. These areas are not easily recognizable as 'dead' on the high-level colour photographs, though some deterioration is evident from the IR scans.

3.2 Groundwater Salinity

Groundwater salinity transects were run at selected sites across the Archipelago (Tables 3 to 10). Because of the limited time of this study, these were confined to areas which are considered to be already stressed, which have the potential for stress, or areas with interesting features, worth visits in the future. These data are referred to in the discussion following, where they are used to highlight specific problem areas.

3.3 Seedling Tagging - revegetation study

Seedlings of Rhizophora stylosa growing at a disturbed site in east King Bay (location 9/474/7719) were tagged and individual heights and leaf numbers recorded (Table 11). These data will be used to gauge viability of seedlings revegetating this site, and to provide some estimate of growth rates. No attempt has been made, at this stage, to tag all seedlings which are established here.

4. DISCUSSION

4.1 Diversity and extent of mangals

The mangals of the Dampier Archipelago coastline occur in a biogeographic region designated as tropical-arid (Semeniuk *et al.* 1978). In such a setting, factors important to their survival might not be expected to operate in an identical manner to those of the more lush mangals of the eastern Australian coastline, or even, for that matter, the more humid, sub-tropical coastal regions further south in Western Austrlia. In that sense the Dampier Archipelago mangals can be viewed as unique. They exhibit fewer species. There are a total of 17 in Western Australia, covering 15 genera. Of these only 7 species are encountered along this section of the coast. Six of these have been reported previously from detailed transects around the west of the Dampier Salt Lease (Semeniuk *et al.* 1980). In the present study only 5 were seen frequently, no doubt because surveys were conducted near the fringing shoreline, visits being made via the landward part of the mangal.

The mangals of this coast appear as a narrow (2-3km or less) belt fringing the shore and tidal creeks backed by extensive salt flats and an arid hinterland. Galloway (1982) calculates a total area of mangroves for the Western Australian mainland (including islands out to 1km) of 2430km^2. From the data in this study (Table 1) it is clear that the Dampier Archipelego contributes only a small percentage to this total (59km^2). Despite this small area there is no doubt of their local importance for shoreline stability, as a breeding ground for birds and a nursery for fish, though quantitative data are lacking.

Along with a relatively low species deversity, there are obvious differences in density and height of the mangals compared with other regions, with mangroves rarely forming trees over 4-5m in height (typically 3-4m) where they form closed, mature forest. One notable example of 'stunted' growth here is that of the tree *Ceriops tagal* which grows typically to 0.5-1.0m in the Archipelago, whereas it is known elsewhere to attain heights some 10 to 20 times greater.

4.2 Natural and man-induced stress

It is difficult to clearly separate factors underlying natural stress in these mangroves with those which are related to interference by man. There will be interaction of a wide range of environmental factors which potentially affect the success of mangroves. These have been well documented and include climate, water temperature, sediment type and stability, degree of shelter, tidal regime, and salinity regime.

More difficult to understand is the long-term history and fate of the mangroves, e.g. whether they display periodic fluctuations in vitality or noticeable cylic changes in their performance, or whether they may be naturally, in a successional sense, 'on the way out'. It is conceivable that natural perturbations, however subtle, especially in mangals in a declining stage, may be sufficient to cause irreparable damage leading to death.

Disturbance from man's interference can usually be detected readily, but symptoms of the stress imposed may be more difficult to directly assign to the source, as the causes may be felt more subtly or indirectly.

A number of the more obvious sources of disturbance have been briefly described by Hegerl (1982) for the Australian scene, including land-fill, canalization, sand-fly control, estuarine dredging, bund-wall projects, water pollution and alteration to freshwater and nutrient inputs. A number of these disturbances presently exist in the Dampier Archipelago, and are described in the Appendix to this report.

In making hypotheses about reasons for mangrove decline in sections of the Archipelago, many of the comments which follow rely to a large extent on speculation based on observation, and would undoubtedly be improved by a more detailed investigation.

Attention has been given to groundwater salinity measurements during these visits, as this seemed intuitively to be of potential significance in a region experiencing low annual rainfall, high temperatures and high evaporation.

It is worth mentioning, in passing, that the usually more dense seaward fringe of the mangal will contribute most to overall productivity, while symptoms of stress are more likely to appear at the landward side of the mangal which is relatively less vigorous. This is considered the case for the mangroves of the Port Hedland area (T. Rose, pers. comm.) and seems likely to occur here also. Salinity transects were concentrated largely on the salt flats and landward mangals. On one occasion readings were continued through the mangal into the seaward zone to include the boundary at the Rhizophora and Avicennia interface, where the mangal is a closed, mature forest (see Table 5).

4.3 Groundwater salinity

The groundwater salinity data (Tables 3 to 10) display some common trends over the sites visited.

1. Healthy Avicennia at the landward limit of the mangals, approaching the salt flat, correlates well with the appearance of groundwater salinity of 70 °/oo or less. This demarkation can be quite distinct from the higher salinities of the salt flat (see Tables 3 to 6, and especially Table 10). There is a gradation of groundwater salinity from very high levels on the salt flats, reducing in value through the mangal to the sea. Slightly higher salinities (70-90 °/oo) are evident at the back of some salt flats where smaller Avicennia trees are found. The salinity values are consistent with previous salinity tolerance values reported for Avicennia marina (MacNae 1968).

Lower groundwater salinities occur on the salt flats adjacent to tidal creeks (e.g. King Bay, South, Table 5). In Withnell Bay the narrow but distinct zone of Avicennia/Brugueria adjacent to the supratidal displays a slightly higher salinity (87 °/oo, Table 3) than the seaward mangal. Presumably the peripheral narrow zones of mangal fringing the salt flat are able to survive through contributions of freshwater via runoff and drainage. The Withnell Bay site, in particular, shows a very clear gradation in groundwater salinities correlated with zonation.

2. Areas where there are dead mangroves, particularly Avicennia, are associated with high groundwater salinities. This is most noticeable at Levee 24 (Table 7), Popes Nose Creek (Table 8), and the landward side of the Cossack Road Causeway (Table 10). The groundwater values over these sites of dead or dying mangroves ranged from 92-155 °/oo. Johannes (1982) has reported moribund and dead Avicennia marina in Mangrove Bay, North West Cape, at salinities ranging from 84 to 102 °/oo. He also reported seedlings growing at salinities of 102 °/oo, extending the range reported by MacNae (1968).

The observations on groundwater salinity suggest that this may be a significant factor to survival of Avicennia in the Dampier region. Observations on Rhizophora at these sites suggest that they are confined to areas of much lower groundwater salinities (sea salinity up to 40 or 50 °/oo) in areas where there is good tidal flushing.

The groundwater story, however, does not appear to be simple. This is exemplified by some data collected at South King Bay, and from sequential sampling in one location at Levee 24. In South King Bay very high groundwater values were obtained in the middle of the salt flat (160 °/oo, Table 5). Less than 1 m away from this site under a healthy stand of Avicennia and adjacent to a tidal creek, salinity was down to 70 °/oo. Further holes dug in this area revealed sharp spatial boundaries, between high and low groundwater values. Salinities recorded in a zone of dead Avecinnia on the salt flat at Levee 24 gave readings of 155, 137 and 156 for the same location on the 26th, 27th and 30th April at low tide in the afternoon. Variation in groundwater salinities across the salt flat here can be gauged by comparing the data sets for different samples from the one transect (Table 6). Differences of 10 to 20 °/oo occurred.

A further point here is whether high salinities in an area with dead mangroves, e.g. at the back of the Levee 24 salt flat, arise naturally or as a result of unnatural processes. The possibility that these figures reflect natural salinity levels at the extreme landward edge of this mangal at Levee 24 seems unlikely because the trees over which the salinities were measured are gnarled and presumably very old. Whether there is an influence of the bitterns pond adjacent to the site requires futher investigation.

4.4 Inundation

Related to groundwater salinity is the extent and efficiency of tidal flushing. The relationship between fate of surface water entering the mangal on flood tides and subsequent values measured in the groundwater needs to be studied more fully here, particularly as there is the suggestion of spatial and short-term temporal variation. Substrate-type will also be significant here. The extent of inundation will be controlled, at undisturbed sites, by the natural spring-neap tidal cycles and topography, and this may characterize the groundwater range of salinities encountered.

Interference with tidal flushing is an obvious factor related to mangal decline, and in the Dampier Archipelago, sites where mangals are now dead or dying over a large area all have some interruption to flushing. This appears to occur through altered road construction and inadequate flushing of the landward side of the causeway. Two sites are considered in further detail here, viz the rock-seep causeway at Pope's Nose Creek and the causeway at Cossack Road, which cuts across two tidal creeks and limits flushing on the landward side (see Appendix). There is, indirectly, some correlation between groundwater salinities and sites with freedom of flushing. In those areas where tidal flushing is adequate, e.g. the King Bay causeway, which has a very large passage for water movement, groundwater salinities are not unusually high in the landward mangal (Table 4). This is also apparent in some small 'ponds' isolated by road construction north of the Pope's Nose Creek causeway, where water moves relatively freely through culverts, and groundwater salinity levels are acceptable (Table 9).

Water movement through the Pope's Nose Creek causeway is confined to rock seepage, while the Cossack Road causeway has tunnel culverts which allow restricted water movement landward. The results of this can be seen when both sides of the causeway are inundated, with different water depths occurring on each side.

The following observations were made at Cossack Road causeway, on separate days, on an incoming and outgoing spring tide, On flood tide the seaward side filled up (5 m during spring) while the landward side filled up much more slowly and was 'dry' for much longer. Eventually the landward side inundated, and, on the subsequent ebb tide, water remained at a high level, even when the seaward side had already 'emptied'. This 'flushing differential' results in a significant alteration in the time of inundation of mangroves on the landward side. These observations lead to the hypothesis that the dead mangal on the landward side of the Cossack Road causeway is a symptom of stress from a combination of 'forced water-logging' by restricted ebb flow, and increased groundwater salinities brought about by extended 'dry' periods on the landward side (due to tidal restriction interfering with rapid flushing) increasing evaporation and reducing flushing with low salinity water. This dry period will be particularly felt in the summer months on neap tides when the extent of inundation is reduced (high water neaps) and there is increased evaporation. Waterlogging, on the other hand, may not be as much a problem on neap tides when there is less tidal penetration. In any event, the effect of the natural spring/neap tidal cycle and, indeed, the semi-diurnal tidal cycle at this site, will be considerably altered by the causeway.

Limited groundwater salinity figures taken on each side of the causeway at Cossack, over 2 days, (Table 10), show marked differences between landward and seaward sites. Salinity values landward of the causeway, and within the zone of dead Avicennia, are above the tolerance limits for this species.

Interestingly, the data collected on 28//4/83, in Table 10, again show the appearance of low groundwater salinities (77 $^{o}/oo$) at the edge of the zone of healthy Avicennia to seaward of the causeway. High salinities on the seaward side adjacent to the road are presumably a continuation of the sub-surface aquifer on the landward side, running under the causeway. This area of high salinity contains dead Avicennia similar to the landward side.

The Pope's Nose Creek mangal is more complex, as its salt flat, landward of the causeway, communicates with that of the Sam's Creek mangal further south (see Appendix). The tidal dynamics here resemble those of the Cossack causeway, with restriction of water movement out of the system on ebb tides (reflected in the difference in water depth on either side of the causeway), subsequent extended periods of inundation, and consequent possible effects of waterlogging. Similarly, on flood tides, the landward side would exhibit prolonged periods without inundation (delayed inundation). It may also be hypothesized here that death of the extensive Ceriops tagal/Avicennia marina community to landward here may be the result of a combination of waterlogging through prolonged inundation at certain times and delayed and reduced flushing resulting in high groundwater salinities and increased evaporation.

In both the Cossack and Pope's Nose systems, the time and extent of inundation are critical to efficiency of flushing through the mangals. In both these areas, construction of causeways appears to have interfered with efficient water movement, thereby affecting not only the extent of inundation but the semi-diurnal tides operating.

Water movement across the Sam's Creek mangal is not restricted, but because the salt flats of this and Pope's Nose Creek are in communication, some water exchange may occur at the transition of these zones. The Sam's Creek salt flat drains more efficiently, to the north-east, than that of Pope's Nose Creek, which drains to the east. On flood tides these areas inundate but presumably at different rates (see above). Water retention on the subsequent ebb tide can be clearly seen on the Pope's Nose salt flat. At the transitional zone there is localized death of some Avicennia, which may have been killed by soil erosion around roots, scouring being brought about by differences in rate of water movement out of each system.

4.5 Transpiration

Another potentially useful way to assess stress in the mangal is to measure leaf transpiration rates in problem areas. This was attempted here crudely on a trial basis using a portable porometer (Delta T Devices, Mk II, Cambridge, England) to measure stomatal conductance. The machine also provides leaf temperature measurements, which would be of interest also as indicators of stress. Unfortunately, the equipment did not stabilize during the field work here, and no data could be obtained on this visit. The technique does have merit, and would be feasible for future field work. Limited measurements on leaves of Avicennia trees in adjacent'dead' and healthy zones of mangal near the Cossack Road causeway indicated some differences in stomatal conductance at one time of day (mid-day). Further trials would be worthwhile.

5. ACKNOWLEDGEMENTS

The following people are thanked for their help during this study. Mr C Nicholson of the Department of Conservation and Environment for providing an introductory visit to the mangroves of the Archipelago, and for useful information and discussions about problem areas. Mr E Paling and Mr A Chiffings for field assistance and stimulating discussion. Mr R Thorman for information on the vegetation maps. Mr R Nunn and Mr D Haughton of Woodside Offshore Petroleum Pty Ltd for their co-operation in providing access to the King Bay Supply Base, and for kindly providing low-level aerial photographs of the site. Mr K Gillen and Mr N Sammy of Dampier Salt (Pty) Ltd for background information on the Salt Works, and permission to visit mangals within the site. Mr T Rose, Mt Newman Mining Co, Port Hedland, for valuable discussion on features of the mangroves of the north-west. Dr M Atkinson for use of the salinity meter. Dr R G Chittleborough, Marine Sciences Group, Department of Conservation and Environment, and Associate Professor A J McComb, Department of Botany, University of Western Australia for providing facilities, logistical and financial support for this study. The work was undertaken during tenure of a temporary (3 months) Research Fellowship by Dr D M Gordon in the Department of Botany, The University of Western Australia.

6. CONCLUSIONS

1. The total area of mangroves in the Dampier Archipelago, including islands, is 71 km^2. Of this, 59 km is living mangal. This is dominated by Avicennia marina (87%) and Rhizophora stylosa (13%).

2. Of the total mangal, over 16% (12 km^2) is now dead. Much of this area is associated with the evaporation ponds of the Dampier Salt salt works.

3. Transects of groundwater (subsurface) salinity indicate a strong correlation between zonation of Avicennia and subsurface salinity.

4. Healthy Avicennia, at the landward limit of the mangals, occur where salinities are 70 /oo or less. Higher salinities occur in the mangroves fringing the back of salt flats (70-90 ^{o}/oo).

5. The range of salinity readings associated with healthy Avicennia marina is consistent with previous tolerance limits reported for this species.

6. Groundwater salinities exhibit marked spatial variation and day-to-day (tide-to-tide?) variations at sites studied (Levee 24, Dampier Salt and South King Bay).

7. Rhizophora stylosa appears seaward of the major zone of Avicennia where tidal flushing is strong and groundwater salinity low (seawater to 40-50 ^{o}/oo).

8. Areas with extensive dead mangal have high groundwater salinities (ranging from 92 to 155 ^{o}/oo over the sites visited).

9. Sites with obviously stressed mangroves occur at King Bay (Woodside Spoil Area 4), Dampier Salt Levee 24, Pope's Nose Creek (Pt Sampson) and the Cossack Road causeway (Cossack). Potential reasons for stress of the mangroves of the Archipelago are:

A. elevated groundwater salinity (e.g. Levee 24, Pope's Nose Creek, Cossack causeway);

B. reduced or altered tidal flushing by causeway construction interfering with time and extent of inundation (e.g. Pope's Nose Creek, Cossack Road causeway);

C. "waterlogging" during part of tidal cycle as a result of restriction to flow of water on ebb tide, landward of causeway (e.g. Pope's Nose Creek, Cossack Road causeway);

D. deposition of dredge spoil (smothering) (e.g. John's Creek Fishing Harbour, Spoil Area No 4, King Bay);

E. soil erosion around roots reducing stability (shoreward Avicennia and mangroves or muddy substrates (e.g. Nickol Bay).

10. Causes of death or decline of mangals by natural and unnatural processes are difficult to separate. Natural processes of high

groundwater salinity in combination with high evaporation may be important in this region which is characterized by low rainfall and high summer temperatures.

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8. APPENDIX I - SITE DETAILS

Below are listed the sites visited during this study, including location references, a brief description of each mangal and the reasons why the area is of interest for further study. Sites are listed here geographically, for convenience (see Fig. 1).

8.1 Withnell Bay, north Reference 9/478/7725

Mangal on north shore is little-disturbed. Access by 4-wheel drive vehicle on road running along the east shore of the Bay. A major part of south Withnell Bay, in contrast, is presently being developed by Woodside Petroleum Pty Ltd as part of the North West Shelf Gas Project. The northern shore is potentially a good site for study of an undisturbed mangal, as it has interesting features in a compact system, viz. well-developed seaward fringe of Avicennia marina. Behind this is a salt flat with blue-green algal mats and a landward narrow fringe of Avicennia marina and Bruguiera exaristata, adjacent to the supra-tidal. In both zones of mangal, seedlings are growing. A well-defined tidal creek runs through the mangal, along which there are smaller, but dense stands of Rhizophora stylosa. There appears to be little siltation at the mouth of the creek. Water quality in the Bay was visually good on the day visited. No restriction to tidal flushing is apparent on the north shore. The area is popular for fishing.

8.2 King Bay, south-west Burrup Peninsula

A. King Bay Causeway Reference 9/475/7719

The causeway cuts across the landward limit of Avicennia marina to the north-east of King Bay, and carries the road from Dampier/Karratha to the North West Shelf gas project. It was constructed in 1981 and its path through the mangal can be clearly seen by Company aerial photographs before and after construction (May 1980; July 1981). Tidal flushing landward of the causeway is made possible by large cement culverts under the causeway. There appears to be little restriction to flushing here. Limited damage to the mangal occurs adjacent to the causeway where there is some rock-fill added as part of construction. The mangal here is dominated by Avicennia marina on both sides of the causeway (3.4 m high). A small area of Rhizophora exists on the seaward side near the road verge. The main Rhizophora zone develops further seaward. Seedlings of Avicennia are successfully growing within the mangal on each side of the causeway. The salt flat, behind the landward limit of Avecinnia has been disturbed by dredge spoil, and construction of a large water channel. Observation of this site at high spring flood tides indicate that seawater can penetrate far back onto the salt flats, despite the disturbance. The mangal adjacent to the causeway is readily accessible from the road. Monitoring the future success of the small landward zone of Avicennia and seedlings at this site would be worthwhile.

B. King Bay, east Reference 9/474/7719

This site is dominated by a narrow zone of Rhizophora stylosa along the rocky eastern shoreline. It is connected to a larger mangal further south. The mangroves here are healthy (flowering during the study period), well-flushed, and there is, adjacent to it, higher ground (igneous rock) which would presumably contribute freshwater from run-off. Behind the shoreward Rhizophora zone is a smaller one of Bruguiera exaristata and limited Avicennia further landward.

One site is of particular interest here, as it has been disturbed and is now re-vegetating. This occurs within the Rhizophora zone where there is a 15 m section of the seaward fringe which has been truncated by construction of a jetty and access road. The jetty has now been removed and with it some, but not all, of the construction spoil. Numerous Rhizophora seedlings are now establishing across the open shoreline. These have been tagged and their heights and leaf numbers recorded. Access is by unsealed roads from the main highway (North West Shelf Gas Project).

C. King Bay, south Reference 9/474/7718

This is an undisturbed section of mangal showing a complete zonation from the dense seaward Rhizophora zone, through mature Avicennia, a large salt flat and to landward a narrow fringing zone of Avicennia marina, next to the supra-tidal. There appears to be no interruption to tidal flushing. There is also extensive growth of Avicennia along a tidal creek draining the salt flat, to the south-west. Blue-green algal mats are well-developed on the salt flat. The site is readily accessible by unsealed road, to the edge of the salt-flat. This site has been used for a study of blue-green algal mats (Paling 1983).

D. King Bay, 'Spoil Area 4' Reference 9/475/7719

This area is the most disturbed mangal in King Bay, and lies within the boundaries of Woodside Offshore Petroleum Pty Ltd supply base. Low level (300 m) aerial surveys made available by the Woodside Site Environmental Officer clearly show the progress of deterioration of the mangal. Dredge spoil from the harbour construction was deposited in an area which included a large section of Avicennia and a small portion of the landward limit of the Rhizophora zone. This area was killed by the spoil (May 1981), which was separated from the remaining healthy mangal (dominated by Rhizophora) by construction of a bund wall (April 1981). This wall was subsequently breached and there was extensive smothering of the mangal to seaward. The 'siltation' affected a wide area of the mangal, with up to 2 m of spoil deposited on the mangroves adjacent to the bund wall. Increased elevation by spoil in the area presumably also hindered flushing effectiveness for the mangroves, leading to their demise. Much of this area deteriorated rapidly and was subsequently cut-down and removed over a period of 3 months. The deterioration can be seen clearly in the sequential set of low-level (300 m) aerial photographs (18.11.81 to 2.3.83).

1. 18.11.81 — Clear demarkation between healthy and dead or dying mangal seaward of wall; low tide before clearing.

2. 17.2.82 — Clearing and removal of dead Rhizophora under way; low tide.

3. 17.3.82 — Further clearing undertaken; photo at high tide shows the extent of inundation over the cleared area.

4.	24.5.82	Following clearing; low tide. Rhizophora fringe to landward obviously stressed.
5.	17.9.82	More dying off of mangal apparent (cf 24.5.82).
6.	2.3.83	Present limit of the mangal; low tide. Stressed areas still apparent on landward fringe.

Using the above photographs on the digitizer, the area of mangal removed by death and clearing, seaward of the bund wall, has been estimated, here, to be over 14,000 m^2. Estimates of area for the entire King Bay area, from high-level photographs in May 1980 and subsequently in July 1981, give some idea of the total loss of mangal in this region over that time. This figure does not include cleared mangal as this commenced after the July 1981 photograph. Total area in May 1980 was 8.86 km^2 and in July 1981, 7.39 km^2, giving a 'loss' of some 1.5 km^2 of mangal in King Bay over this 14-month period.

There is presently, seaward of the bund wall, a reduced but healthy zone of mangal dominated by Rhizophora. This is presently being monitored by a group of consultants for the Woodside Petroleum Company. Some revegetation by seedlings of Rhizophora and Avicennia is now apparent at the existing landward fringe of the mangal. Access to the area is restricted and requires permission from the Woodside Site Office. The mangal is of research interest for monitoring seedling establishment and growth following a major disturbance.

8.3 Hearson Cove, south-east Burrup Peninsula

Reference 9/478/7720

A small mangal exists on the northern shore. Healthy Avicennia marina, 2-3 m up to 4 m high, growing on mud flats. This area is relatively undisturbed but is adjacent to a popular beach. The site is of interest for monitoring growth of seedlings in an area removed from perturbations, as there are numerous Avicennia seedlings growing within the mangal. The site would be useful for comparison with Avicennia mangroves fringing the Nickol Bay shore (Ref. 485/7709), the latter growing on a similar muddy substrate but adjacent to the townsite. The northern shore of Hearson Cove appears to be prograding, with the seaward fringe of Avicennia colonizing the flats. Access to the site is good by road.

8.4 Levee 24, Dampier Salt Bitterns Pond

Reference 9/476/7715

This site is situated in south-west Nickol Bay and is dominated by Avicennia marina. The mangal has a well-developed system of tidal creeks draining the mud flats, so their development can be readily followed. Behind the landward limit of Avicennia is an extensive salt flat supporting blue-green algal mats and shrubby halophytes. The salt flat is bisected by a bund wall which runs some 3-4 km north-west to south-east and separates the mangal and salt flat, to seaward, from the Dampier Salt bitterns pond. The latter was used originally (1969-1974) to contain the residual 'brine' solution (bitterns) following extraction of salt from the evaporation ponds of the saltworks. This pond is no longer in operation, bitterns now being carried directly out to Nickol Bay via a channel through the pond area and into Nickol Creek.

The mangroves at the south-west corner of the salt flat close to the bitterns pond wall are now either showing signs of extreme stress or have already died. This area lies at the extreme limit of _Avicennia_ growth in this mangal and is of interest for further study, as the dead mangroves may be reflecting the effects of either natural stress or interference from perturbations related to the nearby bitterns pond. This needs to be investigated further.

Blue-green algal mats have been studied on the salt flats at Levee 24 (Paling 1983). The area is accessible by unsealed road from the western and the eastern approaches to the pond. Entrance to the bund wall is restricted by a security gate and requires permission from the Dampier Salt Office.

8.5 Nickol Bay, Karratha Townsite

Reference 5/485/7709

This is part of a continuous narrow (250 m) belt of mangal fringing over 10 km of the Nickol Bay shoreline. It is dominated by _Avicennia marina_ growing on soft, muddy sediments. Salt flats are not well developed near the townsite, but these are extensive futher west. The mangal is healthy, with seedlings establishing. Trees are 2-3 m, very gnarled and presumably very old, with numerous pneumatophores. These form a well-spaced but closed low forest. Flushing is not restricted here, but inshore waters of the Bay are typically turbid and there is, presumably, movement of silt through the mangal. The site is of interest because of potential problems from siltation and the interference of root stability by erosion. The latter can be seen within the mangal. Some outwash is suggested from aerial photographs of the coast, the silt moving onto the extensive salt flats behind the mangal in the west of the Bay.

The site close to Karratha is readily accessible by road; vehicles may be driven on the narrow beach adjacent to the mangal. The proximity to the town earmarks the mangal as an area for future disturbance. The fringing mangal of Nickol Bay has importance to shoreline stability, particularly since processes of erosion and siltation appear evident.

8.6 Point Samson Reference 7/519/7719

A number of mangals are of interest here in proximity to the commercial fishing base at Point Samson. This area is important as it includes the largest, undisturbed tract of healthy _Rhizophora_ on the east of the Archipelago.

A. John's Creek Fishing Harbour

Reference 7/519/7719

This site lies on the north-east extremity of a large and healthy mangal seaward of the Pope's Nose Creek Causeway and is accessible by road from the Pt. Samson Road. The mangal is characterized by an extensive seaward Rhizophora zone with Avicennia behind. It is now being disturbed by the construction of a fishing harbour. The dredge spoil from the harbour is being deposited on the northern shore; some of the fringing Avicennia has been smothered by spoil. Some pneumatophores have managed to survive this deposition, while others have been destroyed - the Avicennia is now dead along the shoreline. Jetty construction has widened the natural break in the fringing shoreline Rhizophora zone on the north shore of the creek, next to the harbour. Originally, a 6 m stone wall was planned to cross the harbour near the creek mouth. This was not recommended as providing suitable flushing (File 136/74, Department of Conservation and Environment), and was instead constructed at 3.5 m by the contractors. Besides local smothering, the potential problems here are i) reduced flushing effectiveness, which is a factor critical to successful establishment or survival of Rhizophora, and ii) increased siltation and concomitant reduced water quality at the harbour entrance. It is worth reiterating here that the extensive area of mangal seaward of the Pt Samson region and south-east to Mt Beach, is a healthy, well-flushed, undisturbed mangal. Presumably the seaward zonation is well-developed though no boat surveys were undertaken.

B. Pope's Nose Creek   Reference 7/518/7719

This site is an important one for further investigation for a number of reasons - i) the landward southern side of the causeway at Pope's Nose Creek contains an extensive area of dead and highly stressed mangal (Ceriops tagal and Avicennia marina); ii) the causeway across Pope's Nose Creek was originally a bridge (1965) which was converted to a rock-fill causeway (1966) using stone quarried from the Aboriginal Land's Trust Reserve (Reserve No 30433) immediately south of the causeway. Construction has presumably affected tidal flushing to landward of the causeway (see Discussion); iii) there is a new road being laid north of Pope's Nose Creek causeway, as part of the Pt Samson Road. This is still not completed (May 1983) and will replace part of the present sealed road, which itself, replaced the now disused Roebourne-Pt Samson tramway (1920's?). The new road construction immediately north of the causeway and the old tramway has resulted in some of the Avicennia at the back of the seaward mangal, north-east of the causeway, being truncated. Flushing is still made possible into thse small 'ponded' areas via tunnelled culverts. These ponds contain healthy Avicennia (1-2 m), pneumatophores are present, and seedlings can be seen in some sections.

The landward side of the causeway, and in particular the mangals on the northern and southern shores of the creek are, in contrast to the seaward side, now showing obvious signs of stress. This can be seen to some extent by comparing the mangals on each side of the causeway in the IR photographic runs. The salt flats of the Pope's Nose Creek mangal are in communication with the salt flats of Sam's Creek further north (Ref 7/519/7721). It is appropriate to deal with both these systems together (see Discussion and below).

The zone of dead mangroves which is showing on the southern landward side extend for some 500 m back from the creek into the salt flat. The extreme landward limit of the mangal is composed of a mixture of stunted Ceriops tagal (0.5-1.0 m) and well-spaced, gnarled Avicennia marina (0.5-1 m high, 2-3 m across, bole diameter 5-10 cm). These grade into Avicennia marina (dead) with numerous healthy halophyte shrubs and eventually into the relatively more healthy (2-3 m) fringing zone of Avicennia near the southern shore of Pope's Nose Creek. In this area, there are pneumatophores present, the substrate is very muddy and with numerous crab burrows. Both sides of the mangal are accessible from the Pt Samson road.

8.7 Sam's Creek, Cape Lambert   Reference 7/519/7721

Sam's Creek harbour lies some 2 km north of the Pope's Nose Creek causeway, accessible by an unsealed road. The creek forms part of a small (0.30 km^2), discrete Avicennia mangal immediately landward of a set of beach storm ridges. Small areas of Rhizophora occur along the tidal creek. The salt flat of this mangal directly communicates with the northern, landward salt flat of Pope's Nose Creek. The mouth of Sam's Creek is used as a harbour for fishing boats. There is no restriction to tidal flushing here with effective inundation of the salt flat on flood tides. The mangal is healthy at present, but there are potential problems on the west of the mangal, near the source of the creek, which is adjacent to the Cliffs Robe River Iron export facility. Iron-ore is stockpiled here for shipment. Further stress may occur from effects of discharge of cooling water from the power plant. Dust from a pellet plant was previously a problem, but this operation has been disbanded (1979). Continuous environmental monitoring is being undertaken by the company, including regular aerial photographic coverage, with colour and IR scans, following the initial runs in 1977.

There is a localized area of dead Avicennia in the transitional zone between the salt flats of Sam's Creek and Pope's Nose Creek. Aerial photographs suggest some 'scouring' of the flats in this region, which may be a result of altered tidal flushing (see Discussion).

The mangal is accessible from Sam's Creek road, off Pt Samson Road, or from the Cliffs Robe River Iron access road.

8.8 Cossack Road Causeway   Reference 19/517/7712 and 19/518/7712

The causeway is situated on the Cossack Road which runs north-east from the Roebourne-Pt Samson Road. It bisects the back portion of a large mangal at the mouth of the Harding River. The mangal to the seaward side of the causeway is very healthy, dominated by Avicennia (3-4 m) and with large tracts of healthy Rhizophora fringing sections of the River mouth, near the entrance to Butcher Inlet.

The causeway cuts off the landward one-third of each of two well-developed creeks from the seaward section of the mangal. This is clearly discernable on the aerial photographs (e.g. May 1980, IR run 2). There is extensive dead and very stressed Avicennia landward of the causeway, extending west for 400-500 m, behind which there is a large salt flat with blue-green algal mats. This salt flat was once separated from a salt flat further north, by the old Cossack tramway. This has since been breached, and both salt flats are now in communication, along sections of the tramway. This is clear in aerial photographs.

Flushing is restricted at this site, landward inundation depending on tunnel culverts constructed through the causeway close to each tidal creek. To landward, the *Avicennia* is healthy only where it is in proximity to the creeks or where it occurs colonizing the verges of the causeway.

During separate visits to this site, poor water quality was apparent in the landward section during inundation. The possibility of nutrient-enrichment across the salt flat from the Wickham sewage pond (see below) should not be discounted here, as there is no obvious restriction to such movement from this source.

8.9 Cossack Townsite, western shore of Butcher Inlet

Reference 19/519/7713

This area is highlighted here, to draw attention to a local, narrow (5 m) fringing mangal on the eastern shore of Butcher Inlet immediately south of the 'parking area'. At this site there is a diversity of species which are growing together over a small section of the shoreline, including *Avicennia marina*, *Rhizophora stylosa*, *Ceriops tagal*, and especially *Osbornia octodonta* and possibly *Avicennia eucalyptifolia*(?). A detailed floristic description of this site and nearby mangroves would be valuable. Though not visited during this study, the opposite shore, on the east of the Inlet, appears to exhibit distinct zonation (not clear on aerial photographs) along the seaward fringe, and may also display a large diversity of species.

8.10 Wickham Sewage Pond   Reference 7/516/7715

Outflow from a channel in the south-east corner of the pond drains an extensive salt flat to the east. There is prolific growth of vegetation in the outside channel with healthy *Avicennia* growing further east. The salt flat here is part of that which lies north of the breached Cossack tramway and is therefore likely to provide a source of nutrients as far as the Cossack causeway, during periods of inundation. Blue-green mats are prolific on the salt flats adjacent to the pond (from aerial photographs) and the potential contribution of nutrients to the nearby mangals and salt flats is of interest for further investigation. Comparison of the May 1980, July 1981 photographs suggests that the mangal along the channel from the pond has increased over this period, presumably reflecting the ready source of nutrients.

8.11 Other sites of possible interest

A number of sites have been surveyed from aerial photographs alone, and may be of some interest for further study.

A. Mangal west of 'Pond Zero', Dampier Salt

Reference 4/461/7710

This is a very healthy zone of mangal on the seaward side of 'Pond Zero'. It is accessible by the Dampier Salt Causeway and its ready accessibility makes it valuable for monitoring an undisturbed site in the mangal of the west Archipelago. This area has been described in some detail already (Le Provost *et al.* 1980; see in particular transect 5A, Fig. 20). It consists of a landward zone of *Ceriops tagal*, low, closed forest of *Avicennia marina*, a seaward zone of *Rhizophora*, as closed forest, and a narrow *Avicennia* zone fringing the shore. In this sense, it displays typical zonation of the mangals of this region.

B. Cowrie Cove, east Burrup Peninsula

Reference 9/480/7722

Avicennia marina, healthy mangal, pristine, limited access by vehicle.

C. Watering Cove, east Burrup Peninsula

Reference 9/481/7723

Avicennia marina, healthy mangal, pristine, limited access by vehicle.

D. Mangal, east Nickol Bay

Reference 6/492/7710 and 6/493/7710

One of 3 large mangals running east along coast towards Dixon Island. Accssible by road off the North-west Highway north of Karratha (Nickol River Road). Mostly *Avicennia marina*, with well-developed tidal creeks.

E. Field's Creek mangal   Reference 6/495/7711

Second of 3 large mangals running east from Nickol Bay. Mostly *Avicennia* with small *Rhizophora* stand (see 495/7711), well-developed tidal creek.

F. Mangal opposite Walcott Island

Reference 6/497/7714 and 6/498/7714

Third of 3 large mangals on east Nickol Bay. *Avicennia* most obvious, but with more *Rhizophora* than previous two mangals. All 3 mangals are connected at the shoreline by a narrow fringing zone of *Avicennia*.

Table 1.

Area of live mangal (km^2), Dampier Archipelago, Western Australia

Data were obtained from planimetry of maps prepared from aerial photography (May 1980; July 1981) and ground-truthing (Thorman 1983) for the coastline between Cape Preston and the east shore of Butler Inlet, Cossack, Western Australia.

Map No. (Fig 1)	Grid* Location	Total 'Living' Mangal (km^2)	'*Avicennia*'		'*Rhizophora*'	
			% map covered	area (km^2)	% map covered	area (km^2)
1	417/7702	5.02	4.28	4.75	0.24	0.27
2	435/7702	4.28	1.93	4.16	0.06	0.12
3	435/7714	1.94	0.86	1.85	0.04	0.09
4	453/7714	14.20	4.67	10.10	1.90	4.10
5	417/7714	3.98	1.84	3.98	0	0
6	489/7714	8.56	3.91	8.45	0.05	0.11
7	507/7726	6.75	2.48	5.35	0.65	1.40
8	489/7726	2.91	1.06	2.29	0.29	0.62
9	471/7726	2.74	1.20	2.59	0.07	0.15
10	453/7726	0.70	0.29	0.62	0.04	0.08
11	435/7726	0.62	0.20	0.43	0.09	0.19
12	435/7738	0	0	0	0	0
13	453/7738	0.11	0.03	0.06	0.02	0.05
14	471/7738	1.73	0.67	1.45	0.13	0.28
15	496/7745	0	0	0	0	0
16	489/7750	0	0	0	0	0
17	451/7750	0.64	0.27	0.59	0.02	0.05
18	453/7750	0	0	0	0	0
19	507/7714	5.06	3.13	4.85	0.13	0.21
	TOTALS	59.28	26.82	51.54	3.73	7.74

*Grid reference is given for upper left corner of each map based on the Australian map grid (1000 m intervals), Zone 50.
Total area of each map is 216 km^2, covering 18 (logitudinal) x 12 (latitudinal) grids, except for maps 1 and 19 which include the limits of aerial plots coverage and therefore have areas of 111, and 150 km^2, respectively.

Table 2.

Total area of 'dead' mangal (km^2)

Data were calculated from planimetry of the mangrove distribution on map 4 of Thorman's survey (reference 4/453/7714) and include both '*Avicennia*' and '*Rhizophora*', killed in the Dampier Salt evaporator ponds.

Total area of mangals (km^2)	Total area of 'dead' mangal (km^2)	% of mangal dead
70.9	11.7	16.4

Table 3.

Groundwater (subsurface) salinities ($^{o}/oo$), north-east Withnell Bay, Dampier Archipelago

Data collected on a transect running seaward across the salt flat from the supratidal to the seaward fringe of the mangal, 24 April 1983, at low tide. Distances shown are with reference to landward edge of the salt flat, adjacent to the supratidal.

Location	Distance from subratidal (m)	Salinity $^{o}/oo$	Comments
Adjacent to supra-tidal, below narrow sandy beach	5	87	Narrow (5-10 m) fringe of mangal at back of salt-flat. Substrate is stoney under mangal. *Avecinnia marina*, *Bruguiera exaristata*, 2-3 m.
Middle of salt flat	45	122	Blue-green algal mats on salt flat.
Landward fringe of seaward mangal	90	62-67	*Avicennia marina.* Landward limit of seaward fringe. Seedlings are growing here. Pneumatophores abundant.
Middle of seaward mangal	110	47	Some seedlings present. Trees gnarled and presumably very old. Numerous pneumatophores. Trees 4-5 m at seaward edge.
Seaward fringe	125	39	Seaward flats at low tide very firm, rather than muddy.

Table 4.

Groundwater (subsurface) salinity ($^{o}/oo$),
King Bay Causeway, Dampier Archipelago

Data collected from sites on the landward and seaward sides of the causeway, at low tide, 23 April 1983.

Location	Salinity $^{o}/oo$	Comment
Landward side of causeway. Extreme limit of mangal. 100 m from roadway.	70	*Avicennia marina*, some stressed with few leaves, seedlings growing in some areas. Tree height 2-3 m. Substrate muddy with numerous crab holes, pneumatophores present.
Landward side of causeway. Adjacent to roadside.	52	*Avicennia marina.* Seedlings are also growing here. Pneumatophores present. Tree height 3-4 m.
Seaward side of causeway. Adjacent to roadside	50	Much clearing adjacent to causeway. *Avicennia* stands here 4-5 m. Some *Rhizophora* here also. Seedlings of *Avicennia* growing near fringe.
Seaward side of causeway. In mangal, 150 m from roadside.	50	*Avicennia marina.* Many seedlings growing - tree height 3-4 m. Pneumatophores present. Some apparent around *Avicennia* roots.
Seaward side of causeway. Edge of mangal 150-200 m from roadside.	70	*Avicennia marina.* Trees 1-2 m. Numerous *Avicennia* seedlings growing. Many *Rhizophora* seedlings washed in here from further seaward, but few are successfully established.

Table 5.

Groundwater (subsurface) salinity ($^{o}/oo$),
King Bay, south Dampier Archipelago

Data were collected along a transect running south-west to north east from the supratidal across the salt flat through the mangal to *Avicennia-Rhizophora* interface (grid reference 9/474/7718), 25 April 1983 at low tide. Distances given are with reference to the landward edge of the salt flat. Where ranges are shown, replicates were taken.

Location	Distance from supratidal (m)	Salinity ($^{o}/oo$)	Comments
Adjacent to supratidal; edge of salt flat	20	134	-
Salt flat	60	112-122	-
Salt flat	100	156-160	-
Salt flat	150	162	-
Salt flat	180	156-158	-
Landward limit of *Avicennia*	200	70	Trees 2-3 m, well spaced, healthy
Within mangal	300	52	Healthy *Avicennia*, pneumatophores present. Trees presumably old, gnarled, well spaced.
Within mangal boundary of *Avicennia-Rhizophora* zones.	350	44-47 42-43	Under *Avicennia* Under *Rhizophora* Substrate is very muddy, unconsolidated.
Seaward edge of *Avicennia*, fringing the landward parts of salt flat	-	65	Healthy *Avicennia* growing around and close to tidal creeks and periphery around salt flats close to supratidal.

Table 6.

Groundwater (subsurface) salinity ($^{o}/oo$),
Levee 24, Dampier Salt Limited

Data collected across a transect running seaward from the bund wall of the Dampier Salt bitterns pond, across the salt flat to the mangal, low tide 26 April 1983, and 1 May 1983. Recent data are compared with salinities measured along this transect in March (Paling 1983). Ranges shown are where replicates were taken.

Distance from bittern wall (m)	Salinity $^{o}/oo$ 07.03.83	26.04.83	01.05.83	Comments
0	155	-	129-139	Above high water spring tides.
5	180	162	-	Salt flat with blue-green mats.
10	205-210	197	179-189	Salt flat with blue-green mats.
30	215	-	-	Salt flat with blue-green mats.
50	210-220	177	152-169	Salt flat with blue-green mats.
80	173	-	-	Salt flat with blue-green mats.
110	175	164-166	152-154	Salt flat with blue-green mats.
155	160	-	-	Salt flat with blue-green mats.
200	142	110-112	124	Salt flat with blue-green mats.
220	105	-	-	Salt flat with blue-green mats.
240	95	62	94-96	Halophytes appearing
250	82	-	-	Halophytes appearing
300	-	50-58	-	Healthy *Avicennia* seedlings here (0.5 m)
350	-	88	-	Halophytes, seaward of *Avicennia* seedlings.
400	-	55-65	-	*Avicennia marina*, 1-2 m, healthy. Tidal creeks to 3 m depth.
500	-	58-60	-	*Avicennia marina.* Trees healthy well spaced, mostly 1-2 m, substrate muddy, reworked, pneumatophores present. Well developed tidal creeks. Some erosion around *Avicennia*

Table 7.

Groundwater (subsurface) salinity $^{o}/oo$,
Levee 24, Dampier Salt Limited

Data collected on the salt flat close to the bitterns bund wall, where there are noticeable dead mangroves, 26-27 April, 1983, low tide. Ranges shown are where replicates were taken.

Location	Salinity $^{o}/oo$	Comment
Adjacent to bitterns pond, south-west, Levee 24.	137-155	Samples taken under dead *Avicennia* trees. Trees 1-2 m high, 3-4 m across, gnarled, hole diameters 5-10 cm, no pneumatophores.
150 m seaward of wall, Levee 24	112	Sample taken under dead tree.
Adjacent to bitterns pond, south-west Levee 24.	70-90	Samples taken under *Avicennia* with some healthy leaves, 'growing' in amongst the zone of dead mangroves. No pneumatophores.

Table 8.

Groundwater (subsurface) salinity ($^{o}/oo$), Pope's Nose Creek, Dampier Archipelago

Data collected along a transect running across the salt flat on the landward, south-west side of the Pope's Nose Creek causeway in an area with extensive dead mangroves, 28 April 1983, low tide. Distances given are with reference to the extreme landward limit of the mangal. Ranges shown are where replicates were taken.

Location	Distance (m)	Salinity ($^{o}/oo$)	Comments
Back of salt flat extreme landward limit of mangal.	0	150	All mangroves dead. *Ceriops tagal* (0.5-1 m) and *Avicennia marina* (0.5-1 m) well spaced.
Salt flat	50	130-132	Dead *Ceriops-Avicennia*. Halophytes starting here
Salt flat	150	104	Dead *Ceriops-Avicennia*. Healthy green halophytes growing.
Salt flat	250	77	Dead *Avicennia-Ceriops*. Fewer *Ceriops* here. Some root erosion apparent. Halophytes very healthy.
Salt flat	300	92-94	Dead *Avicennia-Ceriops* with healthy halophytes.
Salt flat	350	92	Dead *Avicennia*, fewer dead *Ceriops*. Healthy halophytes.
Salt flat	400	92	Dead mangal; Halophytes very healthy (1 m). No *Ceriops* here.
Beginning of tree line	445	-	Some dead *Avicennia*. Some healthy trees (2-3 m). No *Ceriops* start of healthy tree line.
Landward fringe of seaward mangal.	450	57-72	Very healthy *Avicennia* here (2-3 m). Beginning of seaward mangal, close to Pope's Nose Creek. Pneumatophores present.

Table 9.

Groundwater (subsurface) salinity ($^{o}/oo$), new road truncation, Pope's Nose Creek, Dampier Archipelago, 28 April, 1983, low tide.

Location	Salinity ($^{o}/oo$)	Comments
Landward side of new road preparation (sand causeway); in truncated mangal between old and new roads.	70	Trees healthy, seedlings growing, pneumatophores present.
Seaward side of new road, in mangal.	56	Healthy *Avicennia*, seedlings growing.

Table 10.

Groundwater (subsurface) salinity ($^{o}/oo$),
Cossack road causeway, Dampier Archipelago

Data collected on the landward and seaward sides of the causeway, 27, 28 April 1983. Ranges shown are where replicates were taken.

Date	Location	Salinity ($^{o}/oo$)	Comment
27.04.83	Adjacent to road, on landward side of causeway	92-94	Incoming tide, seaward side inundated landward side still 'dry'. Samples taken near dead *Avicennia* close to road verge.
	20 m landward of causeway	102-104	Samples taken in amongst dead *Avicennia*. Not yet inundated by incoming tide. Healthier mangroves growing close to tidal channel and culvert running under causeway.
	150 m landward of causeway	117	Sample taken amongst dead or very poor *Avicennia*.
28.04.83	10 m from road landward side of causeway, at south entrance to causeway	146	Samples taken 5 pm (low tide) when water level still high on landward side but 'dry' on seaward side of causeway.
	10 m from road seaward side of causeway	122-132	Some dead *Avicennia* present here, on seaward side of causeway.
	50 m from road on seaward side of causeway	77	Further seaward enter the zone of healthy *Avicennia* (2-3 m). Soil is muddy, well worked by crabs.

Table 11.

Height (cm) and number of opened leaves on seedlings of *Rhizophora stylosa*, revegetating a disturbed site*, east King Bay, Dampier Archipelago.

Data collected from seedlings taggged on 24 April, 1983

Identification	Height (cm)	Leaf No.	Identification	Height (cm)	Leaf No.
RS 1	40	8	RS 26	51	2
2	37	2	27	42	not yet open
3	45	2	28	40	not yet open
4	42	7	29	15	5
5	32	7	30	12	2
6	38	not yet open	31	51	1
7	42	2	32	50	2
8	51	4	33	42	not yet open
9	4	2	34	25	not yet open
10	18	4	35	43	2
11	47	2	36	53	19
12a	18	4	37	47	2
12b	5	2	38	51	2
13	53	2	39	53	3
14	59	3	40	42	2
15	4	2	41	40	2
16	23	not yet open	42	43	2
17	15	4	43	48	2
18	32	not yet open	44	41	2
19	37	not yet open	45	19	not yet open
20	25	not yet open	46	30	4
21	26	not yet open	47	45	2
22	18	4	48	42	2
23	12	not yet open	49	55	2
24	33	not yet open	50	40	2
25	26	not yet open	51	54	4

*This site was originally disturbed through construction of a landing for seawater extraction during construction of the Burrup Highway.