WEST AUSTRALIAN PETROLEUM PTY. LIMITED

ROLLER OILFIELD DEVELOPMENT

CONSULTATIVE ENVIRONMENTAL REVIEW

APPENDICES

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ROLLER OILFIELD DEVELOPMENT

CONSULTATIVE ENVIRONMENTAL REVIEW

VOLUME 2 OF 2

APPENDICES

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West Australian Petroleum Pty Limited

Roller Oilfield Development

Consultative Environmental Review

APPENDIX 1

EPA GUIDELINES FOR THE CONSULTATIVE ENVIRONMENTAL REVIEW

LEC Ref: J218/R342

PETROLEUM OFFSHORE DEVELOPMENT PROGRAMME ON ROLLER STRUCTURE OFFSHORE ONSLOW GUIDELINES FOR THE CONSULTATIVE ENVIRONMENTAL REVIEW (CER) BY WEST AUSTRALIAN PETROLEUM PTY LTD

PREFACE

These guidelines are issued as a checklist of matters which the Environmental Protection Authority considers should be addressed in the CER. They are not exhaustive and other relevant issues may arise during the preparation of the document; these should also be included in the CER.

The EPA takes particular note that this proposal is for a development well programme (as distinct from a single well).

It should also be noted that the guidelines are not intended to convey the Authority's wishes with respect to the format of the document. The format is a matter for the proponent.

SUMMARY

1 INTRODUCTION

- background and objectives of the proposal with respect to existing facilities;
- a brief account of relevant legislative requirements.

2 NEED FOR THE PROPOSAL

This section is to enable the proponent to provide the justification for the project.

3 EVALUATION OF ALTERNATIVES

A discussion of the possible alternatives, especially with regard to wells located in highly sensitive reef or nearshore environments, and their potential impacts.

4 DESCRIPTION OF THE ENVIRONMENT

It is important to set the context by briefly describing the development programme as tendered to the Department of Mines. The following aspects should be discussed:

- timetable for the various stages of development;
- components of the drilling operations, including details of the drilling muds to be used, other operational discharges and a brief description of standard and non-standard drilling practices, if they have potential for environmental impacts;
- waste treatment and disposal details regarding all solid, liquid and gaseous wastes, with estimated maximum total loads and concentrations;
- pipe-laying procedures and routes; location and design of production platforms;
- processing facilities. If based on Thevenard Island, details of modifications to these works will be required, with particular attention to discharges and new areas to be cleared. (Works licence modifications will be necessary);
- characteristics (weathering and spreading rates, plus implications for environmental impacts) of crude oil expected to be produced;
- marine zones of exclusion should be outlined, at least in general terms;
- attendant shipping, mooring and crude transfer facilities;
- alternative production scenarios;
- location of inshore operations base and its requirements. Aspects such as access, disruption to existing (pastoral, etc.) activities, environmental and social impacts should be discussed;
- size of construction and operations crews, brief description of roster system and transfer operations;
- worker accommodation for the construction and operations phases;
- details of support vessels and rig refuelling procedures.

5 EXISTING ENVIRONMENT

This section should provide a brief description of the broader physical, biological and social environment and coastal processes. It should then detail the systems which are potentially at risk from, or likely to be impacted by all activities associated with this proposal. This would include marine (i.e. seafloor in the vicinity), intertidal and shallow subtidal habitats and assemblages, as well as the social environment (particularly with regard to Onslow and Mackerel Island resort).

This section should include an overview of:

- current terrestrial and marine uses (e.g. island recreation, commercial fishing, etc.);.
- commercial and amateur fishing values;
- conservation and recreational values and
- effects of drilling and production operations (both long and short term) on potentially affected communities (e.g. Onslow).

6 ENVIRONMENTAL IMPACTS

This section of the CER should show the overall physical, biological and social impacts of the proposal on the environment. It should also consider the cumulative risks of all oil exploration and development activities in the region.

The objective is to briefly synthesise all information and predict potential impacts upon the environment. This should include an assessment of the resilience of the systems to natural and human-induced pressures associated with the proposal. The probability and effects of oil spills (small, medium and large) together with their fate should be discussed in this section. Reference must be made to impacts specifically related to the type of crude oil expected to be produced.

Impacts on those conservational, commercial and recreational values identified in Section 5 should be discussed. The potential conflicts with trawling activities should be recognised, especially with regard to timing of activities which are likely to require exclusion of trawlers from an area. The socio-economic impacts of the project on the town of Onslow and Mackerel Island should be discussed.

7 ENVIRONMENTAL MANAGEMENT

Environmental management should be described on the basis of (and cross-referenced to) the potential environmental impacts described in Section 6.

Management of the impacts of the proposal, as well as ongoing monitoring programmes should be specifically addressed in detail, including who will be responsible for the various aspects of these programmes and contingency plans.

The purpose of the management programme is to demonstrate the manner in which potential environmental impacts can be ameliorated either through design or specific ongoing management.

Education programmes for oil personnel may need to be developed.

There should be a discussion of large and small spill scenarios and a description of appropriate responses to each. Equipment on hand, or readily available (such as booms, skimmers and dispersants) that could be used to contain what would be considered the most likely spill scenario should be discussed. As well, there should be a summary of the key points and commitments made in more detail in the Oil Spill Contingency Plan.

The Contingency Plan should be included as a stand-alone appendix to the CER.

Management of the rig, platforms and personnel in the event of a cyclone needs to be discussed.

8 SUMMARY OF COMMITMENTS BY PROPONENT

A summary of commitments made should be included as an appendix to the CER. The commitments should be numbered and include: who makes the commitment; the nature of the commitment; when it will be carried out; and to whose satisfaction.

9 REFERENCES

All references should be listed.

10 CONSULTATIONS

A description should be provided of the public consultation activities undertaken by the proponent in preparing the CER. This should outline these activities, the agencies, groups or individuals involved (e.g. professional fisherman's association, pastoralists, etc.) and the objectives of the activities. A summary of concerns/issues raised should be documented, along with how each of these concerns has been addressed.

The report should include appropriate maps, tables and photographs, as required, to illustrate points made in the text.

West Australian Petroleum Pty Limited

Roller Oilfield Development

Consultative Environmental Review

APPENDIX 2

INTERTIDAL HABITATS OF ONSLOW TO TUBRIDGI POINT COAST AND LOCKER ISLAND

LEC Ref: J218/R342

INTERTIDAL HABITATS OF ONSLOW TO TUBRIDGI POINT COAST AND LOCKER ISLAND

Report to: West Australian Petroleum Pty Limited,
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27 March 1991

LEC Ref: J218

Report No. R343

INTERTIDAL HABITATS OF ONSLOW TO TUBRIDGI POINT COAST AND LOCKER ISLAND

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SUMMARY

The following key points are made on the basis of the coastal habitat survey from Tubridgi Point to Onslow.

- The coastal geomorphology consists of a shallow submarine shelf interrupted by limestone reefs and islands; a coastal tract comprised of beaches, coastal dunes, tidal creek systems and salt flats; and the Ashburton River delta.

- Mangrove communities occur throughout the Ashburton River delta and along the margins of six tidal creek systems between (and including) Urala Creek near Tubridgi Point and Beadon Creek at Onslow.

- Mangrove distribution and diversity is greatest in the Ashburton River delta, particularly in the tidal creek/lagoon system behind Entrance Point (in the north-east sector of the delta).

- The mangrove species pool and zonation in the Ashburton delta is typical of the arid mangrove systems of the Pilbara coastline, with six species represented in mainland settings. Variations in species assemblages occur at the local scale.

- Halophytic shrubs are associated with both mangal flats and salt flats; the species pool and assemblages are generally typical of those found elsewhere on the Pilbara coast, and six species were recorded in this survey.

- Highest priority for protection of coastal habitats from an oil spill is indicated for the Ashburton River delta complex on the basis of the pattern of distribution and diversity of mangroves and associated biota between Tubridgi Point and Onslow, and particularly for those habitats near Entrance Point in the north-east sector of the Ashburton delta.

INTERTIDAL HABITATS OF ONSLOW TO TUBRIDGI POINT COAST AND LOCKER ISLAND

1 INTRODUCTION

1.1 BACKGROUND

West Australian Petroleum Pty Limited (WAPET) is the operator of Permit Area TP/3 Part 1 which contains the recently discovered Roller Oilfield (Fig. 1). WAPET is currently seeking approval to establish offshore production facilities at sites located within this field, which is approximately 6 km north of the Ashburton delta (Fig. 1). The coastal waters off this part of the Pilbara coastal waters lie within a 'Special Protection Locality' (SPL No. 32), as designated for oil exploration and production activities by the Department of Conservation and Environment (Jones, Field & Hancock, 1984). The designation is based on the number of important marine resources and environmentally significant features within the area.

Intertidal and shallow subtidal areas are considered at most risk in the event of an oil spill (Jones, Field & Hancock, 1984). As such, developers of oilfields within SPLs are required to implement management plans and an oil spill contingency plan (OSCP) which are based on adequate knowledge of the type and distribution of the various intertidal habitats in the vicinity of proposed operations. Such information was also required by WAPET to facilitate preparation of a Consultative Environmental Review (CER) for the proposal, as requested by the Environmental Protection Authority (EPA) of Western Australia.

WAPET has a current OSCP for its operations at the nearby Saladin field and Thevenard Island, and information on sensitive marine habitats has already been collected for a wide area lying to the north of the Roller field (LSC, 1987; LSC, 1988; LSC, 1989). However, precise information on the nature and distribution of intertidal habitats lying to the south and south-west of Roller is limited.

WAPET therefore commissioned LeProvost Environmental Consultants (LEC) to undertake surveys of the coastal habitats between Onslow and Tubridgi Point (including those at Locker Island), so that its current OSCP for Permit Area TP/3 Part 1 can be upgraded for the proposed operations at Roller. This document is a technical report which presents the results of the surveys.

1.2 OBJECTIVES OF SURVEY

The objectives of the survey were to:

(i) determine the range and distribution of intertidal habitats located along the Onslow to Tubridgi Point coastline;

(ii) describe the major biotic assemblages associated with each habitat; and

(iii) identify, map and prioritise sensitive areas for the upgrading of the oil spill contingency plan for Permit Area TP/3 Part 1.

1.3 APPROACH AND SCOPE OF STUDY

The approach adopted for this study included:

- reviewing existing information and literature;
- examining vertical plus low-level oblique aerial photographs of the area between Tubridgi and Coolgra Points taken between 1967 and June 1990;
- making a low-level flight along coastline between Tubridgi Point and Onslow at low tide on 27 November 1990; and
- undertaking a ground survey by vehicle and boat between 28 November and 5 December 1990 to describe, at selected locations, the range of habitats and the biota they support.

Habitat descriptions are based on observations and photographs made from low-altitude flights, on data collected during a seven day field survey by LEC personnel, and on interpretations of 1:10,000 colour and 1:20,000 black/white aerial photographs. Ground work involved visits to a wide range of localities between Tubridgi and Onslow to collect data on the various intertidal habitats and assemblages.

Much of the survey was focussed on the extensive area of mangals within the Ashburton River delta, owing to the proximity of this sensitive intertidal area to the Roller field (Fig. 1).

Locations to the south-west of the Ashburton delta (i.e. at Secret Creek, Urala Creek, Locker Point and Locker Island) were also inspected. No data were collected from coastal areas lying to the east of Casuarina Point (Fig. 1), since pertinent information on these areas (e.g. Hooleys Creek and Beadon Creek) has recently been summarised by the Onslow Coastal Study (SPC, 1987) and by the proponents of a solar salt project at Onslow (Gulf Holdings Pty Ltd, 1990).

Travel logistics within the large and remote study area, together with the size and complexity of the Ashburton River delta (Fig. 2), confined the seven day ground survey to providing qualitative descriptions along transects. However, semi-quantitative sampling of benthic fauna was undertaken at selected sites along transects and elsewhere (Section 2). Vegetation surveys were aimed at providing a wide and representative coverage of the Ashburton delta, and hence are largely descriptive.

2 METHODS

2.1 SELECTION OF TRANSECTS AND SITES

The selection of transects within the Ashburton River delta complex was aimed at providing information on:

- representative seaward and landward intertidal habitats of the delta;
- mangals representative of the different geomorphic settings within the delta; and
- areas which potentially had greatest diversity of mangrove species.

Localities for transects were selected following examination of black/white 1:20,000 aerial photographs, low-level and oblique aerial photographs, and colour aerial photo-mosaics (Department of Land Administration, Job # 860111, Urala to Cane River, 27/5/86, 1:10,000). Final selection of transects was made following a low-level aerial reconnaissance of the study area on the day before the ground survey commenced.

A total of 22 transects were surveyed (Fig. 3). Nine of these transects, representing the range of vegetation, substrate and geomorphological settings found within the study area, are presented schematically in Figures 4-12.

In addition to the transects, various sites between Urala Creek and Onslow were chosen for ground-truthing the photographic mosaics and to describe single (i.e. discrete) intertidal habitats. These sites comprised Parkes Reef, the nearshore reef and shoreline between Locker Point and Urala Creek, and the intertidal habitats surrounding Locker Island. Wards Reef and the rocky shoreline at Beadon Point received a cursory and opportunistic inspection near the end of the survey. Subtidal and shoal areas in the vicinity of the Roller field (depicted in Figure 2) are described in Appendix 3 of the Roller Oilfield Development CER.

2.2 SURVEY METHODS ALONG TRANSECTS

All transects were inspected on foot. Transects which intersected major creeks were completed on successive days, using fluorescent tape markers to allow access to be regained by vehicle or boat. Data and observations were recorded of the physical and biological characteristics of discrete habitats intersected by each transect. Recorded habitat characteristics are as follows:

(i) Geomorphology and stratigraphy

Basic descriptions of the geomorphic setting were made using primarily medium-scale units (Semeniuk, 1986). Data relating to shallow stratigraphy and substrate were correlated with mean sea level (MSL) to provide a stratigraphic framework for the vegetation and faunal data collected along each transect.

(ii) Vegetation

Descriptive data were collected on the structure and floristics of mangroves and halophytic shrubs along each transect. Specimens were photographed, or collected and pressed for later identification to species level (confirmed by the Western Australian Herbarium). Plant specimens have been catalogued and retained for future use.

(iii) Fauna

Benthic fauna in discrete intertidal habitats along transects were sampled using several techniques. These were:

- sieving sediments dug from 0.25 m^2 by 0.1 m deep quadrats for burrowing infauna. Animals retained by a 2 mm sieve were either identified and counted on the spot or stored for later processing;

- using 1 m^2 and 0.25 m^2 quadrats to count either conspicuous surface organisms (epibenthos) or distinctive holes made by various crabs, the mud lobster and mudskippers; and

- photographing, noting and collecting biota for assessing diversity (with representatives of unidentified species preserved in 70% alcohol for later identification to at least familial level wherever possible).

Bird usage of habitats was recorded opportunistically using binoculars to minimise disturbance whenever possible. Species were identified by call in dense mangrove habitats. Records comprise of species lists, habitat utilisation and nest sites. Species utilisations are grouped into broad habitats which were defined by the availability of particular resources.

3 INTERTIDAL HABITATS BETWEEN ONSLOW AND TUBRIDGI

3.1 GEOMORPHIC SETTING

3.1.1 Overview

The 65 km stretch of coastline between Tubridgi Point and Onslow forms the western part of the Pilbara coastal system. While the onshore geomorphology of this area is similar to that found elsewhere along the Pilbara coastline, the nearshore bathymetry differs from that found to the west in Exmouth Gulf, and to the east of Coolgra Point. The nearshore bathymetry is relatively deep (always >1.5 m LAT) with no shallow embayments and very few areas where low tidal mud flats extend seaward. The reef and island systems to the west of Coolgra Point are limited in extent by comparison with the Mary Anne and Passage Island chains which lie to the east of Coolgra Point.

Most of the shoreline consists of long, narrow and relatively steep sandy beaches, which are interrupted only occasionally by either rocky platform areas or the mouths of a few small tidal creeks. The shoreline in front of the Ashburton River delta, which presently has one major entrance and a number of minor entrances (Fig. 3), is similar.

3.1.2 Principal Geomorphic Units

The large scale geomorphic units between Tubridgi Point and Coolgra Point comprise:

(i) a gently sloping submarine shelf, with small offshore shoals, sand cays, reefs and islands (e.g. Roller shoal and Ashburton Island);

(ii) a coastal tract of narrow sandy beaches backed by dunal barriers and salt flats (the latter connected to the sea via one of six tidal creek systems)

(iii) a major river delta (Ashburton River); and

(iv) a hinterland of undulating sand plain extending inland towards a series of ranges.

The coastal geomorphology within the Onslow to Tubridgi Point area is dominated by the coastal tract [(ii) above] which is interrupted only by the Ashburton River delta.

(i) Shallow submarine shelf

Apart from Locker Island, the islands, reef systems and sea-floor close to the Roller development have already been surveyed and described by previous studies commissioned by WAPET (see Section 1.1). Locker Island is a vegetated island of sand overlying emergent limestone. It is similar in structure and form to other islands in the region.

(ii) Coastal tract

The coastal tract is an extensive system of sandy beaches backed by coastal dune systems (= barrier islands) and tidal flats. The barrier island dune systems are composed of Pleistocene limestone blanketed by beach and dune deposits, some of which form shoreward migrating dune systems. In some areas the Pleistocene limestone is exposed to form rocky shores and limestone platforms extending into subtidal waters (Fig. 2).

To the rear of the dunal barrier islands, expansive tidal salt flats extend landward to the hinterland sand plain. These salt flats receive water at spring tides via the tidal creek systems, which have breached gaps between the dunal barrier and form a network of narrow drainage channels across the salt flats (Fig. 2). Apart from Beadon Creek and Urala Creek, the tidal channels are small and have relatively narrow and shallow entrances.

(iii) Ashburton delta

At the mouth of the Ashburton River a wave-modified delta has formed containing a complex system of spits, cheniers, tidal flats, distributary channels and coastal dune barriers. The present day entrances are separated by a long (3 km), narrow coastal dune barrier. Behind the coastal barrier there are extensive tidal flats that have been incised by a network of distributary channels and tidal creeks.

The delta system has prograded through the development of sand bars, spits and cheniers at its main mouth in the west (Plate 1) and at Entrance Point in the east (Plate 2). The main channel of the Ashburton River is over 60 m wide and in many places more than 5 m deep. At the time of the survey, the mouth of the channel at Entrance Point was broad and very shallow (<0.5 m LAT). During episodic flood events the Ashburton River discharges large quantities of orange/red terrigenous sediments which become reworked by prevailing wave and tidal regimes.

A net eastward littoral transport system, combined with the influence of a major dunal barrier located between Entrance Point and the main channel mouth, has orientated the main depositional activity towards the eastern side of the delta. In this area, a series of parallel sand deposits (subtidal sand bars, intertidal to supratidal spits and cheniers) are separated by elongate lagoons that are infilling with subtidal, intertidal mangrove and supratidal flats deposits (Plate 2).

These processes have produced a typical progradational sequence of medium scale geomorphic units from the seaward to landward sides of the eastern delta. A generalised sequence contains the following units:

(i) subtidal sand sheets and bars;

(ii) outermost sand spits and cheniers (unvegetated);

(iii) elongate shallow lagoons;

(iv) vegetated cheniers;

(v) extensive high tidal flats dissected by narrow tidal creeks; and

(vi) vegetated cheniers and sand islands.

3.2 HABITAT DISTRIBUTION AND CHARACTERISTICS

The distribution of the various coastal habitats of the study area has been mapped from interpretation of aerial photo-mosaics and hydrographic charts, and is shown in Figure 2. Landforms and habitats within the Ashburton delta are shown in more detail in Figure 3.

Sections 3.2.1 to 3.2.7 describe the characteristics of the various intertidal habitats depicted Figures 2 and 3. These habitats are:

(i) Tidal flats:

- low tidal flats,
- mangal flats,
- salt flats.

(ii) Sand spits and cheniers.

(iii) Sandy beaches.

(iv) Limestone platforms and rocky shores.

(v) Nearshore reefs and shoals.

(vi) Offshore island (Locker Island).

The dunal barrier system and hinterland sand plain are not discussed since these habitats are not at risk from marine oil spills.

3.2.1 Tidal Flats

These are gently-inclined intertidal lowlands which extend from low tidal levels (LAT) to high tidal levels (HAT). While the range of tidal flats (i.e. from LAT to HAT) form a connected system, they have been subdivided into habitat units on the basis of criteria and terminology established by Semeniuk (1986). These habitats are:

(i) low tidal flats, occurring from low (LAT) to mid tidal levels (MSL);

(ii) mangal flats, occurring from mid (MSL) to high tidal levels (MHWS); and

(iii) salt flats, extending from high tidal (MHWS) to supratidal levels (HAT).

3.2.1.1 Low Tidal Flats

These flats typically consist of unvegetated muds, silts or fine sands which extend from the subtidal portions of creeks or river channels to the leading edge of mangal flats (Plate 3) or unvegetated sand spits. They can also be truncated by sand spits and cheniers.

Most of the low tidal flats form narrow bands (10-20 m wide) that link the steep slope of a creek channel and the fringing mangal flats which commence at MSL. However, broad low tidal flats have formed in more progradational areas in the north-east sector of the Ashburton delta. Here, muds, silts and sands have deposited in lagoonal settings to produce wide (up to 100 m) low tidal flats between old cheniers and the shallow subtidal waters in the central portion of the lagoon (Plate 3).

At Entrance Point and the main Ashburton channel mouth, sand and muddy sand flats have formed as low tidal extensions from spits and cheniers into offshore subtidal waters (Plates 1 & 2). These are the only areas along the Onslow to Tubridgi Point coastline where low tidal flats extend into offshore subtidal waters.

(i) Vegetation

Macroscopic vegetation is typically absent at this tidal level. However, isolated stands of mangals, mangrove seedlings or very occasionally small stands of halophytic shrubs are present towards MSL.

(ii) Benthic fauna

Details on the diversity and abundance of the residential benthos recorded in this habitat are shown in Table 1. The principal components are polychaete worms, bivalve molluscs and the mudskipper (*Periophthalmus argentiventralis*; Plate 4).

Ocypodid crabs (e.g. *Uca flammula*) and their burrows were found mainly towards the upper margins of this habitat (i.e. near and alongside the edge of mangals and close to MSL. The deep and distinctive tracks of the mud crab (*Scylla serrata*) are not uncommon, with their large burrows typically located at points where the edges of tidal creeks and tributaries are steep.

(iii) Birds

When exposed during low tides, the low tidal flats provide significant feeding opportunities to shorebirds and some mangrove resident birds. Twenty-nine species of birds including 17 species of waders were observed utilising this habitat (see Table 2). This number represents the highest species diversity for a single habitat recorded during the survey. Feeding opportunities on low tidal flats range from small invertebrates (polychaetes, bivalves, etc.) for waders, to small fish (e.g. mudskippers) and crustaceans (e.g. fiddler crabs; *Uca* spp.) for large waterbirds as well as terns, gulls and the Mangrove Kingfisher. While the Mangrove Heron and Mangrove Kingfisher were mostly found within mangals, they frequently emerged onto fringing tidal flats to feed during low tides.

3.2.1.2 Mangal Flats

Mangroves occur throughout the Ashburton delta complex (Plates 1 and 2), and along the margins of the six tidal creek systems of the study area (i.e. Beadon Creek, the Hooley Creek system, 4 Mile Creek, Secret Creek, Rocky Point Creek and Urala Creek; Fig. 2; Plates 5 & 6). The most extensive developments of mangals occur in the Ashburton delta (Table 3; Plate 7).

In contrast to other portions of the Pilbara coastline, no mangroves occur along the sandy beach and rocky shore settings on the mainland coastline, nor on any of the islands in the immediate vicinity (i.e. Thevenard, Ashburton, Direction, Tortoise, Locker, Bessieres and Serrurier Islands).

(i) Mangroves

In the study area, several medium to small scale physical features within the overall mangal flat habitat allow mangrove stands to be grouped into sub-units, each based on a distinct suite of:

- geomorphic features;
- stratigraphic-hydrologic systems;
- substrates;
- oceanographic conditions.

On this basis, the mangal flat habitat within the study area could be sub-divided as follows:

(i) mud flats;

(ii) steep tidal creek banks;

(iii) sandy spits and cheniers; and

(iv) hinterland fringes.

The vast majority of mangroves in the study area are associated with the first two of these sub-units (i.e. mud flats and the steeper banks of tidal channels; Plate 7). The mangrove communities form associations which vary in both structure and composition of species across the tidal gradient. For consistency, they are described using published schema that were developed to describe the structure and floristics of mangroves in the North West; whereby mangroves or halophytes with heights 0.25-1.5 m are termed shrubs and form heath; plants between 1.5 and 5 m are scored as tall shrubs and form scrub; and those with heights above 5 m are termed trees and form closed forest (Specht, modified after Semeniuk & Wurm, 1987).

Descriptions of mangrove floristics also follow Semeniuk, Kenneally and Wilson (1978) in recognising the appearance of monospecific, paired and mixed stands of mangrove species. Using this scheme, 16 different categories (based on variations in the height, canopy cover and species composition) were recognised from the total of 22 sites surveyed (Table 4). Nine of the transects (W, O, B, Q, C, R, T, F and H) represent the range of community structure and floristics that were recorded, and are shown schematically in Figures 4 to 12.

The mangrove species and halophytic shrubs recorded in this survey are listed in Table 5. Several species of halophytic shrubs (Table 5) also formed part of the vegetation of the mangal flats, usually as a low ground cover of varying density and cover within the mangal. These are dealt with separately in the next section.

Simple zonation of mangrove species is characteristic of the Tubridgi-Onslow coastline, and no complex associations of species were found along the tidal gradient. Neither were significant stands developed at the hinterland margin of the mangals, as is often the case for more humid regions further north (Semeniuk, Kenneally & Wilson, 1978).

Up to three mangrove species were recorded along most transects, with the highest species diversity typically found higher along those transects which intersected mangals lining the tributary creeks in the north-east sector of the Ashburton delta. In this region, the maximum number of mangrove species (6) was observed along separate transects located some distance apart (Transects U, T; Figs 3 & 10).

Avicennia marina, the grey mangrove, was recorded wherever mangals were found in the study area. It was found growing either monospecifically, paired with other species, or in mixed associations of up to five species growing together.

Monospecific stands of *Avicennia* are most prevalent where the trees form either open or closed scrub that fringes tidal creeks (e.g. Transect B, Fig. 6), or where they produce an open heath with halophytic shrubs (e.g. Transects C and H; Figs 8 & 12). *Avicennia* is also prevalent in closed scrub abutting a mixed forest (e.g. Transect R; Fig. 9). Monospecific stands of *Avicennia* also formed a closed forest (Plate 8) at some locations close to tidal creeks (e.g. Transects O & Q; Figs 5 & 7).

Paired associations of *Avicennia* and *Ceriops* were common, forming open scrub both close to and further landward from tidal creeks [e.g. Transect B; Fig. 6 and Transects C & Q (Figs. 8 & 7)], respectively. Such associations were observed at the extreme landward zone of the mangal (e.g. Transect T; Fig. 10).

At some locations in the Ashburton delta, *Avicennia* formed a closed scrub with either *Rhizophora* or *Aegiceras*, or a closed forest with occasional stands of *Aegiceras* as an understorey in the landward portion of the mangal (e.g. Transect O; Fig. 5). At Urala Creek, *Avicennia* was well developed as closed forest with occasional *Rhizophora* on a sandy setting on the north-east shore (Transect W; Fig. 4; Plate 6).

Closed mangal forests of mixed species assemblages are not uncommon in the Ashburton delta, particularly along parts of transects beside tidal creeks. Mixed assemblages forming either open or closed scrub further landward were also recorded within the delta (e.g. where mangals abut cheniers in the north-east sector (Transect H; Fig. 12). The mixed open scrub comprised *Avicennia* with occasional stands of *Aegialitis* and *Aegiceras*, while the closed mixed scrub consisted of *Avicennia* with a well-developed understorey of *Aegialitis* (Plate 9) and an occasional small *Rhizophora stylosa* (e.g. Transect H; Fig. 12). At one site fringing a tidal creek in the north-east delta, the mangal comprised a narrow (<50 m) band of vegetation supporting an open mixed scrub of five different species (Transect F; Fig. 11).

The various transects through the mangals in the Ashburton delta indicate that river mangrove (*Aegiceras*) is extensive in some parts, particularly the central and north-eastern sectors where it lines many of the tidal creeks (e.g. Transect Q; Fig. 7; Plate 11). At some locations, the river mangrove was found growing with club mangrove (*Aegialitis*) as a distinct fringe next to closed forest (e.g. Transect O; Fig. 5).

The meandering pattern of channel development evident in many of the tidal creeks and tributaries in the Ashburton delta, has led to distinct differences in species composition between opposite banks. Thus the gently-shelving, prograding banks of the 'point bar' generally display a higher species diversity compared with the steep and eroding edges on the opposite shore, i.e. on the 'cut bank' (Transect C; Fig. 8).

In these circumstances, river mangroves (*Aegiceras*) were usually present on the shallower slopes of the prograding bank and typically absent from the cut bank.

Mangals fringing the numerous creeks, small tributaries and lagoons in the north-east sector of the delta support a closed forest dominated by *Rhizophora* (Plate 10), with some *Avicennia* and smaller stands of *Aegiceras* lining the creek banks (e.g. Transect T; Fig. 10). By contrast, closed forests in the central and western sectors of the delta were found to be dominated typically by *Avicennia*, and containing an understorey of *Rhizophora* and fringing *Aegiceras* (e.g. Transects C and Q; Figs 8 & 7).

Both the aerial photographs and ground survey confirmed that the most extensive stands of *Rhizophora* in the Tubridgi-Onslow study area occur in the north-eastern sector of the Ashburton delta (Plate 7). Here, they line the tidal creeks and tributaries draining into lagoons near Entrance Point (e.g. Transects T, U & V). In some locations, the closed forests comprised more than three species. For example, in Transect R a closed forest of *Rhizophora* and *Avicennia* contains an understorey of *Aegialitis*, with *Aegiceras* fringing the tidal creek (Fig. 9).

(ii) Halophytic shrubs associated with mangal flats

Salt-tolerant halophytic shrubs are a conspicuous component of the vegetation of the mangal flats at several locations (e.g. along Transects B, F, O & Q; Figs 6, 11, 5 & 7), while they were largely absent in others (e.g. Transects R & T; Figs 9 & 10). Where present, these shrubs are established to varying degrees across the tidal gradient. Close to tidal creeks, they usually comprise a single species (e.g. *Hemichroa diandra* at Transects B & Q; Figs 6 & 7). Sometimes *H. diandra* was found to extend beyond the mangal and down the slope of the creek, and it also formed dense and compact stands throughout the mangal flat (e.g. Transect O; Fig. 5). In other locations, the halophytic vegetation in the mangal consisted of a mixture of species e.g. *Hemichroa diandra*, *Halosarcia pruinosa* and/or *H. halocnemoides* (Plate 12).

(iii) Benthic fauna of mangal flats

The resident benthic fauna recorded in mangal flats is summarised in Table 1. The fiddler crab *Uca flammula* is common at the lowest level of the mangal flat (Plate 13). Within the mangal flat habitat, the composition of the benthos alters at the point where transects intersected narrow and shallow drainage creeks that lay within unbroken mangal forest (on Transects B and Q; Table 1). Thus the mud whelks (Potamididae; Plate 14) were not recorded within these channels, while the reverse was found to be the case for species such as *U. mjobergi*, the mud crab (*Scylla serrata*) and the pistol shrimp (*Altheum* sp.). Thus in Table 1, the fauna recorded next to and within the small and shallow drainage creeks are shown separately.

Compared with the unvegetated lower tidal flats, the most conspicuous changes to the benthos within the mangal flat is an apparent replacement of (at least) the larger species of polychaetes by sipunculids ('peanut' worms), and a marked increase in the number of gastropod and crustacean species. The latter feature is presumably related both to the increased amounts of food and organic material (provided by the decaying leaf litter, detritus, seeds and seedlings of the mangal), and to the increased number of microhabitats that provide shelter, protection and spatial separation. The apparent very low abundance of polychaetes as indicated in Table 1 is treated cautiously, given the large size of the sieve mesh (2 mm).

Animals recorded from the mangal zone at Urala Creek (Transect W; Figs 3 & 4) were not included in the analysis of data for the Ashburton transects. These animals are recorded separately in Table 1 since, unlike the situation for mangal flats within the Ashburton delta, the closed *Avicennia* forest on the north-eastern shore of Urala Creek has formed over a sandy beach setting which is adjacent to a rocky shoreline within the creek itself (Transect W; Figs 3 & 4; Plate 6; see Section 3.2.4). These features probably explain why several crustaceans and gastropods recorded for the muddier and more sheltered mangals in the Ashburton delta were absent along Transect W, and why species recorded at rocky shorelines, spits or beaches were found within this mangal (e.g. *Donax* sp., *Saccostrea cuccullata* and *Scopimera* sp.; Table 1).

(iv) Birds

A total of 22 bird species were observed in mangal flat habitats (mangroves) (Table 2). Of these, 10 species are either confined to mangroves or at least restricted to them for part of their range in the State (Johnstone, 1990). These species, referred to as mangrove birds, comprise the Mangrove Heron, Bar-shouldered Dove, Mangrove Kingfisher, Mangrove Robin, Mangrove Golden Whistler, White-breasted Whistler, Mangrove Grey Fantail, Dusky Warbler, Yellow White-eye and White-breasted Woodswallow.

The distribution of mangrove birds throughout the Ashburton delta varied depending on the vegetation associations available. The Dusky Warbler, Mangrove Grey Fantail, Yellow White-eye and Bar-shouldered Dove were widespread across the different mangrove associations, however the Mangrove Robin and Mangrove Golden Whistler appeared to be restricted to the closed canopy *Rhizophora stylosa* forest found in the north-eastern sector of the delta (e.g. Transect T & U; Figs 10 & 3). The White-breasted Whistler appeared to prefer closed scrub and forest mangals dominated by *Avicennia marina.*

Nests belonging to four species were found in mangal flat habitats during this survey (see Table 2). These included the Brahminy Kite (nest on top of a closed *Rhizophora stylosa* canopy) and the Bar-shouldered Dove, Mangrove Grey Fantail and Dusky Warbler (nests in closed scrub of *Avicennia marina*).

The remaining species recorded in mangal flats are species which use extensive areas of adjacent habitats, but visit mangroves for certain requirements (e.g. to feed, nest or shelter). For example, the Brahminy Kite catches fish from nearshore waters and tidal creek systems, and nests in mangroves. The Brown and Singing Honeyeaters occur extensively throughout the hinterland regions.

3.2.1.3 Salt Flats

Large expanses of tidal salt flats occur between the dunal barriers of the coastal tract and the sand plains of the hinterland (Fig. 2). The salt flats gradually slope from supratidal areas (which are only rarely inundated by extreme tides, major cyclonic surges or floods), down to the level of mean high water springs, where they abut the mangal flat communities fringing tidal creeks. Since the salt flats are only infrequently inundated, they are typically in the form of a desiccated, salt-encrusted mud/clay/fine sand flat, but they do support algal mats and samphire communities.

(i) Algal mats

The algal mats of the coastline near Onslow have recently been examined and described as part of the public environmental assessment of the proposed solar salt project (Gulf Holdings Pty Ltd, 1990; EPA, 1991). These descriptions indicate that the algal mats vary from sheet form in lower elevations (Plate 15) to a pustular or crinkled form at higher elevations. The mat is typically 8-10 mm in thickness (wet) and is composed mostly of a blue-green algae (*Microcoleus chthonoplastes* and, rarely, *Oscillatoria* spp. (in Appendix 3 of Gulf Holdings Pty Ltd, 1990).

Algal mats were present on some of the salt flats inspected during the present survey behind the Ashburton delta. It was not possible, however, to deduce the full extent of cover or development as they were desiccated and discoloured at the time of this survey. Where the algal mats still retained moisture, however, their dark colouring and texture was readily identifiable from a distance, and they could be easily rolled and peeled back from the soil surface (e.g. on Transect J; Fig. 3.; Plate 15).

Patchy mats were also found on the extensive area of unvegetated salt flats behind the mangroves on Ashburton delta (e.g. Transect L; Fig. 3). Although this area is part of the overall mangrove community, its landward location and elevation indicate that it becomes wetted only during very high spring tides or flood events. At the time of inspection, the soil surface was very dry and the mats, where present (or where they could be identified) were desiccated.

(ii) Halophytic shrubs

Halophytic plant communities are established over large sections of the tidal flats, either on an otherwise bare salt flat or over low open heath (e.g. Transects A, B, J, L, O; see Figs 5 & 6). At higher elevations, these communities form a distinct band of vegetation around sand islands and an extensive shrub community at lower elevations (e.g. Plate 16).

Halophytic shrubs also form a narrow but distinct peripheral band of vegetation around the perimeter of the large salt flats behind the mangals of the Ashburton delta (Transect L; Fig. 3). The sandy ridges were vegetated by *Triodia*, with a gentle slope from the sand ridge to the flats colonised by *Frankenia, Neobassia, Halosarcia halocnemoides* and *H. pruinosa.* The halophytes on the flats were clearly zoned, with the outer zone consisting of *Halosarcia pruinosa* adjacent to a zone of *H. halocnemoides.*

The most common species encountered on salt flats were *Halosarcia pruinosa, Halosarcia halocnemoides* (ssp. *tenuis*), *Muellerolimon salicorniaceum* and *Hemichroa diandra. Halosarcia pruinosa* and *H. halocnemoides* were found to be common at Transects A, B and O (Figs 3, 6 & 5; Plate 16). However, other locations were vegetated either by a mixture of *H. halocnemoides* and *Muellerolimon* that opened into extensive stands of *H. halocnemoides* (e.g. at Secret Creek; Transect M; Fig. 3), or by monospecific stands of *Muellerolimon* which form a heath at the edge of open mangrove scrub at Transects B and P (Figs 6 & 3; Plate 17).

(iii) Benthic fauna

The abundance and diversity of the benthic fauna in the salt flat habitat was low, with records of animals or their activities restricted to those areas immediately behind the rear edge of the mangal flat. It is likely, however, that both the diversity and numbers of benthic animals would markedly increase immediately following periods when much of the salt flat habitat becomes inundated by equinoxial spring high tides, storm surges or flooding.

(iv) Birds

A low diversity (10 species) of birds were observed amongst or flying over salt flats (Table 2). Typical grassland and shrubland species such as the Singing Bushlark, Richard's Pipit and the White-winged Wren were seen within the extensive samphire communities. Aerial feeders frequently seen over the salt flats included the White-backed Swallow, Rainbow Bee-eater and White-breasted Woodswallow. Observations of salt flats during periods of inundation may reveal their use by wading birds, although none were noted at the time of this survey.

3.2.2 Sand Spits and Cheniers

Sand spits and cheniers typically occur as a series of 'shoestring' or bar deposits of sandy sediments that are built up to high spring tidal or supratidal levels (Plates 1 & 2). Sand spits and a small chenier have formed at the main mouth of the Ashburton River, but they are most prominent in the eastern section of the delta where they produce a series of ridges parallel to the mainland shore (Fig. 3; Plate 18)

In the eastern section of the delta, the most seaward (i.e. youngest chenier) is not vegetated. The seaward flank of this chenier dips into subtidal sandy sheet some 1.5-2 m deep, which extends offshore and gradually slopes down to a shore parallel 5 m bathymetric contour (Fig. 3). The landward flank slopes into low to subtidal muds and fine silty sands that have been deposited in a lagoon setting.

The next chenier to landward supports some scattered low mangroves, with its seaward flank sloping into the lagoon described above. The landward flank of this chenier slopes into a smaller low tidal lagoon fringed by mangroves (Transect H, Fig. 12).

Further inland, older cheniers are vegetated by hinterland plants (e.g. *Triodia pungens*) and are fringed by halophytic shrubs such as *Frankenia ambita, Neobassia astrocarpa* and *Halosarcia* sp. The flanks of these cheniers lead onto high tidal to supratidal salt flats.

(i) Benthic fauna

The benthos recorded from the sandy spits and cheniers at the Ashburton River delta are summarised in Table 1. The distribution of the fauna across these sand bars is governed principally by the degree of exposure to the seaward wave climate. Thus pipis (*Donax* sp.) were sieved from sediments on the seaward sides of the sand spits protruding from the main mouth of the Ashburton River, while the burrow holes and pellets of sand bubbler and soldier crabs (*Scopimera* and *Mictyris* spp.) were often abundant on the protected, landward-facing flanks (e.g. Transect R, Plates 19 & 20). Similarly, small whelks (*Nassarids*), juvenile prawns (*Penaeus*) and hermit crabs were found only on the protected flanks, while the highest numbers of polychaetes were collected on the inner side of the main chenier that dips into the lagoon on the eastern side of the delta.

(ii) Birds

Sand spits and cheniers were used primarily as resting areas for some large waterbirds, waders and a large number of terns (Table 2). Flocks of up to 300 Gull-billed Terns, 200 Whiskered Terns and 150 Crested Terns were seen congregating on sand spits at the main Ashburton channel mouth. Birds frequently gathered on spits and cheniers at high tide and then dispersed to feeding grounds during lower tides. Some waders were seen feeding on the lower peripheral slopes of the more seaward spits and cheniers.

3.2.3 Sandy Beaches

Sandy beaches, composed of medium to coarse grained calcareous sands and shelly sands, are widespread along the seaward margin of the coastline (Fig. 2). The beaches are backed by low foredunes (vegetated by coastal species, e.g. *Spinifex longifolius*, *Rhagodia preissii* and *Ipomea brasiliensis*), which front parabolic dune blowouts or vegetated parallel dune systems (e.g. the long curving beach running between the main mouth of the Ashburton river and Entrance Point; Fig. 3).

(i) Benthic fauna

The macro-infauna of sandy beaches along both the mainland coastline and at Locker Island is typically depauparate, and comprises surf-zone bivalves (burrowing pipis; *Donax* spp.), together with isopods and low numbers of polychaete worms. Ghost crab (*Ocypode* sp.) burrows are sporadic in distribution. The beach benthos data are summarised in Table 6.

(ii) Birds

A total of 11 bird species were observed on the mainland sandy beaches (Table 2). These were mostly wading birds feeding on small invertebrates in the lower portion of the beach. Crested and Caspian Terns also used the higher tidal portions of the beach as a resting area.

3.2.4 Rocky Shores

Nearly 2 km of eroded rocky shoreline lies between the Ashburton delta and the entrance to Hooleys Creek (Fig. 2; Plate 21). Rocky shores along other portions of the coastline between Tubridgi Point and Onslow are shorter in length, but no more developed except along parts of Tubridgi Island and at Beadon Point (Fig. 2). The rocky shore lying halfway between Urala Creek and Locker Point (Fig. 2) was the least developed, comprising a smooth limestone pavement that protruded from the sandy beach at MSL. The rocky shore inside the entrance to Urala Creek lies adjacent to a mangal dominated by *Avicennia marina* (Plate 22).

(i) Benthic fauna

Agglomerations of the rock oyster *Saccostrea cuccullata* along the mainland coast occur along the rocky shores at Urala Creek, east of Entrance Point (at Site S on Fig. 3), and are most developed at Beadon Point (near the ruins of the old town jetty). The diversity of species recorded at these sites is typical for rocky shores in the Pilbara region, and is summarised in Table 6.

(ii) Birds

When exposed during low tides, the rocky platforms are used as feeding areas by reef dwelling birds (e.g. Eastern Reef Egret) and waders, and as resting areas by terns. A total of 15 bird species were observed at this habitat (Table 2).

3.2.5 Nearshore Reefs and Shoals

Nearshore and fringing reefs close to the mainland coastline occur due west of Locker Point (Plates 23 & 24), around Locker Island (see Section 3.2.6) and Ashburton Island, and at Ward Reef (Fig. 2). A large area of *Turbinaria* coral was observed on the south-west and south sides of Ward Reef, and this reef has been reported to represent one of the closest coral areas to the mainland coast in the region (e.g. Gulf Holdings Pty Ltd, 1990).

However, patches of inshore reef colonised by *Turbinaria*, *Porites* and faviid corals and lying less than 20 m from the mainland shore were found to extend for almost 1 km beside a steep sandy beach that runs between 1 km and 2 km south-west of Locker Point (Fig. 2). This observation was made at a time when water clarity was high and when the tide was close to LAT (morning of 5 December 1990). The small patches of coral-covered reef lie in the sheltered 'Boat Channel' that runs between Locker Point and Urala Creek, as marked on R.A.N. hydrographic chart AUS 774. While coral cover on the linear nearshore reef, that runs along the seaward side of the boat channel, was low (<10%; Plates 23 & 24), species diversity was much higher (Table 7). The diversity was also greater than that recorded on the low-tidal portion of the limestone platform surrounding Locker Island (Table 7; Section 3.2.6).

Hydrographic chart AUS 774 also depicts a drying nearshore reef ('Parkes Reef') some 300 m long by 100 m wide that lies immediately to the south-east of the main mouth of the Ashburton River. However, a careful grid search of the area at low tide (3 December 1990) using a Furuno paper-recording echosounder failed to detect any sign of this structure. The bottom trace remained smooth throughout the search, with water depth ranging slowly between 1.5 m (inshore) and 4.0 m (offshore).

Shoal areas where depths rise from between 8 and 10 m to less than 5 m are shown on Figure 2. Descriptions of the sediments and benthic fauna of the seafloor in the shoal areas of the Roller field are given in Appendix 3 of the Roller Oilfield Development CER.

3.2.6 Locker Island

The intertidal habitats of Locker Island were inspected on two occasions when the tide was near MLWS. Narrow and steep beaches of medium to coarse grained calcareous sands encircle this island (Plate 25). The sediments of these beaches grade to a thin sheet of coarse shelly grit near MSL. This point marks the protrusion of a wide and extensive peneplanar intertidal limestone pavement which at certain points on the north and north-west sides extends over 400 m from the sandy shoreline. Wide depressions within this pavement are filled with sand veneers colonised by patchy meadows of seagrass (*Halophila ovalis*) and macroalgae (Plate 26). Thick sand sheets have built up to form low sand spits on the seaward edge of the pavement that extends from the north-west side of the island.

The seaward edge of the pavement is broken and strewn with coral and limestone rubble. On the north-east side of Locker Island, the rubble-strewn platform supports large agglomerations of rock oysters (*Saccostrea cucculata;* Plate 27). In this region, a comprehensive suite of rocky shore fauna is present (Table 7; Plate 28).

The broken pavement terminates at about the level of MLWS, and beyond this area lies a fringing reef where coral cover exceeds 30%. Aerial photography indicates that the fringing reef is present on most (if not all) sides of the island. On the south-west side, the fringing coral reef is less than 15 m from the beach owing to the narrowness of the limestone pavement. Beyond the fringing reef, aerial photography indicates that there are extensive tracts of macroalgae colonising subtidal limestone.

Locker Island is an A-Class reserve (No. 29011) vested with the National Parks Authority (NPA) for the conservation of fauna and flora. A large number of Wedge-tailed Shearwaters (mutton birds) make their nesting burrows on this island, and at the time of the visit, recent tracks and nest hollows of turtles were observed on the sandy beach on the north side of the island.

4 DISCUSSION

4.1 BACKGROUND

There can be little doubt that of the intertidal habitats surveyed for this report, the tidal flats of the Ashburton River delta are the most important ecological resource within the study area. However little information is available regarding the delta's conservation value, other than at a very broad level of discussion [e.g. in 1975 the EPA, through its Conservation Through Reserves Committee (EPA, 1975) recommended that in the coastal region from Exmouth Gulf to the Mary Anne Islands that biological and sedimentological surveys be carried out on tidal and supra-tidal flats 'in the belief that the area may provide a supply of nutrients to the adjacent marine ecosystem as well as being a nursery area for fisheries'.

Mangrove systems are generally regarded as being biologically productive but, as pointed out previously (LSC, 1987) this does not in itself necessarily mean that they should automatically receive a high ecological, scientific or commercial importance.

Compared with mangrove systems elsewhere in Australia, those in Western Australia have been little studied with respect to their role in supporting nearshore productivity or their contribution to the maintenance of commercial and other fisheries. Usually the link has been made indirectly. Nevertheless, all mangroves are believed to serve several important functions:

(i) buffers against storm surge and coastal erosion;

(ii) contributors to primary productivity of the marine environment; and

(iii) food sources and nursery and breeding areas for important commercial and recreational fish and other organisms.

The lack of comprehensive data on the productivity of the local mangrove habitats and the extent to which they provide food and nursery sites to fish and other organisms makes it difficult to define the absolute conservation value of these systems. This comment relates not only to the mangroves themselves but the mangrove community, which includes the extensive salt flats and halophytic shrubs constituting the intertidal.

Although the role of mangroves in sediment stabilisation and shore protection are relatively easy to demonstrate on the Pilbara coastline, a recent review of research relevant to conservation of tropical mangroves addresses the difficulty in demonstrating the importance of other factors, including the role in contributing "outwelled" nutrients to the nearshore ecosystem and their role in providing nursery grounds for fish (Hatcher, Johannes & Robertson, 1989). In addition, the primary productivity of mangrove systems can vary enormously at both local and regional scales (Hatcher, Johannes & Robertson, 1989) and the nutrient dynamics of mangrove habitats are still poorly understood for nearly all of the Western Australian coastline where it supports mangroves.

Similarly, there have been few quantitative studies of the importance of mangroves as fish nursery grounds at low latitudes, although greater fish abundance and diversity has been demonstrated in mangrove-lined lagoons compared with adjacent habitats (see Hatcher, Johannes & Robertson, 1989). More directly relevant to the study area, however, are the findings of Staples and others in northern Australia, who have clearly demonstrated that the prawn *Penaeus merguiensis* is found only in mangrove-lined creeks during its juvenile phase (see Hatcher, Johannes & Robertson, 1989). These findings are also supported by those of Robertson and Dukes (1987, cited by Hatcher, Johannes & Robertson, 1989) who have shown that densities of fish and prawns in mangrove habitats of four different estuaries in north-eastern Australia were up to an order of magnitude greater than in adjacent areas.

The above findings lend support to the notion that the mangroves are indeed important in maintaining some stages of the life cycle of fish and thus maintenance of the fishery. What remains to be established, is the extent to which the local fishery relies on the mangroves on account of their recognised high productivity (i.e. contribution of carbon, organics and nutrients) or, as recent findings from other locations suggests, on the dependence of juvenile phases of particular species on the estuarine characteristics of the regions, such as their ability to provide freshwater outflow (see Hatcher, Johannes & Robertson, 1989).

Given the above unknowns and lack of available data on local and regional mangroves, the conservation value of the study area must be evaluated at this stage from a limited perspective.

4.2 CONSERVATION VALUE OF THE ASHBURTON RIVER DELTA

For this report assessment of conservation significance is made largely on the basis of the extent and diversity of the mangrove assemblages observed and placed in regional context.

The significance of the mangrove systems of the Ashburton River delta and offshore islands has been previously assessed on the basis of aerial surveys (LSC, 1987). Similarly field inspection of the mangroves north of Onslow (Gulf Holdings Pty Ltd, 1990) provides a general picture of the mangrove settings north of Onslow.

In the absence of other information, these earlier surveys provide a regional perspective to complement the present surveys of mangrove environments from Tubridgi to Onslow.

Mangals of the Ashburton delta display features characteristic of the Pilbara mangals, with simple zonation and relatively low species diversity compared with mangals in wetter, more humid climates at lower latitudes on the Western Australian coast (Semeniuk, Kenneally & Wilson, 1978).

The total mangrove species pool of the delta is identical to mangrove settings on the Pilbara coast further north, e.g. the Dampier Archipelago (Semeniuk & Wurm, 1987), the results of the present survey extend the species records for the mainland mangrove habitats around Onslow, with *Bruguiera* recorded growing along with the other five species at the same location in the eastern sector of the Ashburton delta.

Previously only three mangrove species had been recorded from the Onslow region (*Avicennia, Rhizophora* and *Ceriops*), with the latter two not abundant; see Semeniuk (1983). A more recent aerial survey of the region from Ashburton River to the Mangrove Islands indicates that the diversity is somewhat greater than previously reported, with six mangrove species recorded (LSC, 1987).

One of the mangroves recently recorded, *Bruguiera exaristata*, was presumed to be restricted to the islands, although the present survey confirms its presence on the mainland. *Bruguiera* was not recorded at Urala Creek or on any of the transects in the western sector of the Ashburton delta during this survey. Limited stands of *Bruguiera* have recently been reported as far south as Gales Bay, in Exmouth Gulf (Johnstone, 1990). In the absence of further information and the present survey, it is likely that the southern limit of *Aegiceras* and *Aegialitis* in Western Australia is centred on the Ashburton delta.

Like the mangroves, halophytic shrub species recorded during this survey were typical of those found in similar habitats in other mangrove environments on the Pilbara coast (Craig, 1983).

Johnstone (1990) recorded eleven species of mangrove birds in the mangrove systems of the Pilbara region. Ten of these species were recorded (during this survey and by Johnstone, 1990) in the Ashburton delta with the highest diversity existing in the closed Rhizophora forest and adjacent mangal communities found in the north-eastern sector of the delta. Two of these species, the Mangrove Golden Whistler and Mangrove Robin, both which depend on Rhizophora, have their southern limit of distribution as Exmouth Gulf (Johnstone, 1990).

The occurrence of mangrove birds along the Pilbara coastline displays a distribution reflecting areas of high mangrove diversity and extensive development (and high mangrove bird diversity) between large areas of low diversity and extent (low bird diversity) or no occurrence. In this context, the diverse and expansive mangals of the Ashburton delta are important for both the local and regional maintenance of mangrove bird populations. The low tidal mud flats that are connected to mangal flats in the seaward edge of the delta, were also identified as important for two mangrove bird species (Mangrove Kingfisher and Mangrove Heron) and shorebirds (Section 3.2.1.1).

The Ashburton River delta is thus given high conservation value because:

(i) it is the most southern of the delta settings on the Pilbara coast with typical mangrove assemblages found in the arid north-west;

(ii) it contains species of mangroves which, on account of the setting, are probably at their southern geographic limit on the western coastline of Australia;

(iii) at the local level, mangroves are not abundantly distributed other than on the delta and these are therefore considered to have an important role as sites of primary production and nutrient recycling, as nursery grounds for the local prawn fishery, and as habitat for maintenance of regional mangrove bird populations.

The mangrove habitats of the Ashburton delta are potentially highly sensitive to the potential effects of oil spillage and as such warrant special protection.

It should be noted, however, that these communities can be affected also by natural processes. For example, the delta complex is highly dynamic. Cyclonic activity in summer and flood events create periods of instability to the mangrove settings around the delta mouth. Major events can modify or entirely remove sections of the barrier islands and beaches, and can alter the lagoons and mangrove habitats, with resulting loss of mangroves through burial by sand (see Plate 7), by wind-throw or through heavy wave action undermining roots and eroding existing substrate. In addition, the arid climate can impose periods of natural stress, e.g. through atypical weather patterns which create prolonged periods of low rainfall. Periodic die-back of mangroves from natural causes such as this has been observed in tropical-arid settings elsewhere (Cintron et al., 1978) and can be expected to occur also on this coast.

4.3 RECOMMENDED PRIORITY AREAS FOR CONSERVATION AND PROTECTION

Areas presently designated as having the highest priority for protection against oil spill in the current OSCP for Permit Area TP/3 Part 1 are as follows:

(i) first priority is assigned to mangroves within the Ashburton River system and Beadon Creek;

(ii) shallow coral reefs receive second highest priority;

(iii) beaches at Thevenard, Airlie and Serrurier Island are accorded high priority during the turtle breeding season.

Secondary protection was assigned to mangroves around the Onslow townsite and to the series of tidal creeks and mangrove embayments immediately north of Onslow (LSC, 1987).

On the basis of the findings of this study these priorities are still considered appropriate. Within the Ashburton delta, however, priority should be given to protecting the Ashburton delta mangrove ecosystem, particularly the system of creeks, tributaries and lagoons close to Entrance Point, as these display the greatest structural complexity and diversity of mangrove species and are important areas for a wide variety of birds.

Additionally, because of the importance of the Beadon Creek system, both regionally and to the residents of Onslow, for recreational and commercial pursuits and as a safe anchorage, this creek should also be given priority for protection.

The mangrove systems at Tubridgi and in tidal creeks between Tubridgi and the Ashburton River generally display lower species diversity and less extensive mangrove habitats than the Ashburton delta and, consequently, they are given second priority on the basis of their likely ecological significance.

5 REFERENCES

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TABLE 1

DISTRIBUTION OF BENTHIC FAUNA WITHIN THE ASHBURTON RIVER DELTA AND ADJACENT TO URALA CREEK

HABITAT TYPE	LOCATION	BENTHIC FAUNA		ABUNDANCE*
Ashburton River delta				
Low tidal flat (mud flats)	Transects O and R	POLYCHAETES	Orbinids, Phyllodocids, Glycerids	High
		MOLLUSCS		
		Gastropods:	Onchidae (*Onchidium* sp.)	Low
		Bivalves:	Tellinidae (2 spp.)	Low-Medium
			Veneridae (1 sp.)	Low-Medium
		CRUSTACEANS		
		Shrimps:	Alpheidae (*Alpheus* sp.)	Low
			Penaeidae (*Penaeus latisulcatus*)	Unknown
		Crabs:	Ocypodidae (*Uca flammula, Uca* sp., and *Macrophthalmus* sp.)	Low-Medium
			Portunidae (*Charybdis* sp.**)	Low
		TELEOSTS		
		Gobioidae:	*Periophthalmus argentiventralis* and other gobioids	Low-Medium
Mangal flats	Transects B, Q, T and U	SIPUNCULIDS	*Phascolosoma* sp.	Low
		MOLLUSCS		
		Gastropods:	Planaxidae (*Planaxis* sp.**)	Low
			Potamididae (*Telebralia palustris, T. sulcata, Telescopium teloscopium*)	Low-Medium
			Neritidae (*Nerita* sp.)	Low
			Cerithiidae (several spp.)	Low-Medium
		Bivalves:	Tellinidae (1 sp.)	Low-Medium
		CRUSTACEANS		
		Lobster:	Astacura (*Thalassina anomala*)	Low
		Crabs:	Ocypodidae (*Uca flammula, U. mjobergi, U.* spp. and *Macrophthalmus* sp.)	Low-Medium
			Grapsidae (*Metopograpsus frontalis*)	Low-Medium
			Sesarmidae (*Sesarma* sp.)	Low-Medium
		TELEOSTS		
		Gobioidae:	*Periophthalmus argentiventralis*	Low-Medium
Creeks within mangals	On Transects B and Q	SIPUNCULIDS	*Phascolosoma* sp.	Low-Medium
		MOLLUSCS		
		Gastropods:	Onchidae (*Onchidium* sp.)	Low
			Cerithiidae (2 spp.)	Low-Medium
		CRUSTACEANS		
		Shrimps:	Alpheidae (*Alpheus* sp.)	Low
		Lobster:	Astacura (*Thalassina anomala*)	Low
		Crabs:	Ocypodidae (*Uca flammula, Uca* sp. and *Macrophthalmus* sp.)	Low-Medium
			Portunidae (*Scylla serrata*)	Low
			Sesarmidae (*Sesarma* sp.)	Low-Medium
		TELEOSTS		
		Gobioidae:	*Periophthalmus argentiventralis* and other gobioids	Low-Medium

* Low = less than 1 per m^2
Medium = between 1 and 10 per m^2
High = over 10 per m^2
** identification tentative

TABLE 1 (Cont'd)

DISTRIBUTION OF BENTHIC FAUNA WITHIN THE ASHBURTON RIVER DELTA AND ADJACENT TO URALA CREEK

HABITAT TYPE	LOCATION	BENTHIC FAUNA		ABUNDANCE*
Ashburton River delta				
Salt flats (with halophytes)	End of Transects T and U	MOLLUSCS		
		Gastropods:	Littorinidae (2 sp.)	Low-Medium
			Ceriithidae (1 sp.)	Low
		CRUSTACEANS		
		Crabs:	Ocypodidae (*Uca* sp.)	Low
			Sesarmidae (*Sesarma* sp.)	Low
Sand spits and cheniers	Mouth of Ashburton River and Transect R	POLYCHAETES	Lumbrinerids, Phyllodocids, Glycerids	Medium
		MOLLUSCS		
		Gastropods:	Nassaridae (*Nassarius dorsatus*)	Low
			Cerithiidae (1 sp.)	Low
		Bivalves:	Donaciidae (*Donax columbella*, *Donax* sp.)	Medium
			Tellinidae (1 sp.)	Low
		CRUSTACEANS		
		Isopods	Shore slaters	Medium
		Shrimps:	Alpheidae (*Alpheus* sp.)	Low
			Penaeidae (*Penaeus latisulcatus*)	Unknown
		Crabs:	Ocypodidae (*Ocypode* sp., and *Scopimera* sp.)	Low-High
			Mictyridae (*Mictyris* spp.)	Low-Medium
			Anomurans (hermit crabs)	
Urala Creek				
Mangal flats	Transect W (Urala Creek)	POLYCHAETES	Phyllodocids	
		MOLLUSCS		
		Gastropods:	Limpets (*Siphonoria*)	Low
			Littorinids (2 sp.)	Low
			Nerita (1 sp.)	Low
		Bivalves:	Mytilidae (1 sp.)	Low
			Osteidae (*Saccostrea cuccullata*)	Low-Medium
			Donaciidae (*Donax* sp.)	Low
		CRUSTACEANS		
		Lobster:	Astacura (*Thallassina anomala*)	Low
		Crabs:	Ocypodidae (*Ocypode* sp.)	Low
			Grapsidae (*Metopograpsus* sp.)	Low
		TELEOSTS		
		Gobioidae:	*Periophthalmus argentiventralis*	Low

* Low = less than 1 per m^2
Medium = between 1 and 10 per m^2
High = over 10 per m^2

** identification tentative

TABLE 2

BIRDS OBSERVED UTILISING HABITATS DURING FIELD SURVEY

BIRDS*	CREEK AND RIVER CHANNELS	LOW TIDAL FLATS	MANGROVES	SALT FLATS	SPITS AND CHENIERS	SANDY BEACHES	ROCKY PLATFORM
LARGE WATERBIRDS							
Pied Cormorant	X				X		
Australian Darter	X		X		X		
Australian Pelican	X	X			X		
Eastern Reef Egret		X					X
Great Egret		X					
White-faced Heron		X	X		X		X
Mangrove Heron		X	X				
RAPTORS							
Brahminy Kite	X,A	X,A	X,A,N				
White-breasted Sea Eagle	X,A		X,A		X,A		
Osprey	X,A	X,A	X,A		X,A	X,A	
Australian Kestrel				X,A			
WADERS							
Grey Plover		X				X	X
Large Sand-Plover		X			X	X	X
Red-capped Plover		X			X	X	X
Red-necked Stint		X				X	X
Sanderling		X			X		
Curlew Sandpiper		X					
Grey-tailed Tattler		X					X
Great Knot		X					
Ruddy Turnstone					X	X	X
Bar-tailed Godwit		X			X	X	X
Whimbrel		X					X
Eastern Curlew		X	X				
Marsh Sandpiper		X					
Common Greenshank		X	X		X		X
Common Sandpiper		X	X		X		
Terek Sandpiper		X					
Black-winged Stilt		X					
Pied Oystercatcher		X				X	X

* common names follow Slater, Slater and Slater (1986)

X = recorded during field survey (28.11.90 - 4.12.90)
A = mostly aerial
N = nest record

TABLE 2 (Cont'd)

BIRDS OBSERVED UTILISING HABITATS DURING FIELD SURVEY

BIRDS*	CREEK AND RIVER CHANNELS	LOW TIDAL FLATS	MANGROVES	SALT FLATS	SPITS AND CHENIERS	SANDY BEACHES	ROCKY PLATFORM
GULLS AND TERNS							
Silver Gull	X,A	X,A			X	X	X
Gull-billed Tern	X,A	X,A			X		
Crested Tern	X,A				X	X	X
Caspian Tern	X,A				X	X	X
Fairy Tern	X,A	X,A					
Whiskered Tern	X,A	X,A			X		
LAND BIRDS							
Bar-shouldered Dove			X,N	X			
Budgerigar				X			
Mangrove Kingfisher	X	X	X				
Rainbow Bee-eater			X,A	X,A			
Welcome Swallow				X,A			
White-backed Swallow				X,A			
Singing Bushlark				X			
Richard's Pipit				X			
Mangrove Robin			X				
Mangrove Golden Whistler			X				
White-breasted Whistler			X				
Mangrove Grey Fantail			X,N				
White-winged Wren			X	X			
Dusky Warbler			X,N				
Singing Honeyeater			X				
Brown Honeyeater			X				
Yellow White-eye			X				
White-breasted Woodswallow			X,A	X,A			
TOTAL SPECIES	13	29	22	10	18	11	15

* common names follow Slater, Slater and Slater (1986)

X = recorded during field survey (28.11.90 - 4.12.90)
A = mostly aerial
N = nest record

TABLE 3

OCCURRENCE OF MANGROVE SPECIES ALONG THE ONSLOW TO TUBRIDGI POINT COASTLINE

MANGROVE SPECIES *	COMMON NAME	BEADON CREEK	4 MILE CREEK	MIDDLE CREEK	HOOLEYS CREEK	ASHBURTON DELTA	SECRET CREEK	ROCKY POINT CREEK	URALA CREEK
Aegialitis annulata	Club Mangrove					X			
Aegiceras corniculatum	River Mangrove					X			
Avicennia marina	Grey Mangrove	X	X	X	X	X	X	X	X
Bruguiera exaristata	Ribbed-fruited Mangrove					X			
Ceriops tagal	Spurred Mangrove	X				X	X		
Rhizophora stylosa	Red Mangrove	X				X	X		X

* after Semeniuk, Kenneally and Wilson (1978)

TABLE 4

VARIATION IN COMMUNITY STRUCTURE AND FLORISTICS OF MANGROVE COMMUNITIES IN THE STUDY AREA

(i)	Open heath of monospecific *Avicennia*
(ii)	Open scrub of monospecific *Avicennia*
(iii)	Closed scrub of monospecific *Avicennia*
(iv)	Closed forest of monospecific *Avicennia*
(v)	Open scrub of paired *Avicennia* and *Ceriops*
(vi)	Closed scrub of paired *Avicennia* and *Ceriops*
(vii)	Closed scrub of paired *Avicennia* and *Rhizophora*
(viii)	Closed scrub of paired *Avicennia* and *Aegiceras*
(ix)	Closed forest of paired *Avicennia* and *Aegiceras*
(x)	Open mixed scrub of *Avicennia*, *Aegiceras* and *Aegialitis*
(xi)	Closed mixed scrub of *Avicennia*, *Aegiceras* and *Rhizophora*
(xii)	Open mixed forest of *Avicennia*, *Bruguiera* and *Ceriops*
(xiii)	Closed mixed forest of *Avicennia*, *Rhizophora* and fringing *Aegiceras*
(xiv)	Closed mixed forest of *Rhizophora*, *Avicennia* and fringing *Aegiceras*
(xv)	Closed mixed forest of *Avicennia*, *Rhizophora*, *Aegialitis* and *Aegiceras*
(xvi)	Open mixed scrub of *Avicennia*, *Ceriops*, *Rhizophora*, *Aegiceras* and *Aegialitis*

Notes: 1. Terminology for community structure after Specht, modified by Semeniuk & Wurm (1987), and for floristics, after Semeniuk, Kenneally and Wilson (1978).
2. The most dominant species in the assemblage is listed first.

TABLE 5

MANGROVES AND HALOPHYTIC SHRUBS RECORDED IN THE INTERTIDAL HABITATS OF THE STUDY AREA

MANGROVES
Aegialitis annulata R.Br. (Plumbaginaceae)
Aegiceras corniculatum (L.) Blanco (Myrsinaceae)
Avicennia marina (Forsk.) Vierh. (Avicennaceae)
Bruguiera exaristata Ding Hou (Rhizophoraceae)
Ceriops tagal (Perr.) C.B. Rob. (Rhizophoraceae)
Rhizophora stylosa Griff. (Rhizophoraceae)
HALOPHYTIC SHRUBS
Frankenia ambita Ostenf. (Frankeniaceae)
Halosarcia halocnemoides (Nees) P.G. Wilson ssp. *tenuis* P.G. Wilson (Chenopodiaceae)
Halosarcia pruinosa (Paulsen) P.G. Wilson (Chenopodiaceae)
Halosarcia pterygosperma (J.M. Black) P.G. Wilson (Chenopodiaceae)
Hemichroa diandra R.Br. (Amaranthaceae)
Neobassia astrocarpa (F. Muell.) A.J. Scott (Chenopodiaceae)
Muellerolimon (=*Limonium*) *salicorniaceum* (F. Muell.) Lincz. (Plumbaginaceae)

Note: The taxonomic family to which each plant belongs is given in the parentheses.

TABLE 6

DISTRIBUTION OF BENTHIC FAUNA OF MAINLAND SAND BEACHES AND ROCKY SHORES BETWEEN URALA CREEK AND BEADON CREEK (ONSLOW)

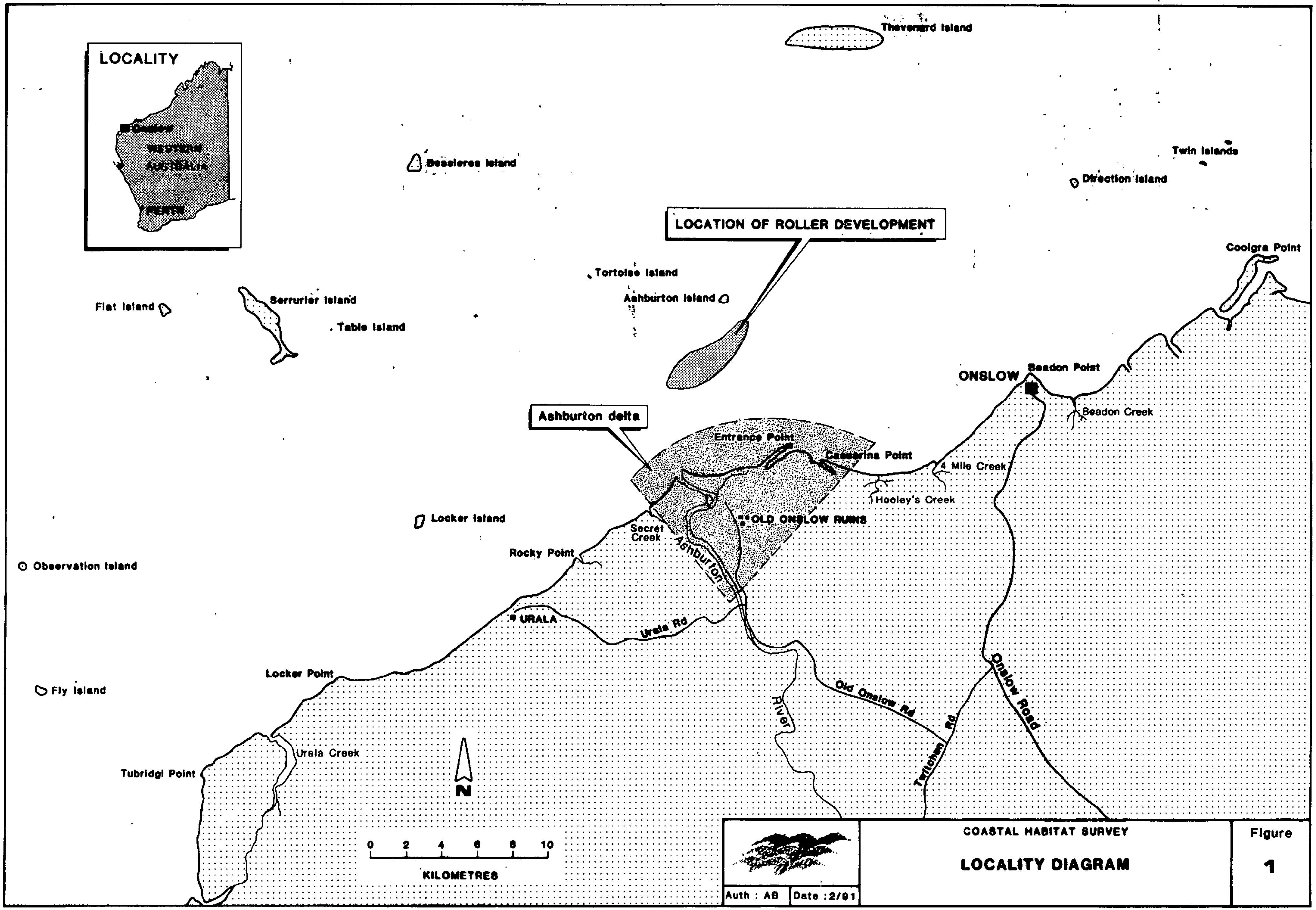
HABITAT TYPE	LOCATION	BENTHIC FAUNA		ABUNDANCE*
Beaches	North end of Transect R; west of Locker Point; and Locker Island	POLYCHAETES	Lumbrinerids	Low
		MOLLUSCS		
		Bivalves:	Donaciidae (*Donax columbella, D.* sp.)	Low-Medium
			Tellinidae (1 sp.)	Low
		CRUSTACEANS		
		Isopods	Shore slaters	Low
		Crabs:	Ocypodidae - Ghost crab (*Ocypode fabricii*)	Low
Rocky shore	East of Entrance Point; and Beadon Point (near old jetty)	MOLLUSCS		
		Chitons:	*Acanthopleura gemmata, A. spinosa*	Medium
		Gastropods:	Limpets (*Acmaeid* spp. and *Siphonoria*)	Medium
			Littorinidae (3 spp., inc. *Nodilittorina nodosa*)	High
			Neritidae (2 spp.)	
			Trochidae (3 spp.)	
			Thaididae (inc. *Morula granulata*)	Low
		Bivalves:	Ostreidae (*Saccostrea cuccullata*)	Low-High
			Mytilidae (1-2 spp.)	Low-High
		CRUSTACEANS		
		Barnacles:	Balanidae (*Tetraclita porosa, Balanus*)	High
			Chthalmalidae (*Chthamalus* spp.)	High
		Crabs:	Grapsidae (*Metopograpsus* sp.)	Low-High

* Low = less than 1 per m^2
Medium = between 1 and 10 per m^2
High = over 10 per m^2

TABLE 7

BENTHIC FAUNA ON THE LOW TIDAL LIMESTONE PAVEMENT AND NEARSHORE REEF OF LOCKER ISLAND

FAUNA		LOCKER ISLAND (LIMESTONE PAVEMENT)	LOCKER POINT (NEARSHORE REEF)
PORIFERA	Ball sponges - 2 spp.	X	
CNIDARIA			
Actinaria:	Sea anemones - 3 spp.	X	
Madreporaria:	*Acropora, Leptoria*	X	
	Pocillophora, Faviidae, Lobophillia, Turbinaria, Porites,		X
	Galaxia (2 sp.), *Montipora, Acropora*		X
POLYCHAETES	Terebellids	X	
	Serpulids	X	X
MOLLUSCS			
Chitons:	*Acanthopleura gemmata, A. spinosa*	X	
Gastropods:	Haliotidae (*Haliotis squamata*)	X	
	Limpets (Acmaeidae 1 sp.; *Siphonaria* sp.)	X	
	Neritadae (1 sp.)	X	
	Nassaridae (*Nassarius* sp.)	X	X
	Cypraea (*Cypraea caurica*)	X	
	Cypraea (*C. caputserpentis*)	X	X
	Cerithiidae (*Pseudovertagus aluco*)	X	
	Turbinidae (*Turbo* sp.)	X	
	Trochidae (3 spp.)	X	
	Trochidae (1 sp.)		X
	Thaididae (*Morula granulata*)	X	
	Thaididae (*M. margariticola, Thais aculeata*)	X	X
	Aplysiidae (*Aplysia parvula*)	X	
Bivalves:	Mytilidae (2 spp.)	X	X
	Pteriidae (*Pinctada* sp.)	X	X
	Ostreidae (*Saccosstrea cuccullata*)	X	
	Tridacnidae (*Tridacna maxima*)	X	X
Cephalopods:	Octopodidae (*Octopus* sp.)	X	X
ECHINODERMS			
Holothuroidea:	2 spp.	X	
Echinoidea:	1 sp.	X	
Ophuiroidea:	1 sp.		X
Asteroidea:	1 sp.		X
CRUSTACEANS			
Amphipods:	Several spp.	X	
Barnacles:	Balanidae (*Tetraclita porosa*)	X	
	Chthalmalidae (*Chthamalus* spp.)	X	
Stomatopoda:	Squillidae (snapping shrimp; 1 sp.)	X	
Crabs:	Xanthidae (*Pilodius areolatus*)	X	X
	Portunidae (*Thalamita* sp.)	X	X
	Majidae (*Schizophrys aspera*)		X
	Dromiidae (*Scytoleptus serripes*)		X
Anomura:	Diogenidae (hermit crabs; 2 spp.)	X	X



COASTAL HABITAT SURVEY

LOCALITY DIAGRAM

Figure 1

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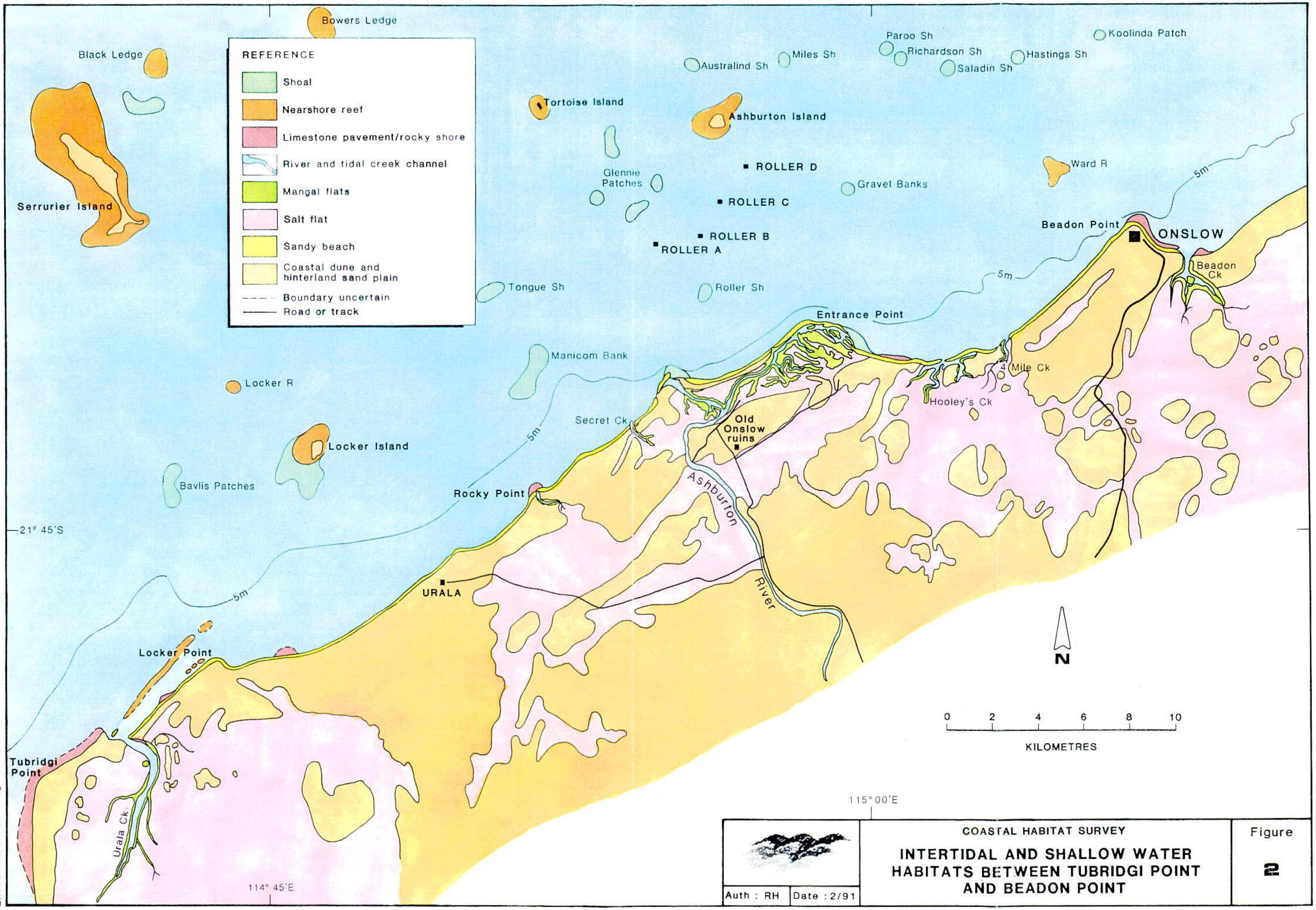

COASTAL HABITAT SURVEY

INTERTIDAL AND SHALLOW WATER HABITATS BETWEEN TUBRIDGI POINT AND BEADON POINT

Figure 2

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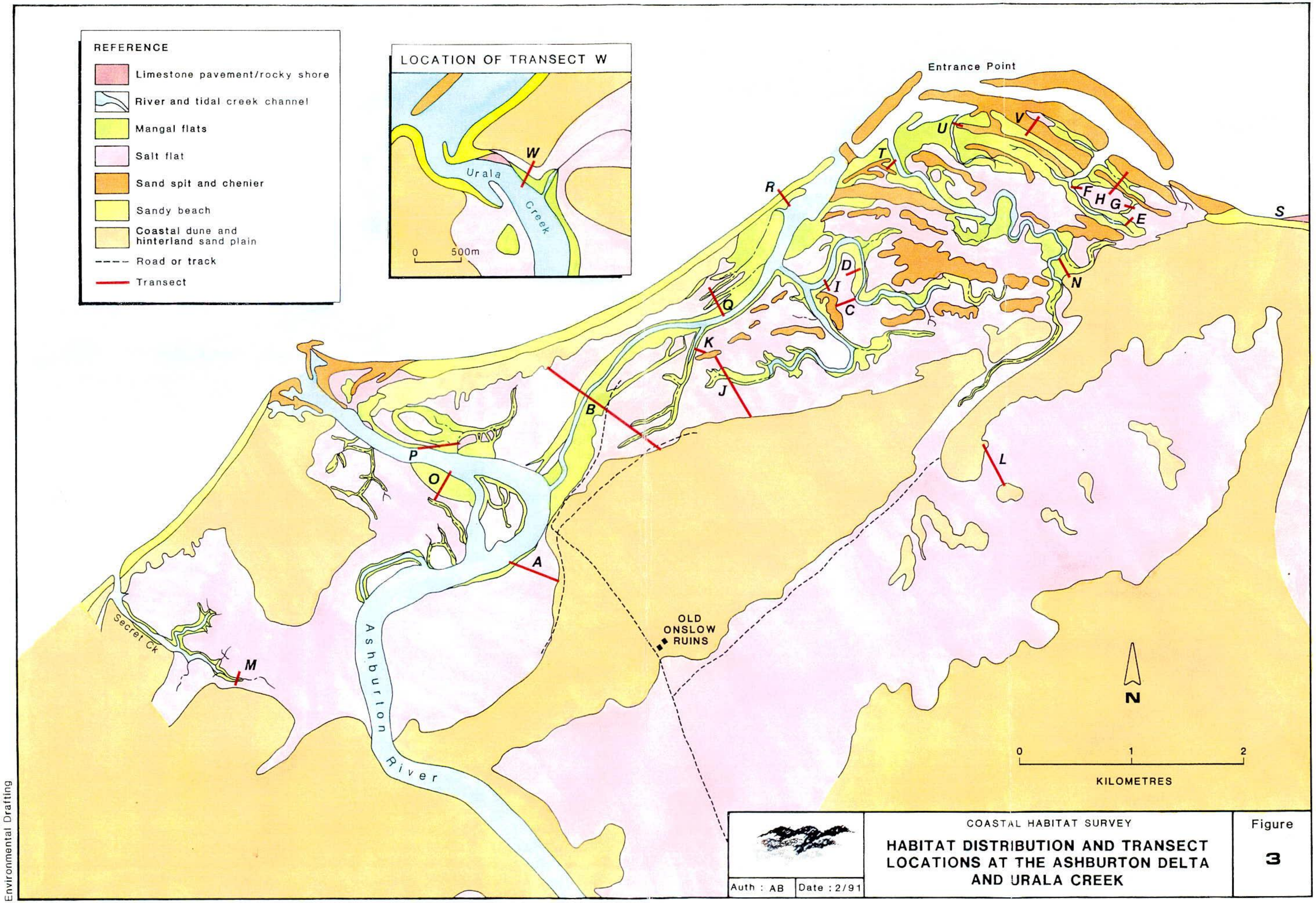

	COASTAL HABITAT SURVEY	Figure
Auth : AB Date : 2/91	HABITAT DISTRIBUTION AND TRANSECT LOCATIONS AT THE ASHBURTON DELTA AND URALA CREEK	3

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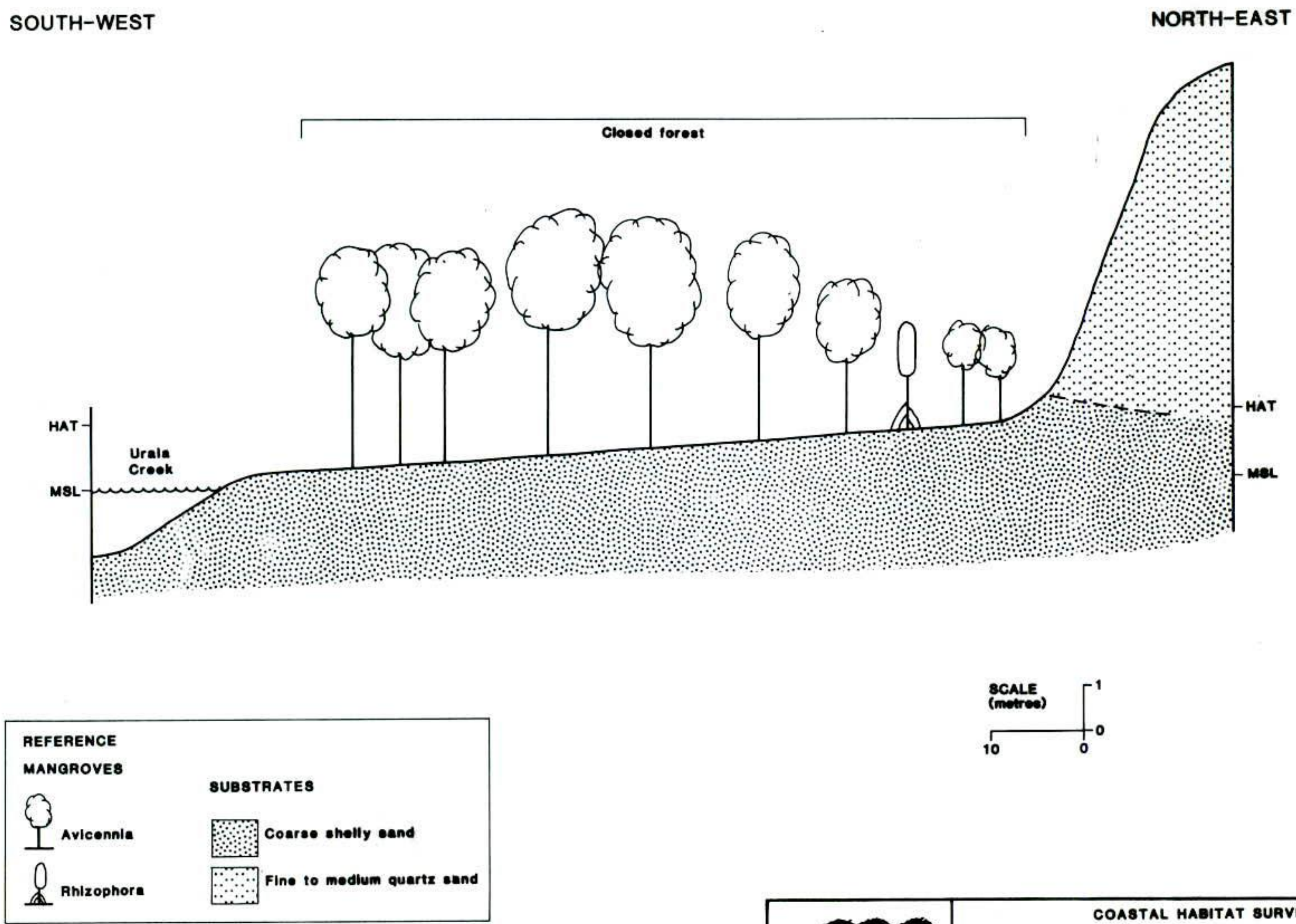

COASTAL HABITAT SURVEY

TRANSECT W (URALA CREEK)

Figure 4

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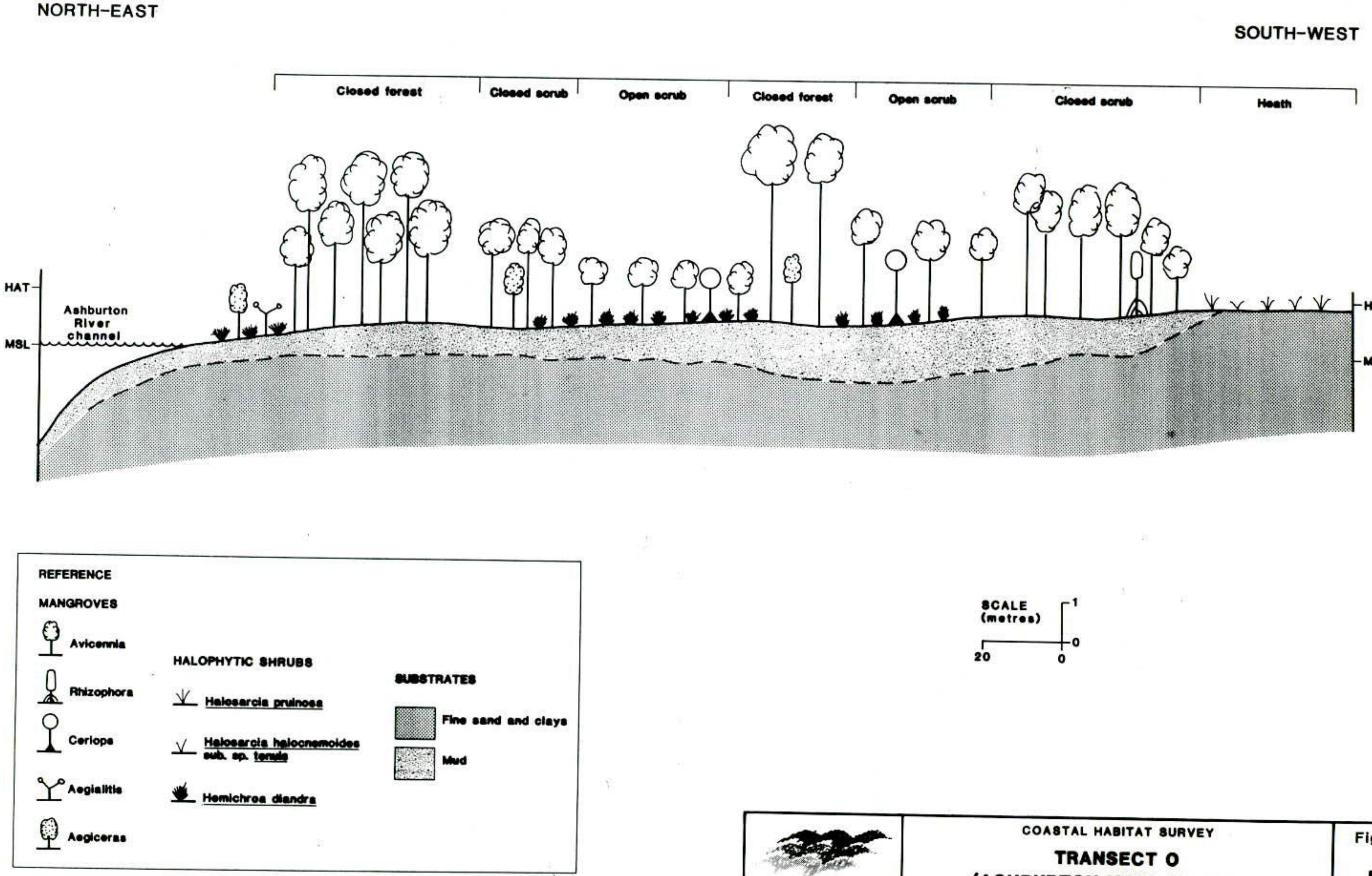

COASTAL HABITAT SURVEY

TRANSECT O (ASHBURTON MAIN CHANNEL)

Figure 5

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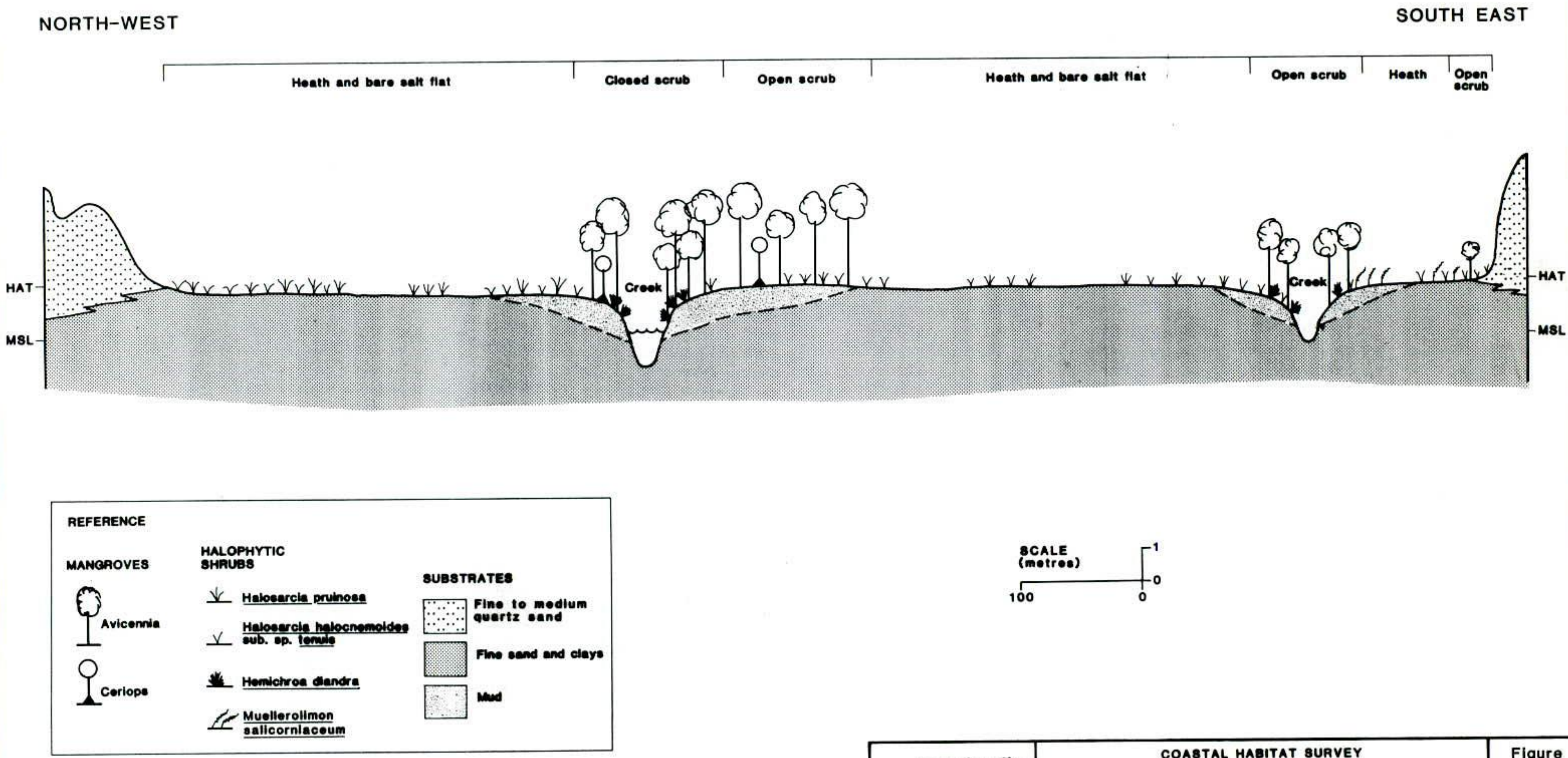

COASTAL HABITAT SURVEY	TRANSECT B (CENTRAL DELTA)	Figure 6
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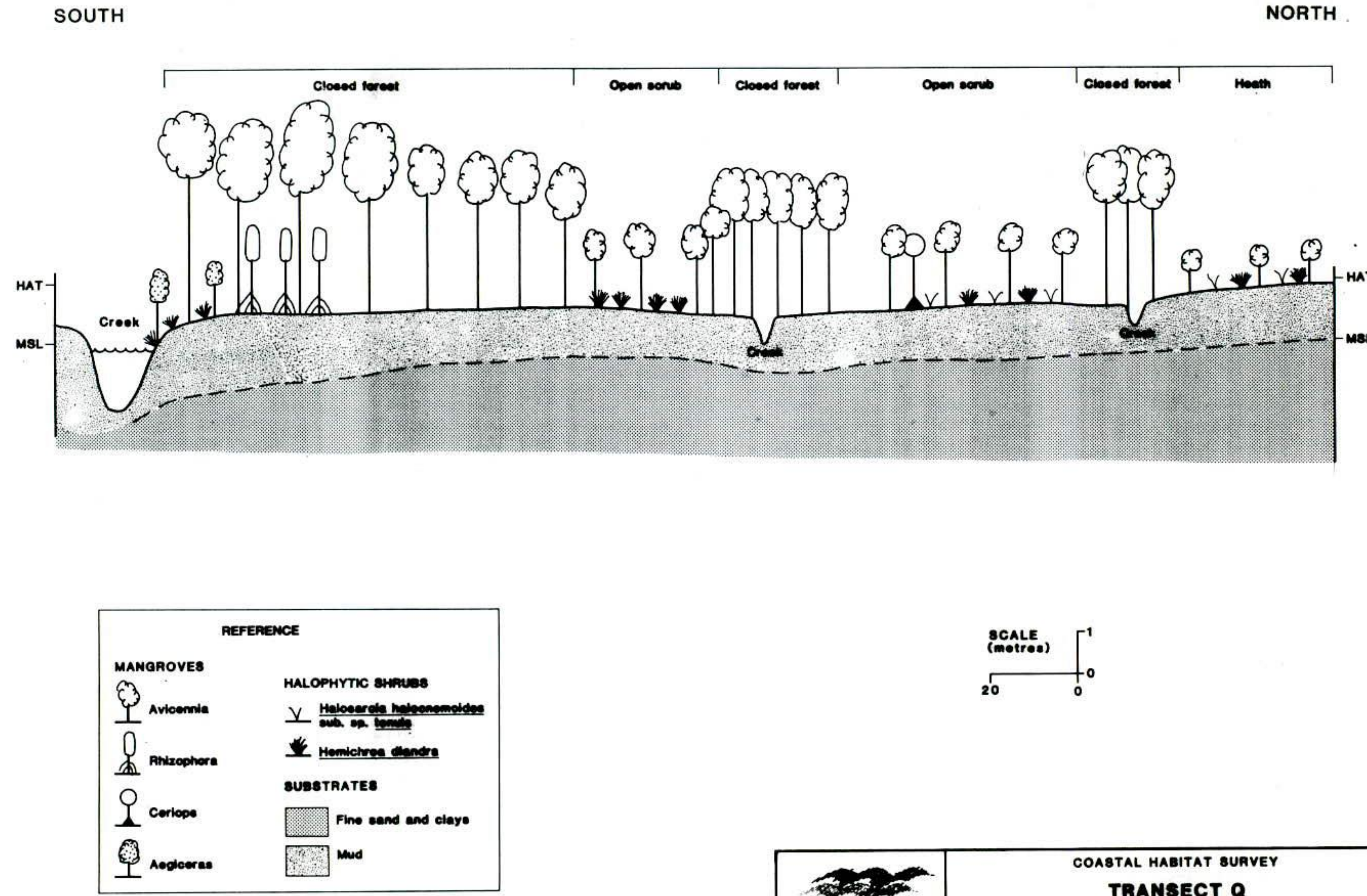

COASTAL HABITAT SURVEY

TRANSECT Q (CENTRAL DELTA)

Figure **7**

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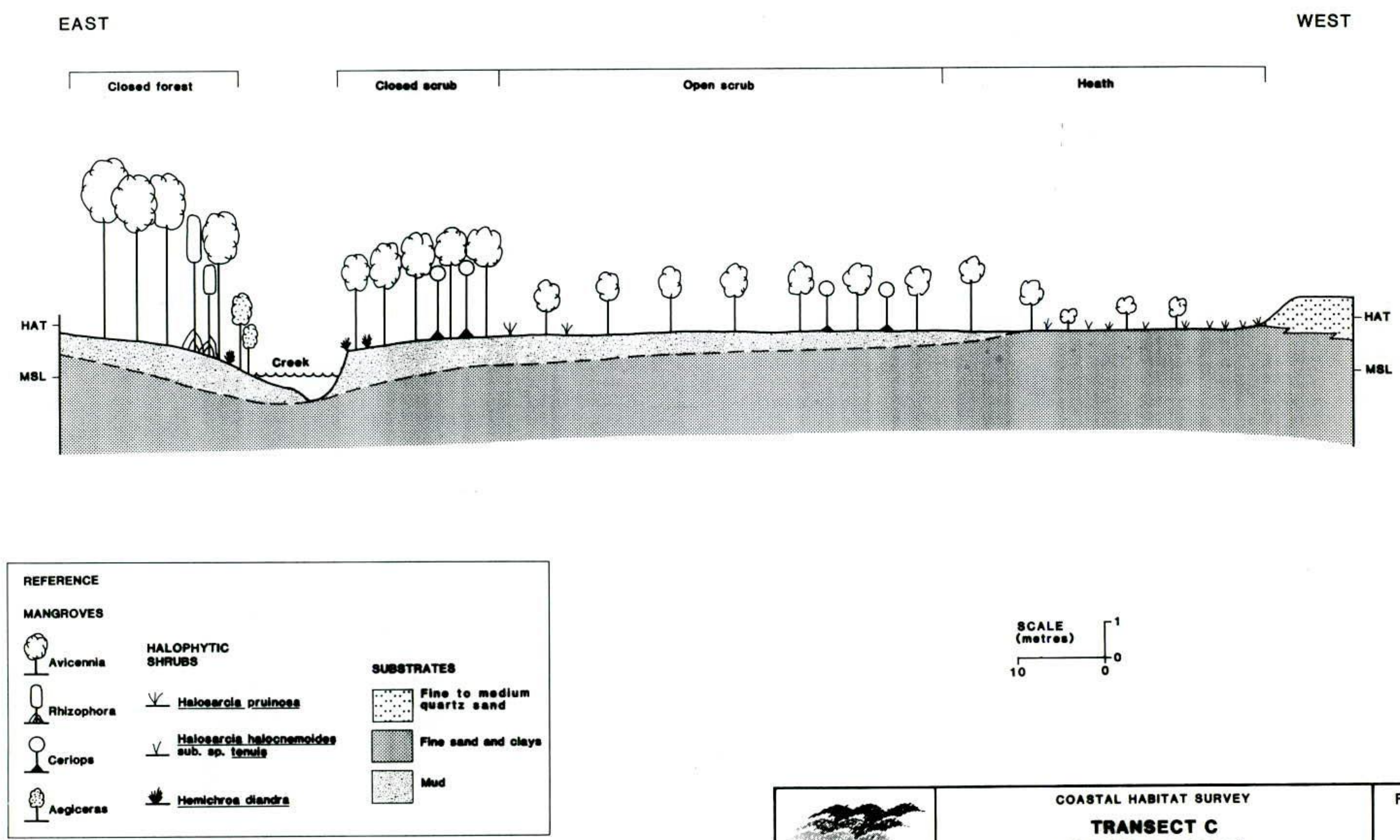

COASTAL HABITAT SURVEY

TRANSECT C (CENTRAL DELTA)

Figure 8

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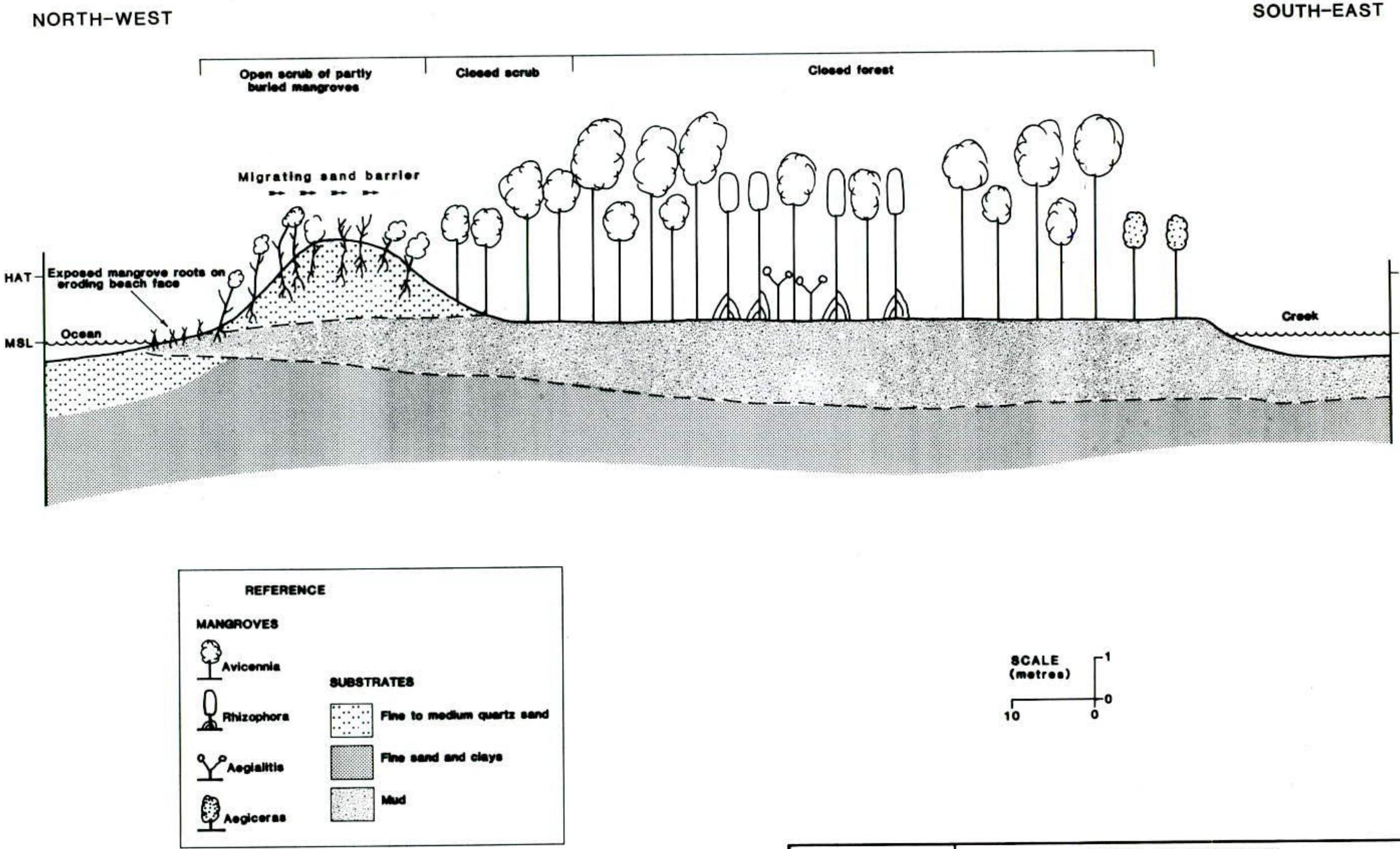

COASTAL HABITAT SURVEY

TRANSECT R (CENTRAL DELTA)

Figure **9**

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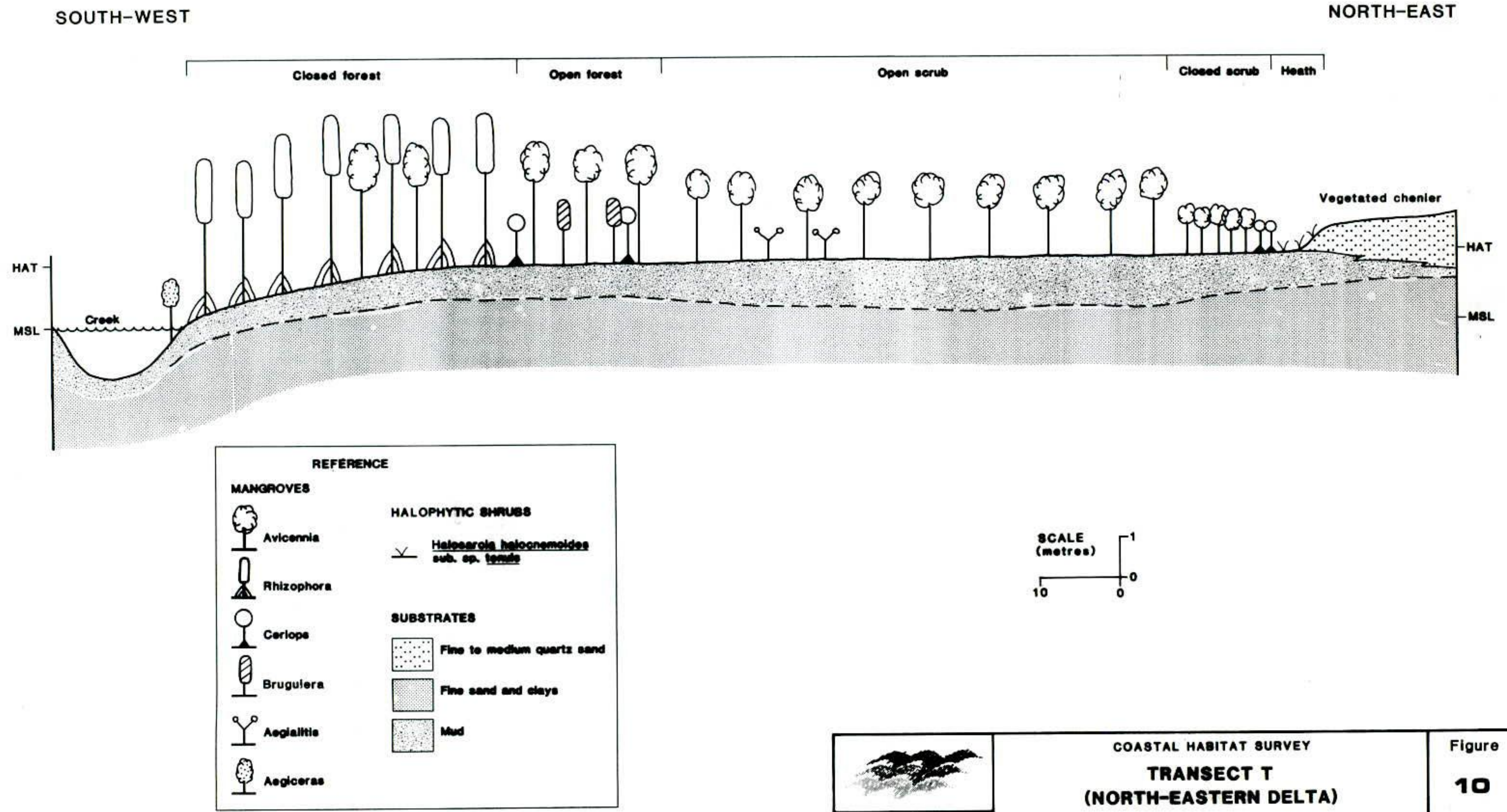

COASTAL HABITAT SURVEY

TRANSECT T (NORTH-EASTERN DELTA)

Figure **10**

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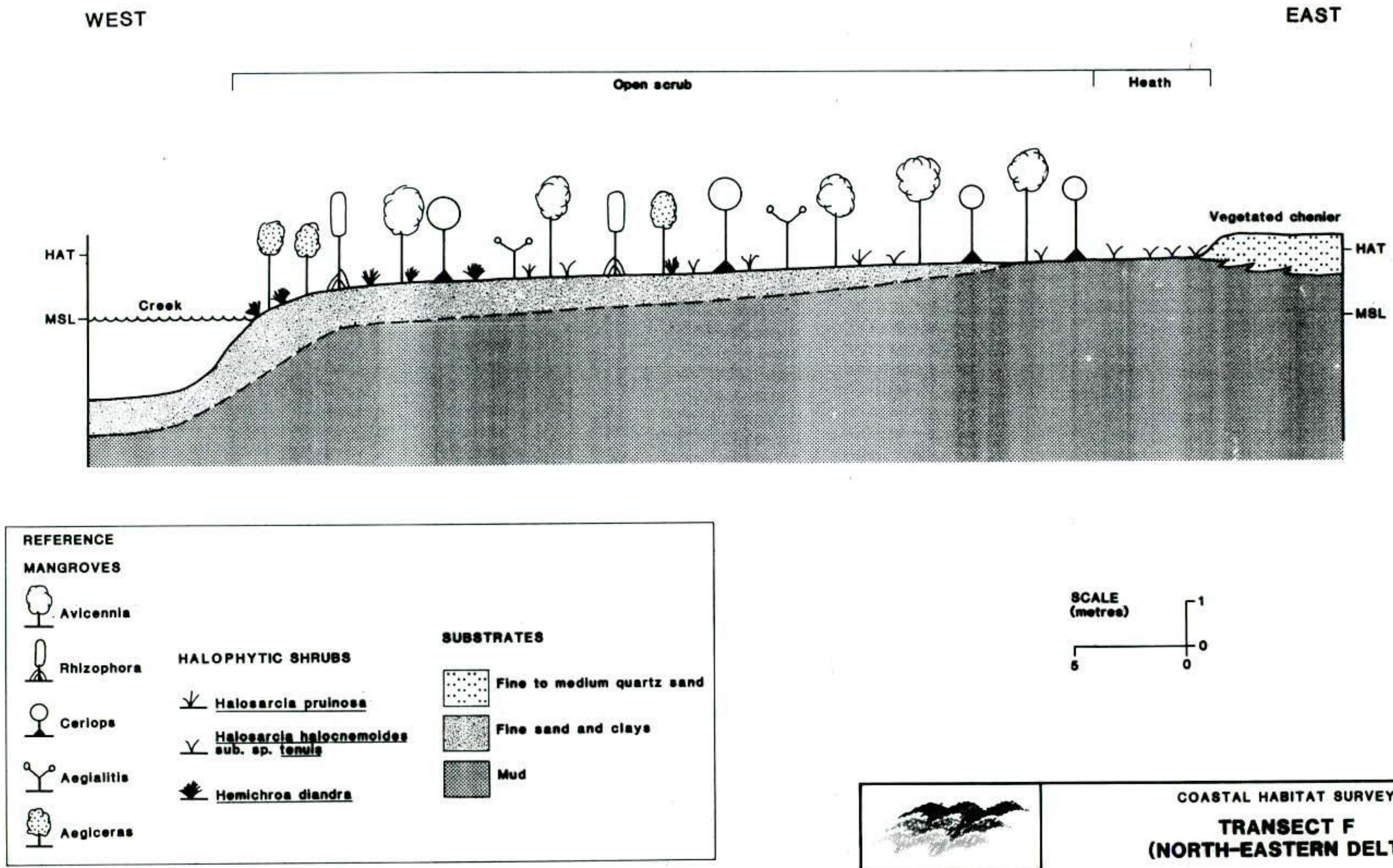

COASTAL HABITAT SURVEY

TRANSECT F (NORTH-EASTERN DELTA)

Figure **11**

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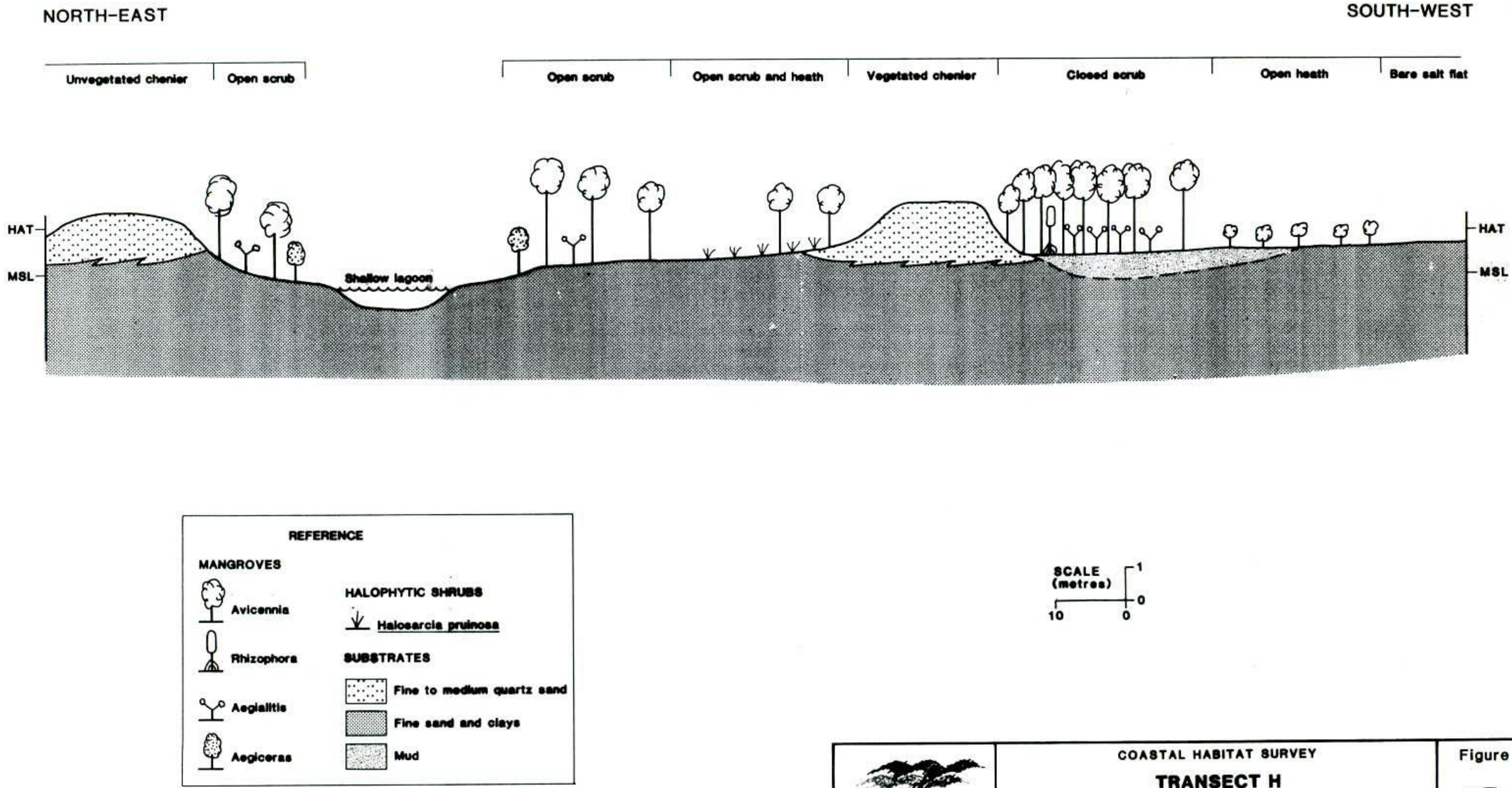

COASTAL HABITAT SURVEY

TRANSECT H (NORTH-EASTERN DELTA)

Figure **12**

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Plate 1: Aerial view of the mouth of the Ashburton River (main channel). Note the sand spits and adjoining low tidal flats in the foreground.

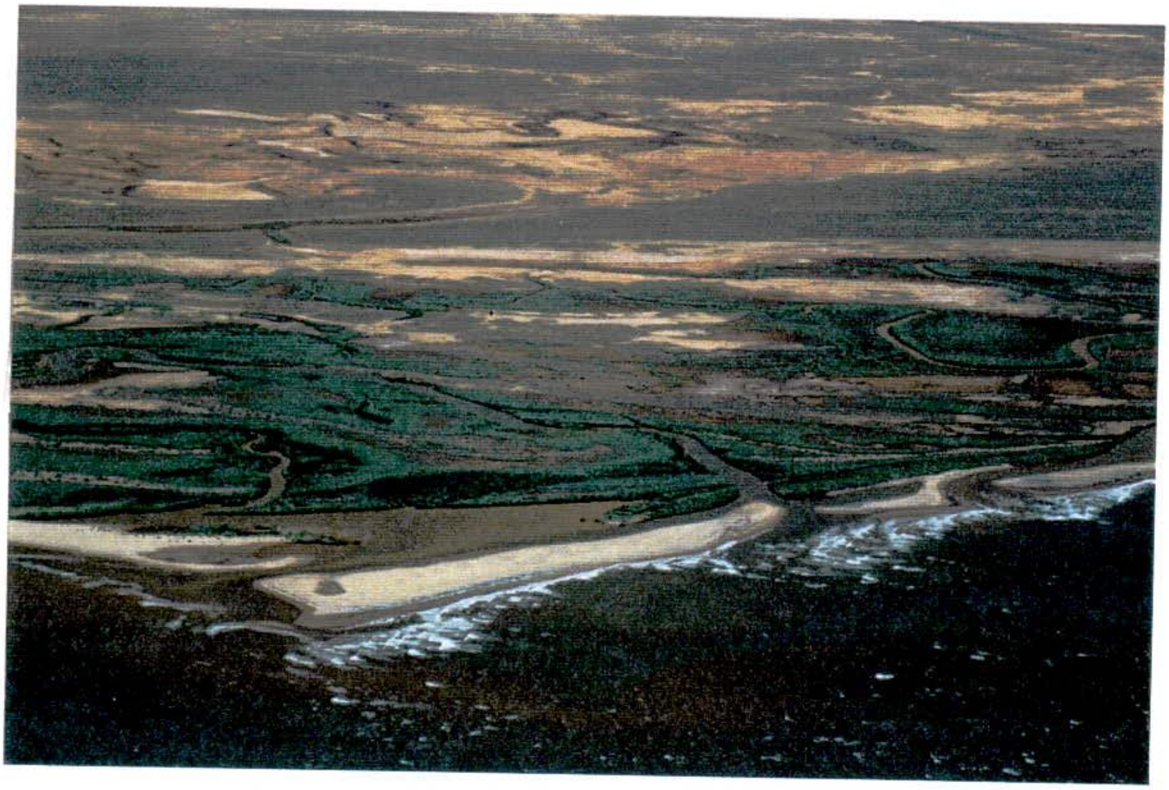

Plate 2: Aerial view of the north-eastern sector of the Ashburton River delta (Entrance Point). Note the cheniers, lagoons and extensive development of *Rhizophora* forest (dark green).

Plate 3: Low tidal mud flats in lagoon setting, backed by a closed mangrove forest in the eastern sector of the Ashburton River delta.

Plate 4: Low tidal mud flat with large mud skippers.

Plate 5: Aerial view of Secret Creek with fringing mangroves.

Plate 6: Aerial view of mouth of Urala Creek, with well-developed mangal on the north-eastern shore.

Plate 7: Aerial view of extensive mangal flats, with mangrove forests fringing lagoons, cheniers and tidal creeks. Note dead mangroves in lower right of picture (Transect R) associated with migrating dune barrier.

Plate 8: Monospecific closed forest of *Avicennia marina* fringing the Ashburton River channel (Transect A).

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Plate 10: Closed forest dominated by *Rhizophora stylosa*, fringing tidal creeks (Transect T).

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Plate 12: Mixed halophytic shrubs (*Halosarcia halocnemoides* and *Muellerolimon salicorniaceum*) with an open scrub of *Avicennia marina* and *Ceriops tagal*.

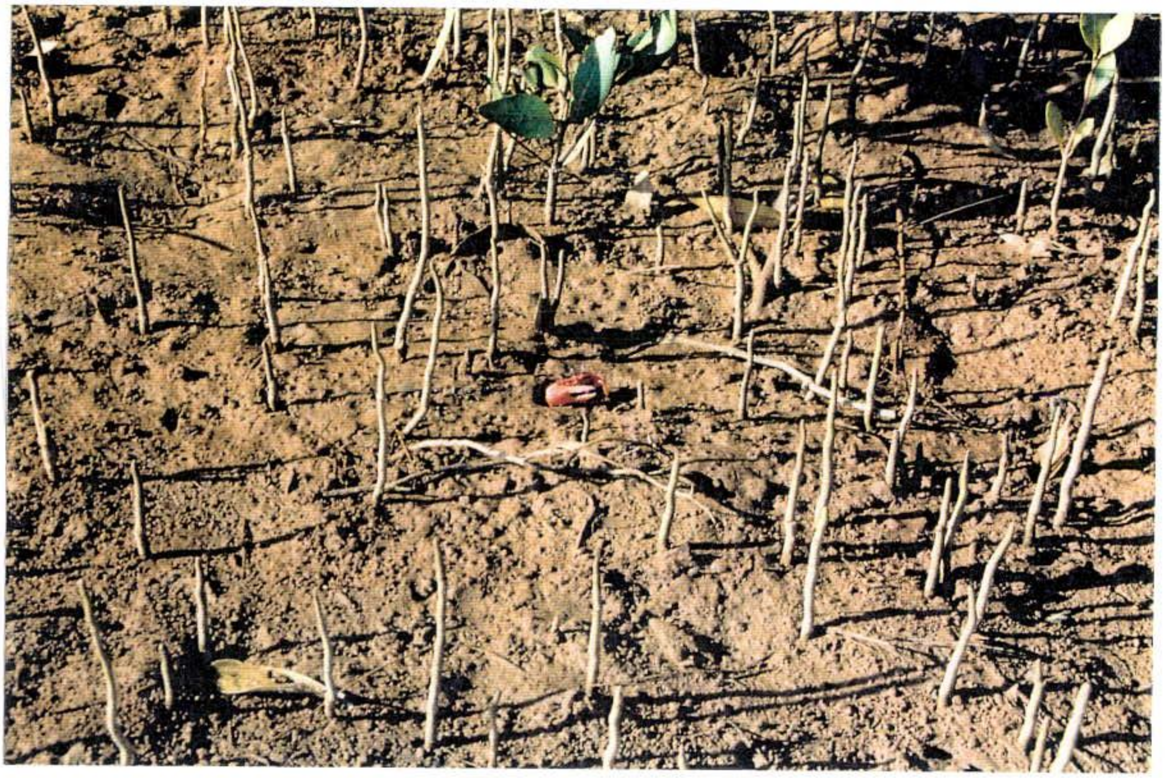


Plate 13: Fiddler crab (*Uca flammula*) at entrance of burrow. Fringing mangrove flat at Transect O.

Plate 14: Mud whelks (*Terebralia sulcata* and *T. palustris*) on mangal flat (Transect Q).

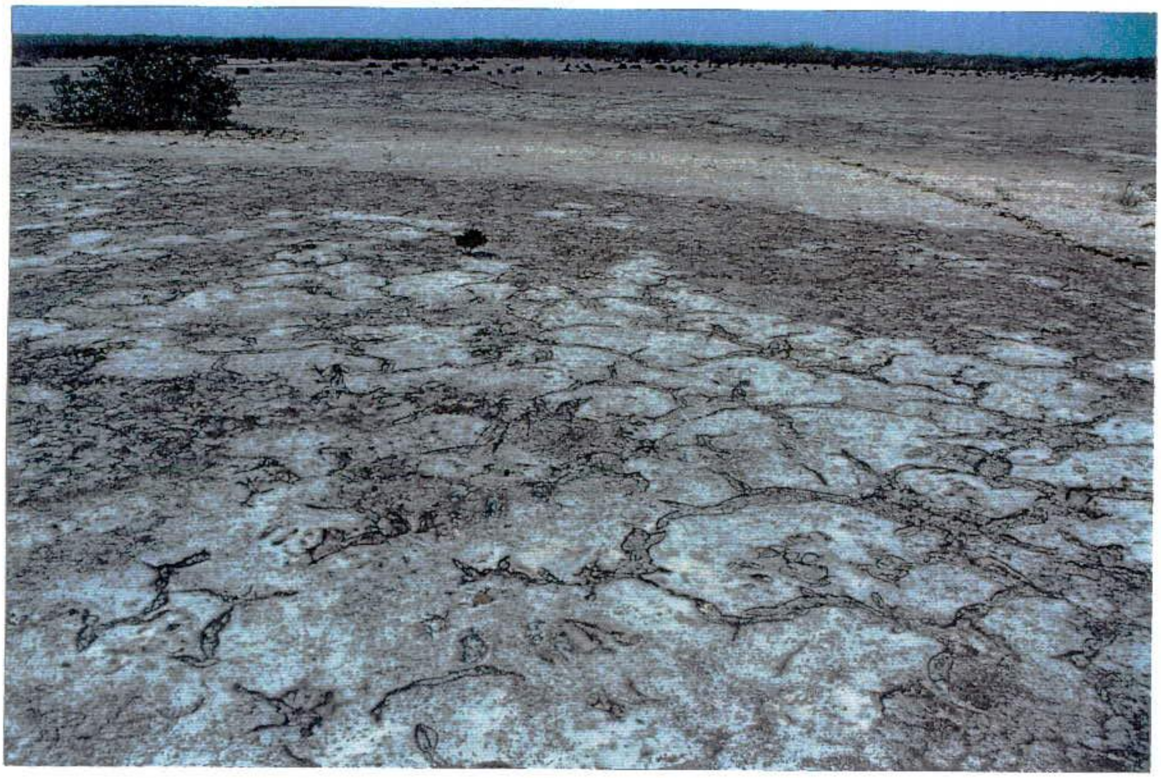


Plate 15: Cyanobacterial (blue-green algal) mat on salt flats (Transect J).

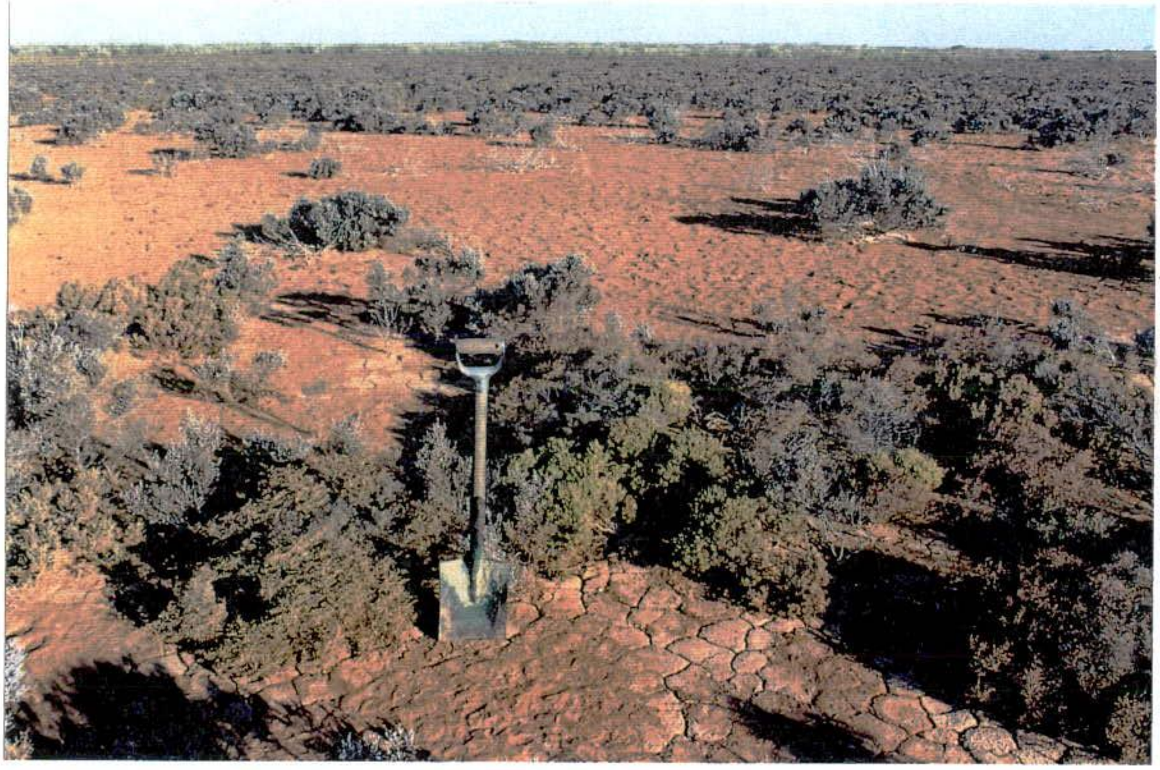
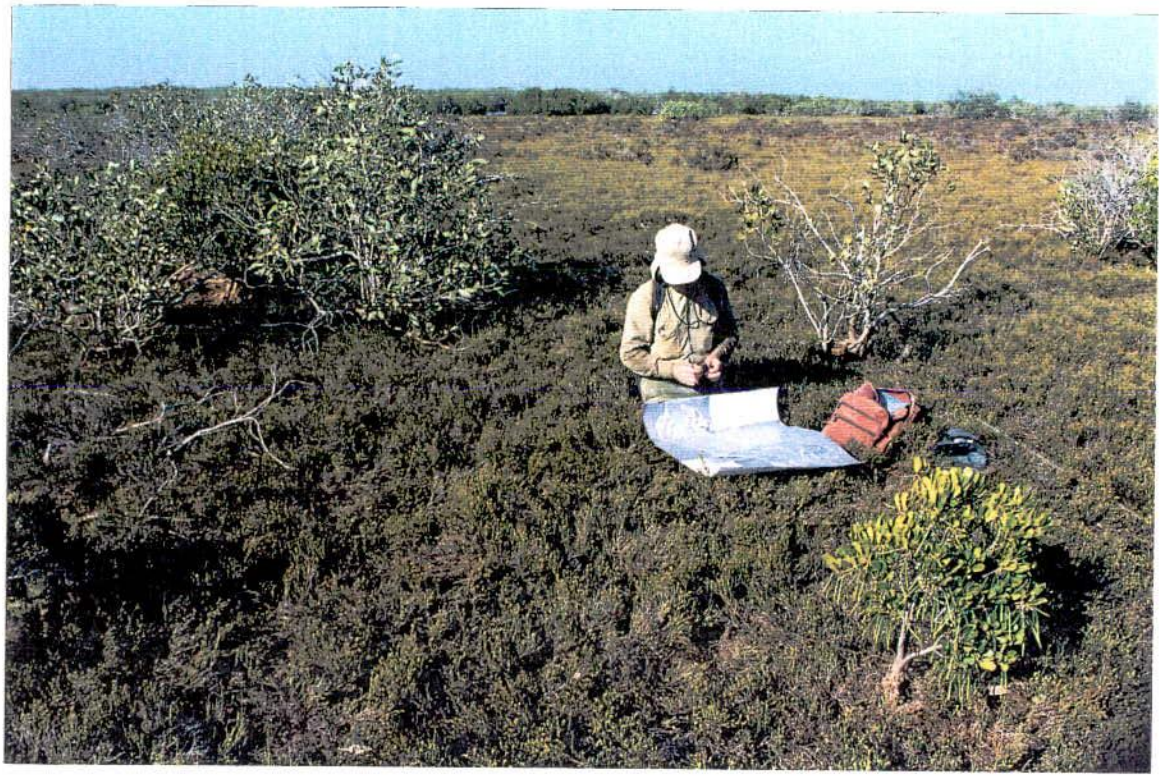


Plate 16: Extensive community of halophytic shrubs (*Halosarcia halocnemoides* and *H. pruinosa*) on salt flat (Transect B).



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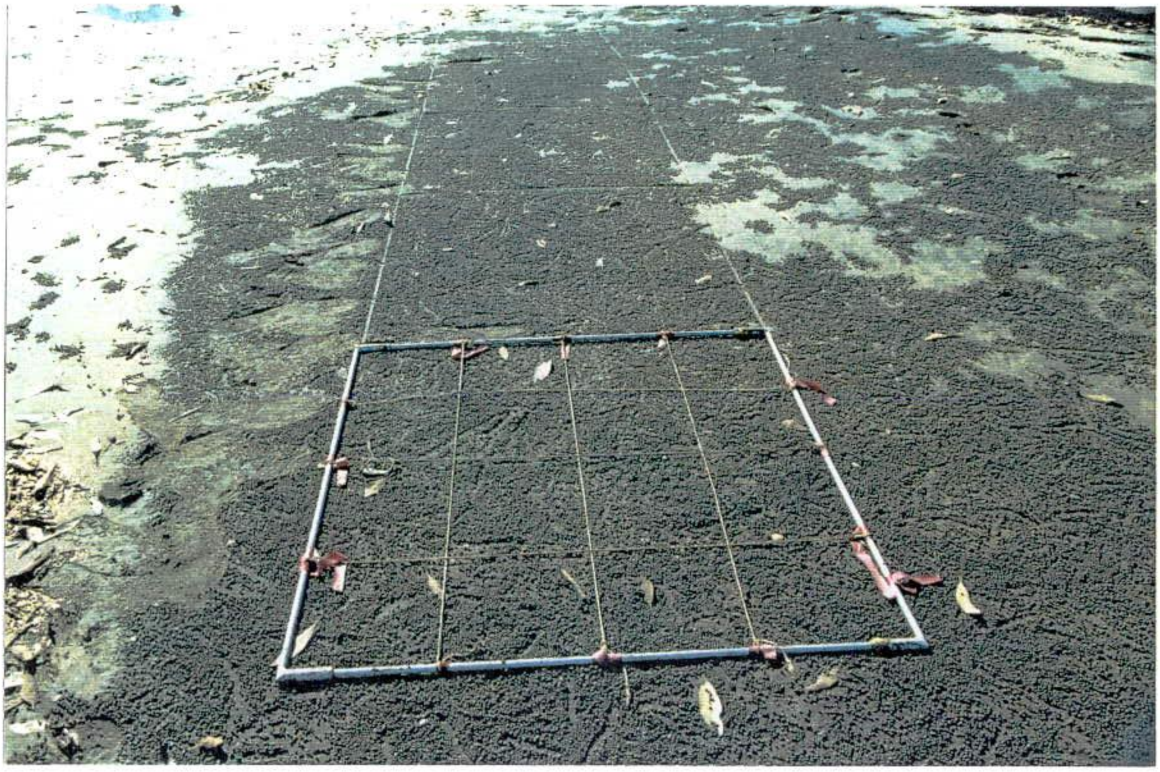

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Plate 21: Rocky shore between the Ashburton delta and Hooleys Creek (Site S).

Plate 22: Rocky shores and mangroves (in background) at Urala Creek near Transect W.

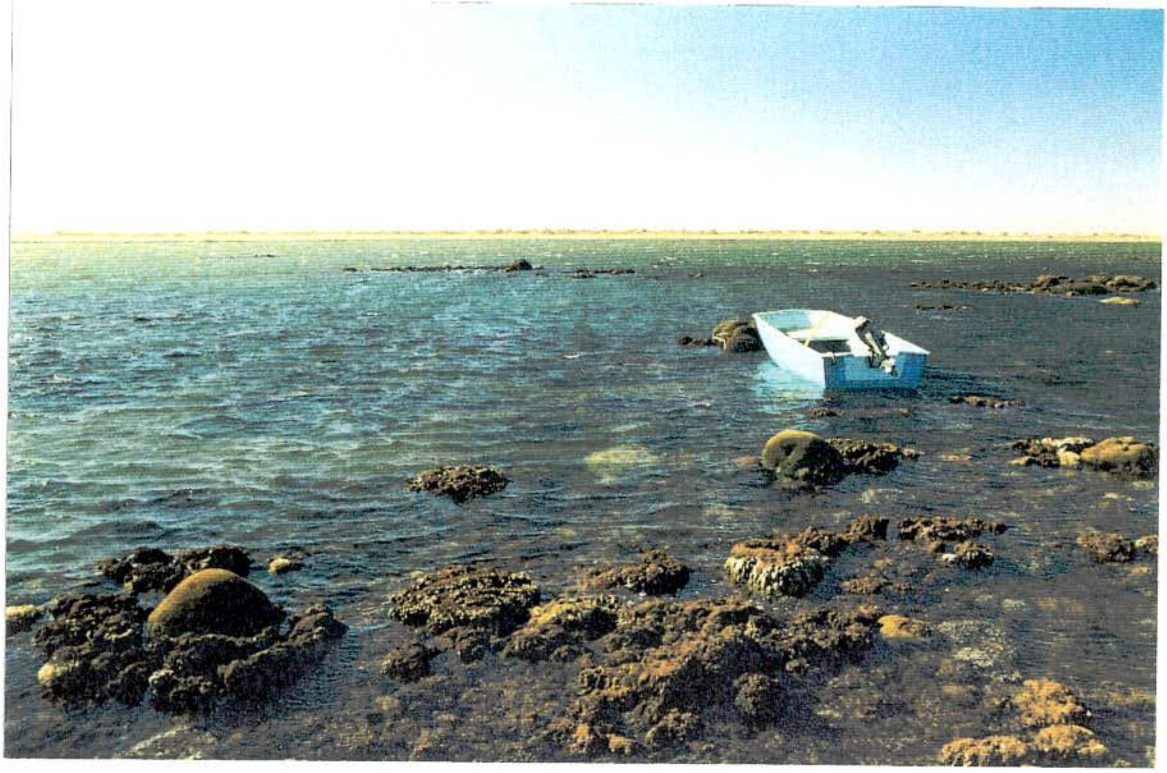

Plate 23: Nearshore reef at Locker Point. Mainland beach in background.

Plate 24: Faviid and poritid (*Porites* sp.) corals exposed during low water, spring tide. Nearshore reef west of Locker Point.

Plate 25: Sandy beach and intertidal limestone platform at south-east corner of Locker Island.

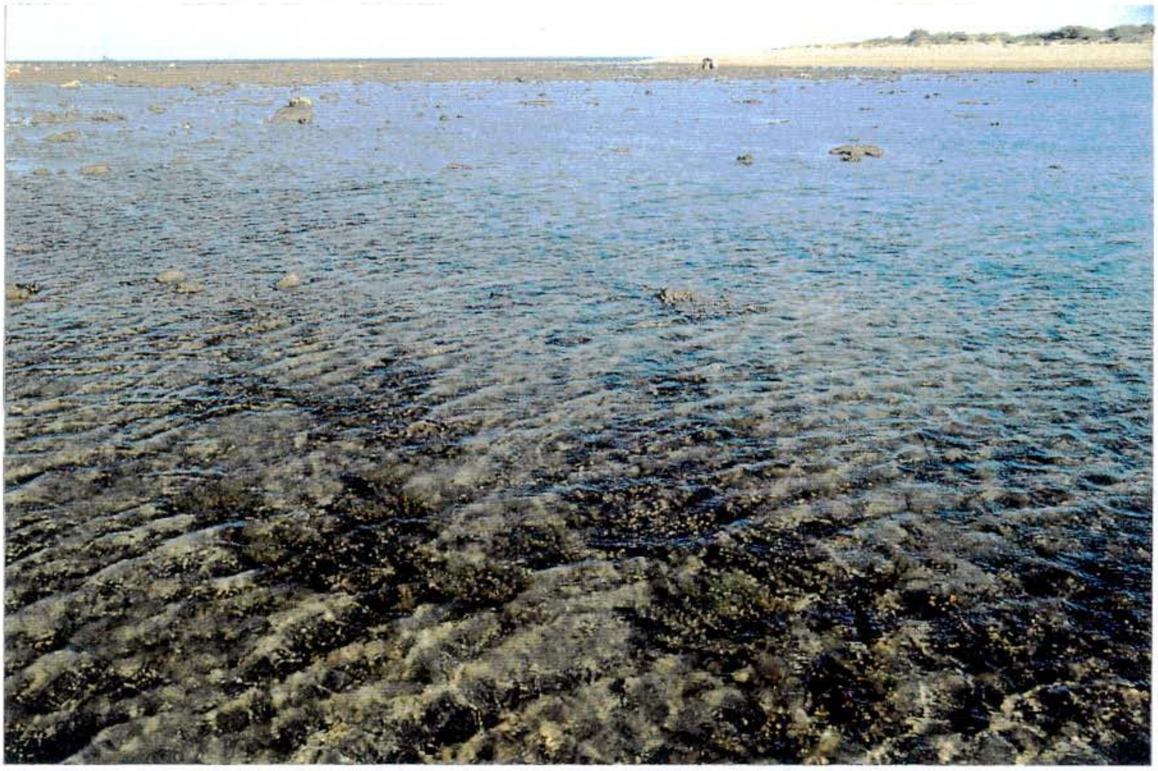

Plate 26: Sand veneered depression in intertidal limestone pavement with patchy meadows of macroalgae and *Halophila* seagrass. North end of Locker Island.

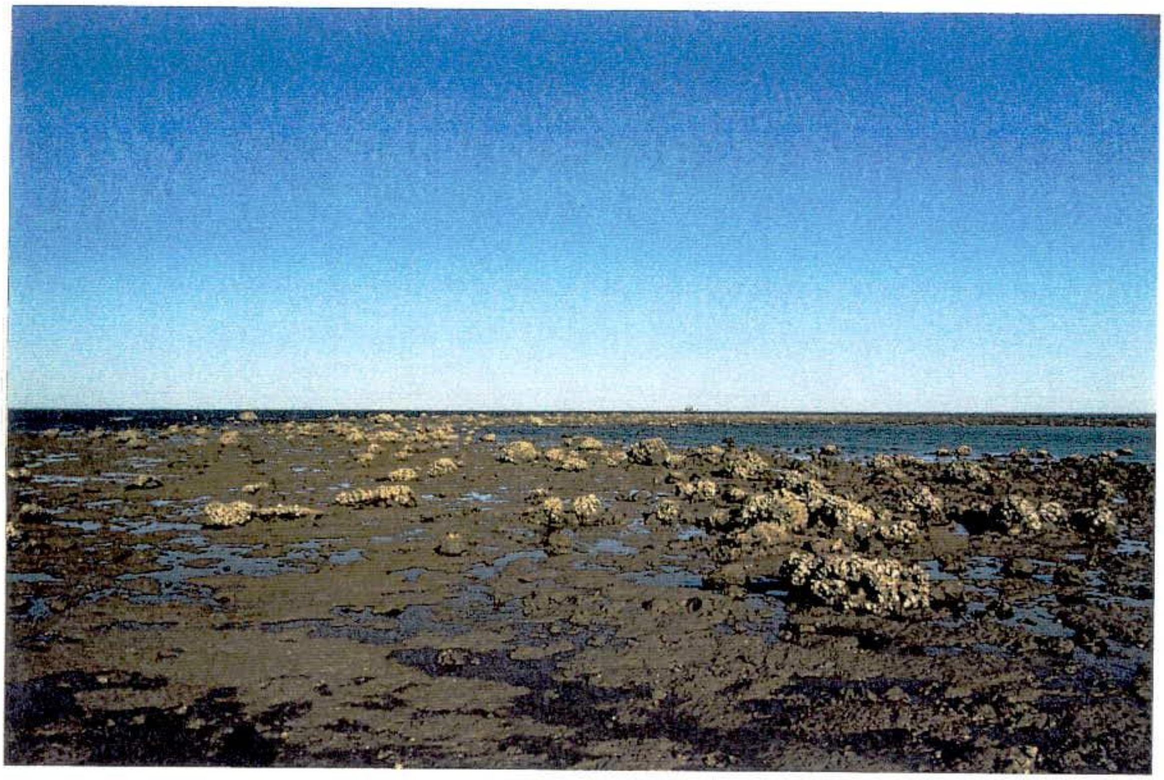

Plate 27: Limestone platform with aggregations of rocky oysters (*Saccostrea cuccullata*). North-east side of Locker Island.

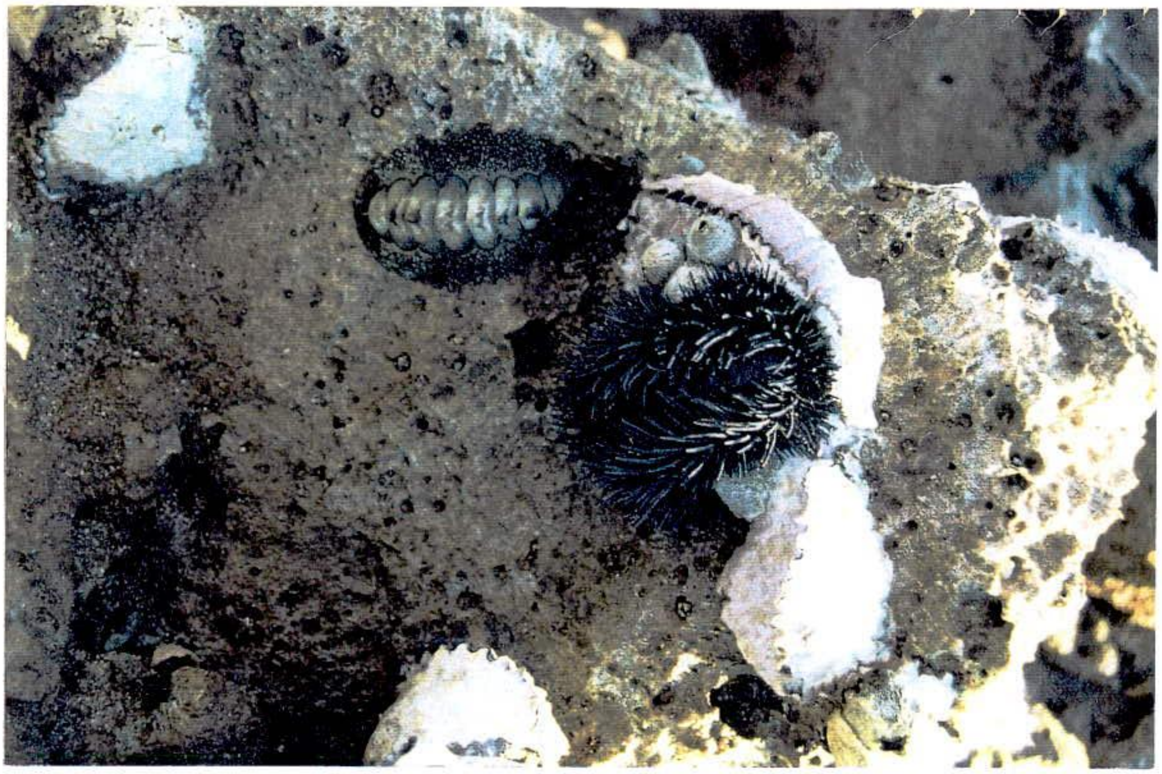

Plate 28: Chitons (*Acanthopleura gemmata* and *A. spinosa*) and rock oysters (*Saccostrea cuccullata*) on limestone pavement, Locker Island.

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APPENDIX 3

UNDERWATER SURVEYS OF

ROLLER OILFIELD

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UNDERWATER SURVEYS OF ROLLER OILFIELD

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UNDERWATER SURVEYS OF ROLLER OILFIELD

1 INTRODUCTION

A survey of the seafloor at the centre of the Roller Oilfield was conducted on 23 November 1989 prior to exploratory drilling at Roller No. 1. This survey was undertaken in order to describe the physical characteristics of the habitats and to briefly describe the biota present in the immediate vicinity of the Roller No. 1 well site and its near environs.

Subsequent to the drilling at Roller No. 1, a regional survey of the seafloor between the mainland coast and Ashburton Island was undertaken between 22 May and 23 May 1990. Survey sites were to chosen to ensure that most of the Roller prospect area was inspected, including a possible pipeline route running north from the Roller Oilfield.

The objectives of these surveys were to describe the substrate, habitat and biotic diversity, and to record the abundance of benthic biota, of the survey area. The data provided by these surveys also assists in assessing the effects of the proposed Roller development.

2 METHODS

Both of the site inspection surveys were undertaken by two biologist divers during neap tides. Neap tides were chosen to maximise the likelihood that water clarity would be sufficient to permit photography of the seafloor.

Prior to the initial survey, the site of the proposed Roller No. 1 exploration well was located by West Australian Pty Limited (WAPET) staff and buoyed to enable relocation by the survey team. The central buoyed site was inspected first, followed by inspection of sites 1,000 m to the north, south, east and west respectively (Table 1; Fig. 1). The second survey comprised 10 sites (Sites A-J), most of which were spread out from Site A (10 km to the south-west Ashburton Island) to Sites I and H (4 km to the north-east of Ashburton Island). Site J was located near the Cowle No. 1 well, some 10 km north-north-east of Ashburton Island (Fig. 1).

During the first survey, the substrate was described and the macrofauna and flora at each site were noted, including signs of animal activity (e.g. burrowing). Photographs of the substrate and representatives of the sessile organisms were taken at each site to provide a record of the condition of the area prior to drilling.

Similar information was collected during the second survey, although very poor water visibility during this survey prevented production of a photographic record of Sites A-J.

3 RESULTS AND DISCUSSION

During the first survey, the seafloor at all of the sites in the vicinity of Roller No. 1 was found to be smooth and flat, with most small scale variability due to localised bioturbation (Table 1).

Sediments at all sites were typically comprised of poorly sorted, cream coloured coarse sands and gravels, generally calcareous in nature, and with a significant proportion of shell fragment. Very small amounts of fine brown silt, evident upon physical disturbance of the substrate, were incorporated in the sediment matrix.

Animals observed at the surveyed sites included sponges, soft corals (sea-whips, etc.) (Plate 1), stinging hydroids (fire 'corals') (Plate 2), solitary ascidians (Plate 3), crinoids (feather stars) (Plate 4), nudibranchs (Plate 5), echinoids (sea urchins and sand dollars), starfish and bryozoans. The only fish observed at these sites were burrowing gobies (Table 1). The dominant plants observed were the seagrass *Halophila* and the macroalga *Caulerpa* (Plate 6), which locally formed small, sparse meadows with a patchy distribution. A calcareous green alga (*Udotea*) (Plate 6), solitary nodular coralline algae and occasional foliose red algae were the only other plants seen (Table 1).

During the second survey, which was carried out over a much larger area, a similar range of substrates and animals were observed, with the addition of some small, isolated hard corals and several species of demersal fish, particularly at the site beside the Cowle No. 1 wellhead (Table 2).

While the substrate composition was similar at all sites, four of the 10 sites had a rippled sediment surface, indicating that the seafloor had been effected by either wave or tidal current action (Table 2). The amount of silt in the surface sediments although consistently low, was also observed to vary from site to site, again indicating variability in the amount of energy reaching the seafloor.

At Site E, approximately 1,000 m to the east of the Roller well site, a quantity of debris (including empty 20 L grease tins) was found. However, it was not possible to determine the source of the debris.

4 CONCLUSIONS

It can be concluded from the results of these surveys that biological and ecological effects of wellhead installation and pipeline trenching in the Roller Oilfield will be small. The abundance of animals is low, as is the range substrate types and biological diversity. The seagrass, *Halophila,* is a 'pioneering' species, the distribution and abundance of which changes on a seasonal basis.

The presence of a variety of teleost fish at Site J (beside the Cowle No. 1 wellhead) supports the view that underwater structures associated with the oil industry often provide an artificial 'reef' habitat in an otherwise semi-barren environment, and that these artificial 'reefs' attract a variety of demersal fish.

TABLE 1

SITE DESCRIPTIONS OF THE SUBSTRATE AND BIOTA AT THE ROLLER No. 1 and No. 2 WELL SITES, AND AT SITES 1,000 m TO THE NORTH, SOUTH, EAST AND WEST OF THE WELL SITES

SITE	POSITION	DEPTH*	SUBSTRATE		BIOTA
Roller # 1 Well site	21°38.10' S 114°55.50' E	10.5 m	Seafloor: Sediment:	Flat, low level of bioturbation (crustacean burrows, worm tubes) Coarse sand and shell fragments, with minor silt component	Porifera (sponge) Cnidaria (hydroids) Bryozoa (lace coral) Mollusca (razor shell) Crinoidea (feather star) Ascidiacea (sea squirt) *Caulerpa* sp. *Udotea* sp.
1,000 m East of Roller # 1	21°38.10' S 114°55.90' E	11.0 m	Seafloor: Sediment:	Flat, occasional bioturbation (crustacean burrows) Calcareous sand and shell fragment, with silt	Porifera (sponge) Mollusca (nudibranch) Ascidiacea (sea squirt) Asteroidea (starfish *Halophila sp.* *Caulerpa* sp.
1,000 m West of Roller # 1	21°38.10' S 114°55.10' E	11.0 m	Seafloor: Surface:	Flat, occasional bioturbation Calcareous sand and shell fragment, with silt	Cnidaria (anemone) Crinoidea (feather star) Echinoidea (sea urchin) Ascidiacea (sea squirt) *Halophila* sp. *Caulerpa* sp. (meadow) *Udotea* sp.
1,000 m North of Roller # 1	21°37.65' S 114°55.50' E	10.0 m	Seafloor: Sediment:	Flat, low level of bioturbation Calcareous sand and shell fragment, with minor silt	Porifera (sponge) Crinoidea (feather star)
1,000 m South of Roller # 1	21°38.65' S 114°55.50' E	12.0 m	Seafloor: Sediment:	Flat, low level of bioturbation Coarse sand and shell gravel, with silt	Bryozoa (lace coral) Asteroidea (star fish) Ascidiacea (sea squirt) *Halophila* sp. *Caulerpa* sp. Foliose red alga Coralline red alga (nodular, concretionary)

* Depth relative to a tide height of 0.9 m (Onslow datum)

TABLE 2

SITE DESCRIPTIONS OF THE SUBSTRATE AND BIOTA OF THE SEAFLOOR IN THE AREA BETWEEN THE ASHBURTON DELTA AND THEVENARD ISLAND

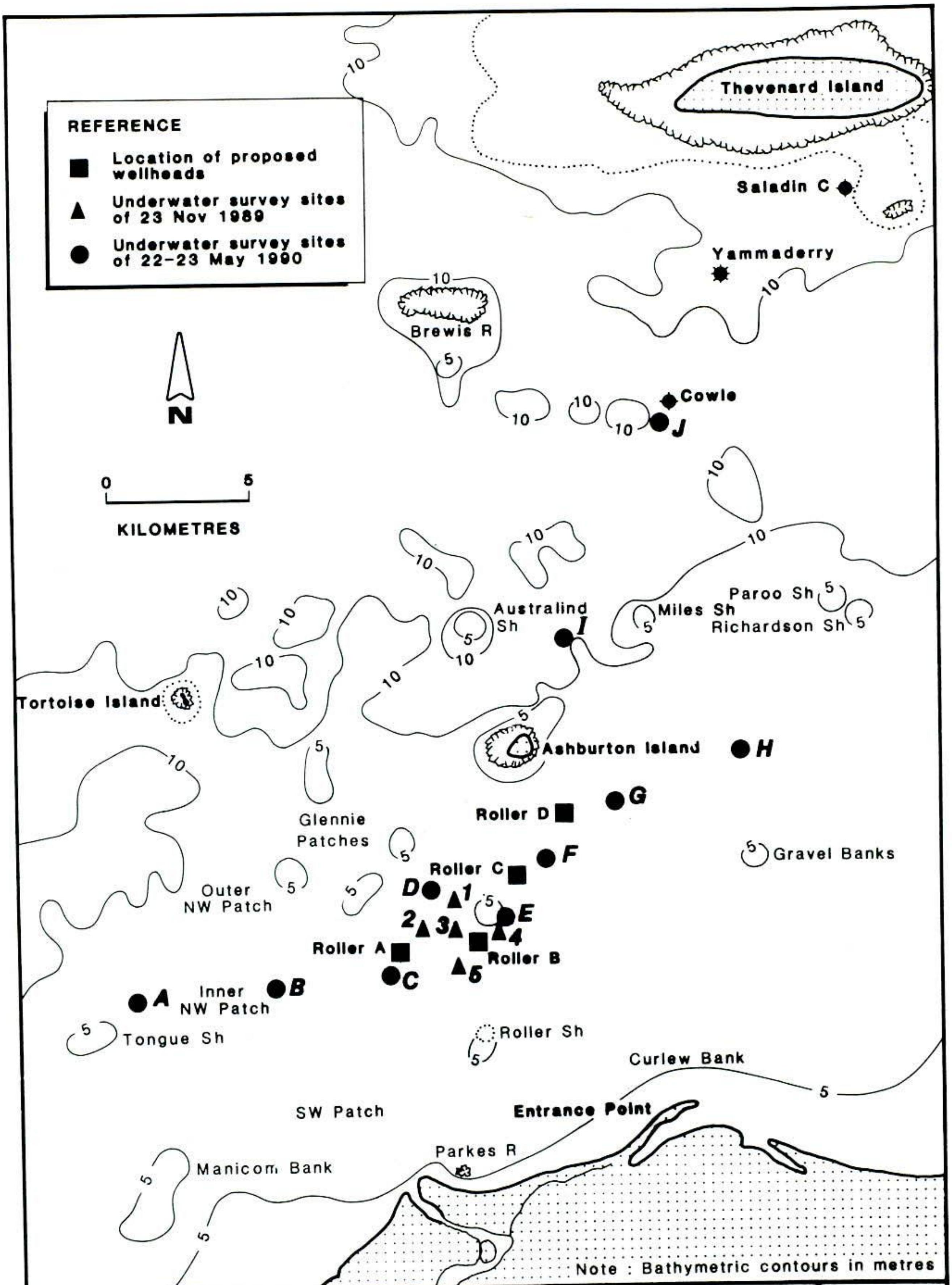
SITE	POSITION*	DEPTH	SUBSTRATE		BIOTA
Site A	21° 39.00' S 114° 51.30' E	9.0 m	Seafloor: Sediment:	Rippled, crests 1 m apart, 10 cm in height Sand, silt and shell fragments	Porifera (vase sponge) Cnideria (stinging hydroids) Polychaeta (worm tubes) Asteroidea (2 types) Crinoidea (featherstars) Holothuroidea (sea cucumber) Ascidiacea (sea squirt) Teleost ('star gazer', Uranoscopid) (low density of fauna)
Site B	21° 38.72' S 114° 52.95' E	7.0 m	Seafloor: Sediment:	Flat Sand, silt and shell fragment, >20 cm thickness	Mostly bare of biota
Site C	21° 38.73' S 114° 54.37' E	10.0 m	Seafloor: Sediment:	Rippled, 2-5 cm crest height Fine sand	Alcyonaria (sea whips, soft corals) Bryozoa (lace coral) (mostly bare of biota)
Site D	21° 37.40' S 114° 54.82' E	9.5 m	Seafloor: Sediment:	Flat Sand, silt and shell fragment, >20 cm thickness	Porifera (vase sponge) Cnideria (isolated small corals - Fungiidae and *Turbinaria* sp.) (mostly bare of biota)
Site E	21° 37.90' S 114° 55.90' E	7.5 m	Seafloor: Sediment:	Flat, occasional bioturbation Sand, silt and shell	Porifera (vase sponges) Hydroids Coral whips Bryozoa (lace coral) Crustacea (shrimp burrows) Asteroidea (star fish) Ascidiacea (sea squirt)
Site F	21° 37.00' S 114° 56.38' E	10.0 m	Seafloor: Sediment:	Rippled, crests 10 cm height Silt and sand, >20 cm thickness	Porifera (sponge) Cnidaria (hydroids, whip corals,soft corals, isolated hard coral [small colony of *Turbinaria*]) Polychaeta (worm tubes) Echinoidea (sea urchin) Ascidiacea (sea squirt)

TABLE 2

SITE DESCRIPTIONS OF THE SUBSTRATE AND BIOTA OF THE SEAFLOOR IN THE AREA BETWEEN THE ASHBURTON DELTA AND THEVENARD ISLAND

SITE	POSITION*	DEPTH	SUBSTRATE		BIOTA
Site G	21° 37'01" S 114° 56'35" E	10.5 m	Seafloor: Sediment:	Flat Sand and silt	Porifera (sponge) Cnideria (hydroids, sea anenome, small isolated hard coral) Polychaeta (worm tubes) Crinoidea (featherstars) Asteroidea (2 types) Echinoidea (urchins and sand dollars) (low density of biota)
Site H	21° 35.43' S 114° 58.78' E	10.0 m	Seafloor: Sediment:	Rippled, crests 2-3 cm in height Fine sand and shell fragment, >20 cm thickness	Porifera (sponge) Cnideria (hydroids, small hard coral [fungiids]) Polychaeta (feather worms) Asteroidea (star fish) Echinoidea (sea urchin) Teleost (Synodus; Lizard fish)
Site I	21° 34.05' S 114° 56.67' E	12.0 m	Seafloor: Sediment:	Rippled, crests 1 m apart, 8-10 cm in height Sand, silt and shell fragment	Cnideria (hydroids, isolated small corals [Fungiids]) Crustacea (shrimp burrows) Asteroidea (star fish) Echinoidea (sand dollars) Ascidians (sea squirt) (mostly bare of biota)
Site J	21° 31.41' S 114° 58.10' E (near Cowle No.1 wellhead)	12.0 m	Seafloor: Sediment:	Flat Medium to coarse grained sand	Polychaeta (worm tubes) Asteroidea (star fish) Echinoidea (sea urchin) Teleosts: Carangids (Trevally) Serranids (Red Emperor) Plotosids (striped catfish) Nemipterids (monocle bream)

* All positions determined by radar and GPS fixing methods.



Environmental Drafting

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SURVEYS OF ROLLER FIELD

LOCATION OF UNDERWATER INSPECTION SITES

Figure 1

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Plate 1 Roller No. 1 well site: soft coral on level seafloor, showing typically sparse distribution of biota.

Plate 2 Roller No. 1 well site: colonial hydroids on lightly bioturbated substrate.

Plate 3 Solitary ascidians on level seafloor with shell fragments and detritus, 1,000 m west of Roller No. 1 well site.

Plate 4 Crinoid (feather star) and sparse *Caulerpa* meadow on level substrate, 1,000 m south of Roller No. 1 well site.

Plate 5 Nudibranch on bioturbated seafloor, 1,000 m south of Roller No.1 well site.

Plate 6 Sparse *Caulerpa* meadow and occasional *Udotea*, on level seafloor composed of poorly sorted sand and shell fragments, 1,000 m west of Roller No. 1 well site.

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APPENDIX 4

OIL SPILL TRAJECTORY MODELLING

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OIL SPILL TRAJECTORY MODELLING

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OIL SPILL TRAJECTORY MODELLING

1 INTRODUCTION

This document summarises a report prepared by Steedman Science & Engineering (1991) on prediction of oil spill envelopes for the wells associated with the Roller Oilfield, proposed by West Australian Petroleum Pty Ltd (WAPET).

The report was commissioned by WAPET to provide predictive information for the Oil Spill Contingency Plan (OSCP) which constitutes part of the Consultative Environmental Review (CER) for the Roller Oilfield Development.

The oil spill trajectory modelling consists of three stages:

(i) a review of the prevailing metocean conditions in the study area;

(ii) input of representative metocean data to hydrodynamic circulation models to predict wind- and tide-driven currents in the study area; and

(iii) input of the combined results of the tide and wind modelling exercises to the oil spill trajectory model, to produce oil slick trajectory envelopes for given metocean conditions.

2 METOCEAN CONDITIONS

2.1 WIND

2.1.1 Available Wind Data

No site-specific meteorological data exist for the Roller Oilfield. The nearest relevant measurements are those collected from Thevenard Island for the Saladin Oilfield development, by Steedman Ltd. Wind data were collected from Thevenard Island between 1 February 1987 and 31 January 1988. They have been summarised and presented in an annual hourly speed and direction joint occurrence matrix in Table 1. Table 2 shows the wind speed persistence and exceedence matrix.

The Roller Oilfield lies approximately 7 km offshore, while Thevenard Island is about 22 km offshore. As such there is potential for differences in the sea breeze regime at the two sites, but comparison of the Thevenard Island wind data with data collected from Onslow by the Bureau of Meteorology shows that the strength and flow direction of the sea breeze are consistent across the region.

2.1.2 Synoptic Winds

Western Australia is subject to two main synoptic air flow systems that prevail during the winter and summer seasons, respectively. In between are the transition seasons when air flow conditions are variable.

During winter (June to August), northern Australia is dominated by an easterly airflow, the speed of which is influenced by the eastward progression of high pressure cells across central Australia. The Roller Oilfield lies on the northern periphery of these highs where south, south-easterly and easterly winds predominate. The winds, known as the 'South-East Trades', comprise of cool, dry air originating over continental Australia.

During summer (October to March), the axis of the high pressure cell system (the subtropical high pressure ridge) is located south of Australia, and together with heating of the Earth's surface, causes a low pressure zone to develop over the north of Australia. These features control the surface winds over the north-west Australian continental shelf. The location of the Roller Oilfield to the west of the semi-permanent low pressure trough usually results in a westerly and south-westerly flow of air. The air parcel has often travelled over warm tropical waters therefore it may be moist and unstable.

April to May is a transitional period when the summer regime gradually breaks down and the high pressure ridge becomes the dominant synoptic feature. The other transitional season is from September to October when the high pressure ridge moves southward and the heat lows form. During the transitional seasons both summer (west and south-westerly) and winter (south, south-easterly and easterly) air flows may occur.

2.1.3 Sea and Land Breezes

In addition to synoptic winds, the Roller Oilfield is also subject to locally-generated breezes. During the summer months in particular, and generally throughout the year, the differential heating and cooling of the sea and land during the daily cycle, generates local sea breezes (onshore) in the afternoon and land breezes (offshore) overnight. This land-sea breeze system usually results in a daily swing in wind direction from southerly in the early morning, to westerly in late afternoon.

2.1.4 Storm Winds

The Roller Oilfield region is subject to three main types of storms: tropical cyclones, pressure gradient storms and squalls associated with thunderstorms.

Tropical cyclones have typical wind speeds of 15-30 m/s and may generate peak wind speeds of 30-50 m/s. The duration of the cyclones typically range from 4-16

Pressure gradient storms may result from strong pressure gradients associated with intense high pressure cells. Depending on the time of the year, the storms may be strong easterly gales or westerly and south-westerly winds. Wind speeds may reach 20 m/s and the storms may endure for 3-4 days.

Squalls accompanying thunderstorms during the summer season result from strong downdrafts in the cumulonimbus cloud. The wind speeds may range from 15-35 m/s with instantaneous gusts to 45-50 m/s. The squalls may come from any direction, but their duration rarely exceeds two hours, which is insufficient to generate waves, surface currents or storm surges of any significance to oil spill trajectory modelling.

2.2 CURRENTS

2.2.1 Available Data

No systematic study of the circulation in the area of the Roller Oilfield has been undertaken, however limited oceanographic measurements commenced at the Roller No. 1 site in April 1990. These measurements have been supplemented by several field measurement and numerical simulation studies undertaken for the Saladin Oilfield development adjacent to Thevenard Island by Steedman Ltd.

Four main types of currents operate in the study area: tidal currents; wind-driven currents; Indian Ocean circulation; and thermohaline circulation.

2.2.2 Tidal Currents

Current monitoring records indicate that the current regime is dominated by a semi-diurnal tide, with a pronounced spring-neap cycle and slight diurnal inequality. During spring tides, mid-depth current speeds at Roller reach 0.4 m/s, with a flood direction of 90° (flowing to the east) and an ebb direction of 250° (flowing to the south-west). Maximum tidal current speeds at mid-depth are reduced to 0.1 m/s during neap tides.

2.2.3 Wind-Driven Circulation

The available current data show that wind-forced currents are dominant during neap tides and appear to be perennially important in determining mean drift directions. Water flow is also influenced by the bathymetric contours.

2.2.4 Regional Oceanic Circulation

There is no obvious evidence of the influence of regional oceanic circulation on the measured currents at Roller. The Leeuwin Current is known to operate in the region, but its influence is relatively weak and the contribution of regional oceanic circulation to the study area is not expected to exceed 0.5 m/s.

2.2.5 Thermohaline Circulation

Occasional flooding of the Ashburton River can contribute markedly to the near-surface thermohaline circulation in the study area. In such instances it is expected that the Coriolis effect will divert the flood flow to the west of the study area, although density-gradient forces may cause north-westerly flows over the Roller Oilfield. These flows are not expected to exceed 0.2 m/s, and due to their infrequency, they have not been taken into account in the modelling exercises.

3 CIRCULATION MODELLING

3.1 MODELS USED

Field data suggest that both wind-driven circulation and tidal motion will dominate water movement in the study area, and hence the oil spill trajectories. The role of the circulation models was to provide a time-varying surface current, for different metocean conditions as study examples to be input as forcing mechanisms for the oil spill trajectory model.

The numerical, hydrodynamic models used for the study comprised a depth-integrated [two-dimensional (2D)] model for tidal-driven cases, and a '2.5-dimensional' (2.5D) model for wind-driven cases. The latter is able to model currents at any given depth, however due to constraints of computing time and data storage, the model was run with only uniform wind fields, constant in time, to produce steady-state current fields. Thus the wind cases to be modelled had to be represented as a constant wind strength from a given direction.

To model conditions driven by both wind and tide, the surface currents predicted by the wind-only 2.5D model were superimposed onto the tidal currents predicted by the 2D model. This approach is at worst conservative, since at times of strong tidal currents (e.g. spring tides) the effect of wind-driven forces is likely to be reduced.

3.2 MODELLING CRITERIA

3.2.1 Model Grid and Bathymetry

The bathymetric grid used for the circulation models contained 87 x 51 node points, with equal x and y axis grid spacings of 1 km. The depth at each grid point was derived from chart AUS 743 and was then adjusted to mean sea level for use in the models.

3.2.2 Input Data

Tidal data from the following periods were chosen to run the tide-driven model for spring and neap tide conditions:

Spring tides: 0000 hours 22/11/88 - 0000 hours 28/11/88 and
Neap tides: 0000 hours 1/11/88 - 0000 hours 7/11/88.

Six days were chosen for each run because the tidal model requires 48 hours to reach steady state conditions and the oil spill trajectory model requires 96 hours of current data for advection of the oil.

The 'worst case' approach was adopted for the modelling of wind-driven currents. Table 2 shows that winds exceeding 10 m/s seldom persist for any length of time (i.e. only more than six hours for 0.7% of the time). Therefore 10 m/s was chosen as the worst case example for non-storm conditions. Eight wind directions were chosen: north, north-east, east, south-east, south, south-west, west and north-west. The model was run for 65 hours to ensure that the steady state value was obtained for each of the eight directions.

Storm conditions were not modelled because they rarely persist for sufficient lengths of time to generate important wind-driven currents, and the assumption is made that during several storm conditions, the oilfield operations will cease thus minimising the risk of an oil spill.

3.3 RESULTS AND DISCUSSION

Figure 1 shows the depth-averaged current strength vectors at each nodal point on the model grid for the tide-driven model under spring tide conditions. Figure 2 shows the vectors for neap tide conditions. Maximum current speeds are attained at approximately midway between high and low spring water. Speed variations are created by changes in water depth across the grid and the presence of obstructions (islands). The maximum depth-averaged tidal currents are predicted to be approximately 0.4 m/s in agreement with the measured data (Section 2.2.2).

The current vector fields generated by the wind-driven model were determined for a depth of -1.0 m (1 m below sea level) at hour 65. The results for the eight cases (wind directions) are presented in Figures 3 and 4. The plots show that surface currents in the study area are strongly influenced by the local bathymetry which constrains the direction of flow. The speed of the wind-generated surface currents ranged from 0.1-0.5 m/s and were typically at least 3% of the wind speed (0.3 m/s) or faster.

4 OIL SPILL TRAJECTORY MODELLING

4.1 RATIONALE

The model used for the oil spill trajectory modelling was a simple tide- and wind-driven, conservative advection model which considers the advection of oil by the superimposition of the time-dependent tidal currents for spring and neap tides with the steady-state wind-driven currents. The model is unable to incorporate the effects of weathering of the oil or its difference in density compared with seawater, so the following assumptions were made:

(i) oil travels with the ocean currents;

(ii) the oil slick is conservative (i.e. no loss through evaporation or chemical transformation);

(iii) both the horizontal and vertical turbulent diffusive processes can be ignored; and

(iv) the wind-driven and tidal currents dominate the oil slick movement through the coastal waters.

It was acknowledged that these assumptions lead to an over-estimate of the distance of travel of the slick, because the slick will tend to maintain the same direction as, but lower speed than, the underlying water.

Estimates of the trajectories were calculated using the oil spill model for durations of 6, 12, 24 and 48 hours after release from the source. Oil travel times in excess of 48 hours were not considered, as contingency plans in the event of an oil spill are expected to allow spill containment action to be taken within 48 hours.

For each duration (6, 12, 24 and 48 hours) the region through which an oil spill may travel under the influence of surface currents was determined from the trajectories of a continuous series of discrete parcel of oil. A parcel of oil is released from the prospect site each 30 minutes.

The oil spill trajectory model was run for release from three proposed well sites: Roller North (near Roller D), Roller Central (near Roller C) and Roller South (near

Roller A and B). Modelling runs from each well site were made for spring and neap tides (tide-driven current only), and for combinations of each wind direction (eight intracardinal directions) with each tide option (spring and neap; a total of 54 scenarios.

4.2 RESULTS AND DISCUSSION

4.2.1 Overview

Trajectories for all 54 scenarios are presented in Steedman Science & Engineering (1991). As this report is a summary of that document, only selected trajectories are presented and discussed.

The results of the modelling runs for combined tide and wind-driven currents are summarised in Table 3, which presents the risk frequencies of the shorelines in the study area from an oil spill from each of the proposed well sites. The percentage likelihood was determined according to the duration of oil spill release before landfall at a particular location and the percentage occurrence given in Table 1 for winds from the given direction. It should be noted that the tables represent discrete wind directions only.

Table 3 indicates that the greatest risk is associated with spills that occur during northerly, north-easterly, south-westerly and westerly winds, i.e. during summer and the transition seasons. The principal shorelines at risk are those in the immediate vicinity to the Roller Oilfield, i.e. Ashburton Island, Entrance Point (at the mouth of the Ashburton River) and the coast adjacent to Rocky Point. The low risk for most other shorelines in the region is due to the very low persistence of winds greater than 10 m/s in the area.

Although Table 1 shows that southerly and south-easterly winds constitute 27.2% of the winds that occur at Thevenard, the wind-driven circulation model (Fig. 4) and the trajectory model showed that under these conditions the oil slick would move to the north-west and west, respectively and would not endanger any of the nearby shorelines. Table 3 shows that a spill associated with a south-easterly wind would only impact on one shoreline, i.e. Sunday Island, and the risk frequency of this occurrence is less than 0.1%.

On the large scale grids used for the modelling, the three well sites are close together, therefore for summary purposes the Roller Central example has been chosen to represent all three wells.

The following sections summarise the impact of the oil slick from Roller Central under spring tide conditions and winds from the north, north-east, south-west and west, respectively.

Only the spring tide condition is discussed because spring tide conditions cause greatest spread of the slicks. Tide-driven forces exceed wind-driven forces during spring tides, so the slicks take on an elliptical shape, compared with the elongated shape which results during neap tides. Overall envelope lengths are comparable for neap and spring tides.

It is important to note that all of the trajectories represent conditions with a sustained wind of 10 m/s over the given period, however in reality wind records from Thevenard Island show that wind speeds of 10 m/s or more only occur for 0.7% of the time; wind speeds are generally less than 10 m/s. The trajectories also do no allow for any weathering of the slick, so the trajectories are very conservative.

4.2.2 Northerly Wind and Spring Tide

Figure 5 shows the oil spill envelopes for release times of 6, 12, 24 and 48 hours for the case of a northerly wind during spring tides. The plots show that the slick moves directly south and by six hours after initial release the spill is starting to impact on the shoreline at Entrance Point. The slick remains essentially circular in shape and is relatively confined by the shape of the coastline either side of Entrance Point.

4.2.3 North-Easterly Wind and Spring Tide

Figure 6 shows the oil spill envelopes for the case of north-easterly wind during spring tides. In this case the slick forms an ellipse with an axis that extends in a south-westerly direction. The slick initially impacts the shoreline north-east of Rocky Point 6-12 hours after the initial release, and then spreads along the coastline to reach Locker Point by 48 hours after the initial release time.

4.2.4 South-Westerly Wind and Spring Tide

Figure 7 shows the oil spill envelopes for the case of a south-westerly wind during spring tides. The slick initially fans outward to the north and north-east, quickly impacting and surrounding Ashburton Island. By 12 hours after the initial release time, the slick has formed a bulging ellipse which extends to the north-east. Bathymetric features south-east of Thevenard Island channel the flow of the water and cause the oil slick ellipse to narrow and then bulge around the eastern side of the Island and continue northward. The bulge in the envelope occurs where the wind is driven at an angle to the tidal currents.

4.2.5 Westerly Wind and Spring Tide

Figure 8 shows the oil spill envelopes for the case of a westerly wind during spring tides. Within the first six hours after initial release the oil slick fans out to the north-east, impacting the eastern side of Ashburton Island. By 12 hours after initial release the slick formed an ellipse whose axis extended toward the north-east. Over the next 12 hours the slick takes on a propeller shape and begins to veer toward the north in response to tidal oscillations.

5 REFERENCE

Steedman Science & Engineering, 1991. *Prediction of Oil Spill Envelopes for the Proposed Wells Associated with Roller Field.* Unpublished report to West Australian Petroleum Pty Ltd. Report No. R491, Steedman Science & Engineering, Jolimont, Western Australia.

TABLE 1

OCCURRENCE OF WIND SPEED AND DIRECTION AT THEVENARD ISLAND BETWEEN 1 FEBRUARY 1987 AND 31 JANUARY 1988

DIRECTION	WIND SPEED								TOTALS (%)
	(km/h) <7	7-14	14-22	22-29	29-36	36-43	43-50	>50	
	(m/s) 0.1-2.0	2.1-4.0	4.1-6.0	6.1-8.0	8.1-10.0	10.1-12.0	12.1-14.0	>14.1	
North	1.3	3.1	2.3	1.3	0.3	0.0	-	-	**8.4**
North-east	0.8	1.8	1.9	1.8	1.1	0.4	0.1	0.0	**8.0**
East	0.7	2.0	2.1	1.1	0.4	0.1	0.0	-	**6.4**
South-east	0.7	3.2	2.8	1.8	0.6	0.0	-	-	**9.1**
South	0.9	3.4	4.9	5.7	2.8	0.5	0.0	-	**18.1**
South-west	0.9	5.3	9.2	9.8	3.2	0.4	0.1	0.0	**28.8**
West	0.7	4.3	4.8	4.0	1.0	0.0	-	-	**14.8**
North-west	0.7	3.1	2.1	0.2	0.0	-	-	-	**6.1**
Total (%)	**6.7**	**26.3**	**30.1**	**25.7**	**9.3**	**1.5**	**0.1**	**0.0**	***100.0**

* Includes occurrence of calm periods (0.3%)

Source: Steedman Science & Engineering (1991)

TABLE 2

PERCENTAGE DURATION OF WINDS AT THEVENARD ISLAND BETWEEN 1 FEBRUARY 1987 AND 31 JANUARY 1988

WIND SPEED		DURATION (hours)								TOTAL (%)
km/h	m/s	>6	>12	>18	>24	>30	>36	>48	>96	
≥43	≥12	0.0	-	-	-	-	-	-	-	0.0
≥36	≥10	0.7	0.0	-	-	-	-	-	-	0.7
≥29	≥8	6.9	3.9	1.6	0.5	0.5	0.5	0.0	-	6.9
≥22	≥6	30.2	21.4	12.2	7.1	5.4	4.2	2.0	0.0	30.2
≥14	≥4	61.5	52.4	44.6	36.1	35.0	33.1	26.4	13.7	61.5
≥7	≥2	91.7	88.9	83.9	75.5	71.7	68.4	61.0	48.7	**91.7**
0-7	≥0	8.3	-	-	-	-	-	-	-	**8.3**
										100.0

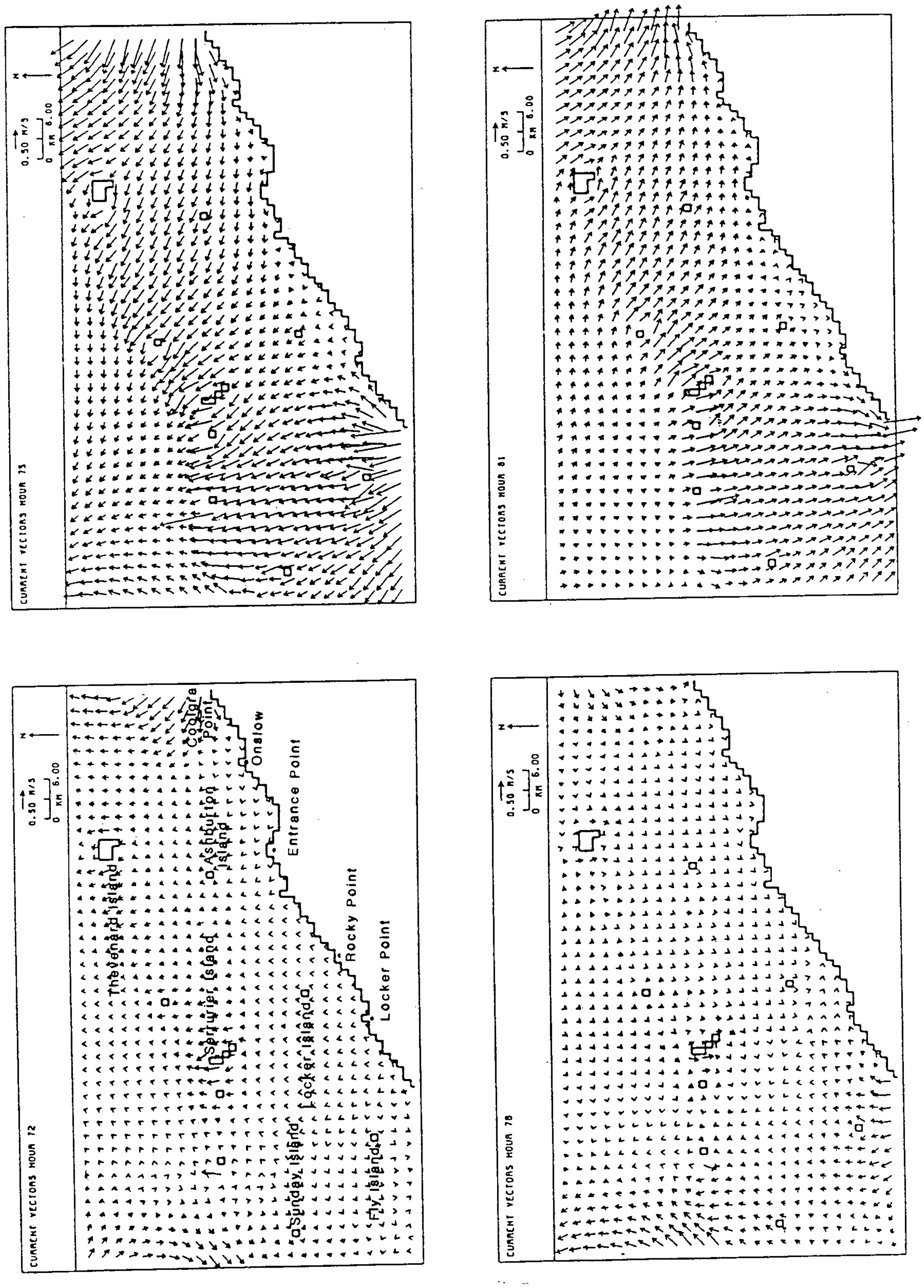
Source: Steedman Science & Engineering (1991)

TABLE 3

RISK FREQUENCY AND TIME TO IMPACT OF AN OIL SPILL

RELEASE POINT	SHORELINES AT RISK	RISK FREQUENCY (%)	WIND DIRECTION	TIME TO IMPACT (HOURS)
Roller North (near Roller D)	Ashburton Island	44.3	Calm, SW, W	6
	Entrance Point	8.4	N	6
	Thevenard Island	0.5	SW	12
	Rocky Point	0.5	NE	12
	Locker Island	0.1	E	12
	Fly Island	0.1	E	24
	Serrurier Island	<0.1	SE	24
	Coolgra Point	<0.1	NW	24
	Sunday Island	<0.1	SE	48
Roller Central (near Roller C)	Ashburton Island	43.6	SW, W	6
	Entrance Point	8.4	N	6
	Thevenard Island	8.0	NE	6
	Rocky Point	0.5	SW	18
	Locker Island	0.1	E	12
	Fly Island	0.1	E	24
	Onslow	<0.1	NW	12
	Coolgra Point	<0.1	NW	24
	Sunday Island	<0.1	SE	48
Roller South (near Roller A and B)	Ashburton Island	28.8	SW	6
	Entrance Point	8.4	N	6
	Thevenard Island	8.0	NE	6
	Rocky Point	0.5	SW	18
	Locker Island	0.1	E	12
	Onslow	<0.1	NW	12
	Coolgra Point	<0.1	NW	24
	Sunday Island	<0.1	SE	48

Source: Steedman Science & Engineering (1991)



Source: Steedman Science & Engineering (1991)

ROLLER FIELD DEVELOPMENT

SPRING TIDAL DEPTH-AVERAGED CURRENTS, AT THREE HOURLY INTERVALS, PREDICTED BY THE 2D CIRCULATION MODEL. (HOUR 72 CORRESPONDS TO 0000 25/11/88)

Figure **1**

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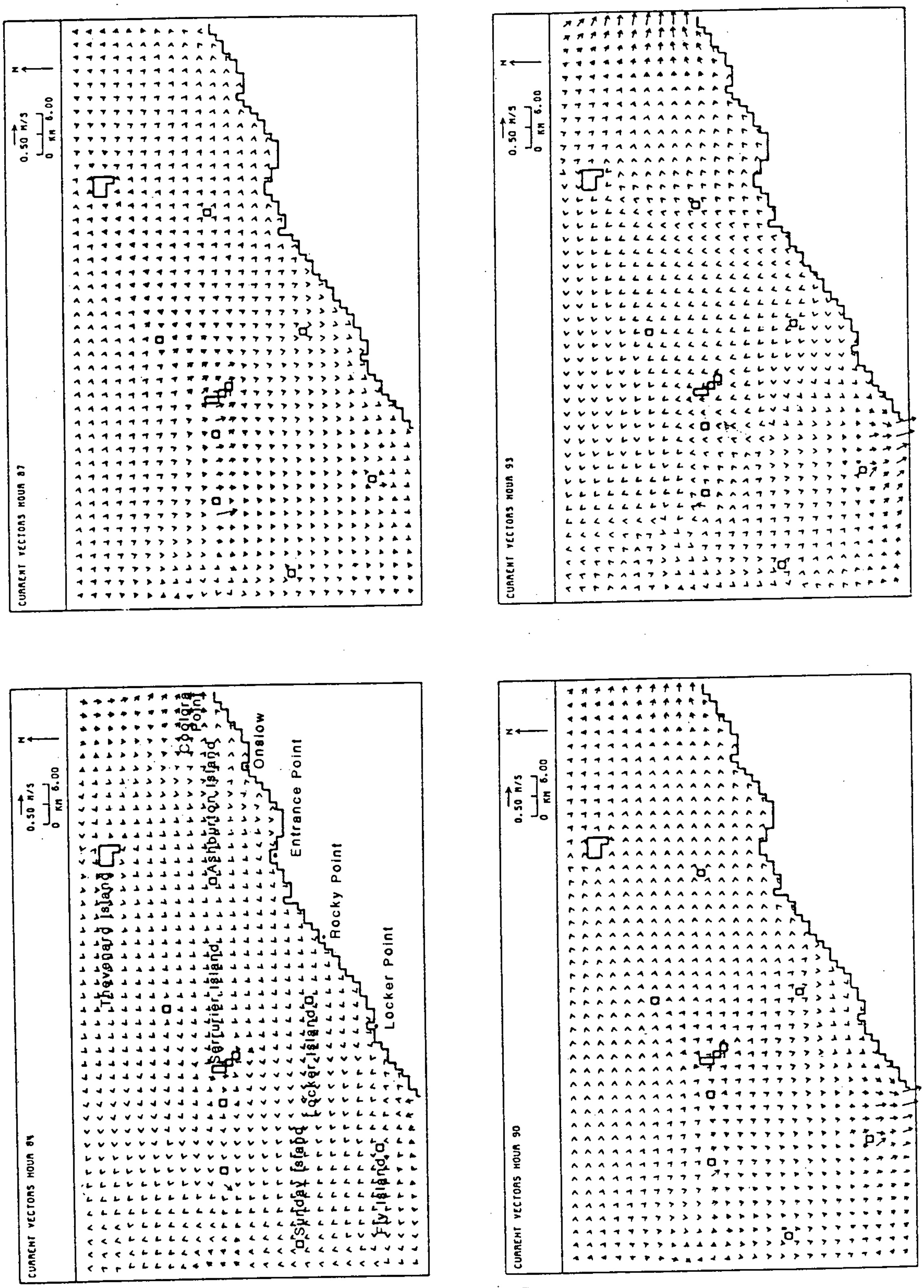

Source: Steedman Science & Engineering (1991)

	ROLLER FIELD DEVELOPMENT **NEAP TIDAL DEPTH-AVERAGED CURRENTS, AT THREE HOURLY INTERVALS, PREDICTED BY THE 2D CIRCULATION MODEL. (HOUR 84 CORRESPONDS TO 1200 4/11/88)**	Figure **2**
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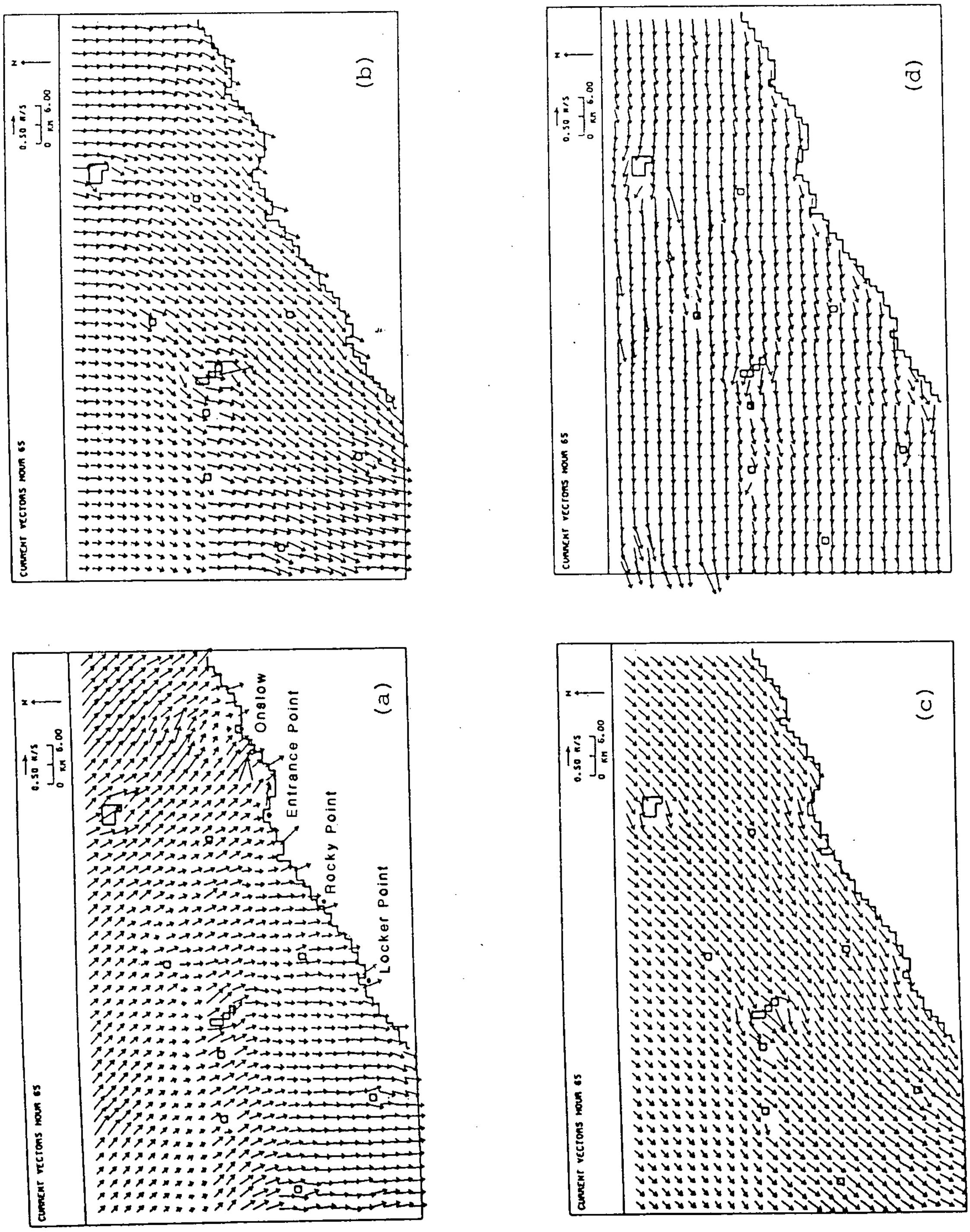

Source: Steedman Science & Engineering (1991)

ROLLER FIELD DEVELOPMENT

SURFACE CURRENTS PREDICTED BY THE 2.5D CIRCULATION MODEL FOR STEADY $10 ms^{-1}$ WINDS FROM THE NORTH, NORTH-EAST, EAST AND SOUTH-EAST.

Figure **3**

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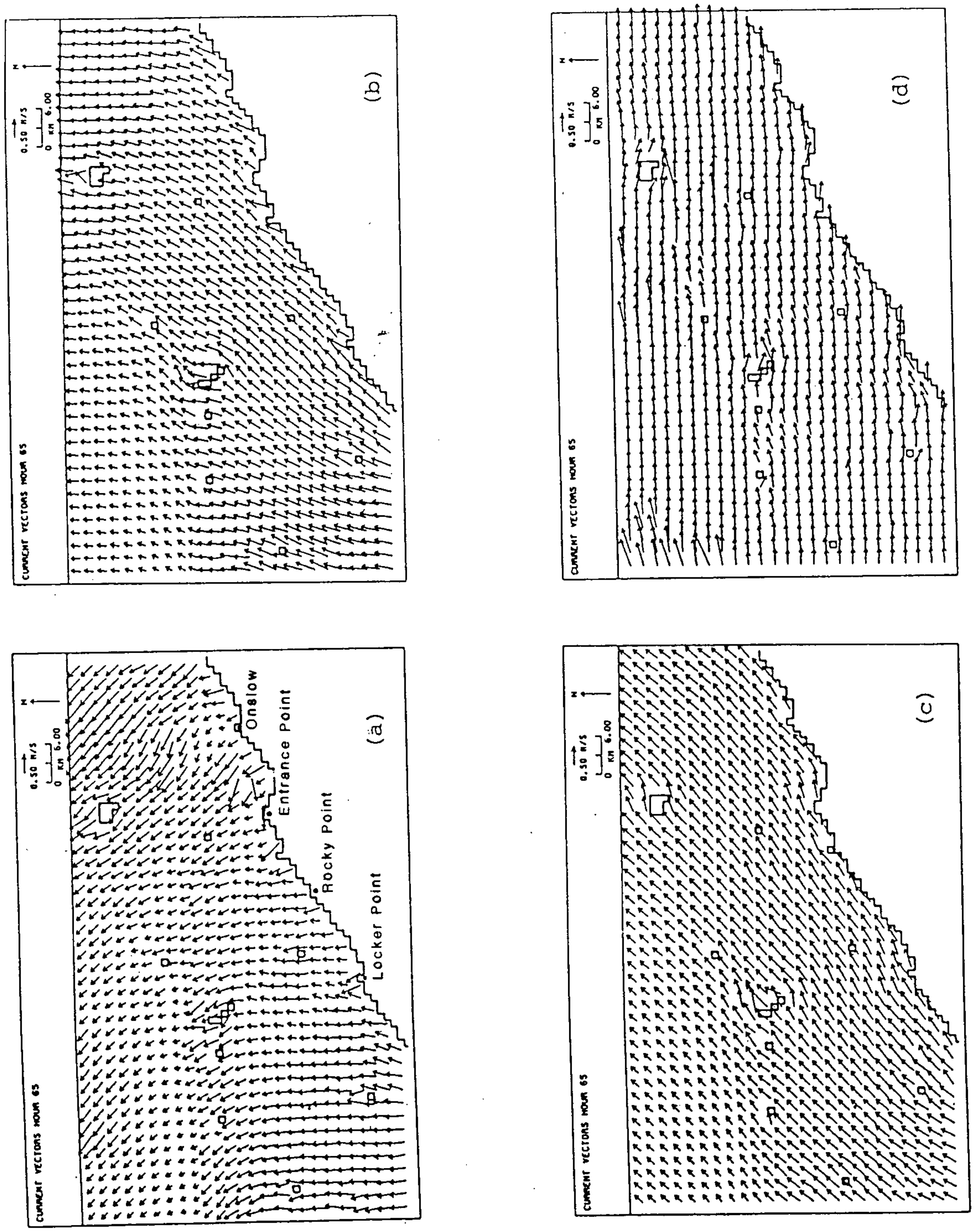

Source: Steedman Science & Engineering (1991)

ROLLER FIELD DEVELOPMENT

SURFACE CURRENTS PREDICTED BY THE 2.5D CIRCULATION MODEL FOR STEADY 10ms^{-1} WINDS FROM THE SOUTH, SOUTH-WEST, WEST AND NORTH-WEST.

Figure 4

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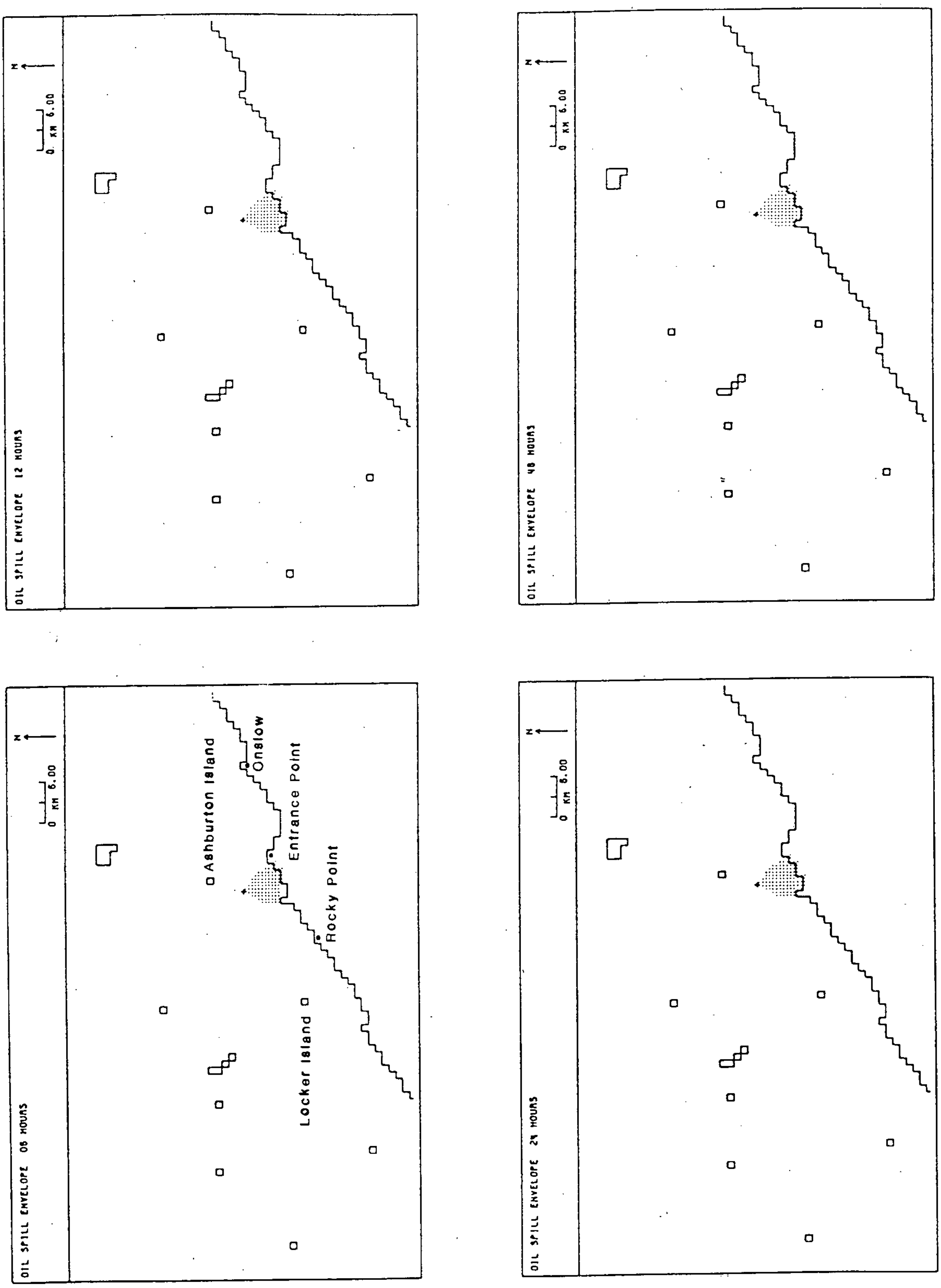

Source: Steedman Science & Engineering (1991)

Auth : / Date : 3/91	ROLLER FIELD DEVELOPMENT **OIL SPILL ENVELOPES FOR RELEASE TIMES OF 6, 12, 24 & 48 HOURS FOR THE CASE OF NORTHERLY WIND DURING SPRING TIDES FOR ROLLER CENTRAL LOCATION.**	Figure **5**

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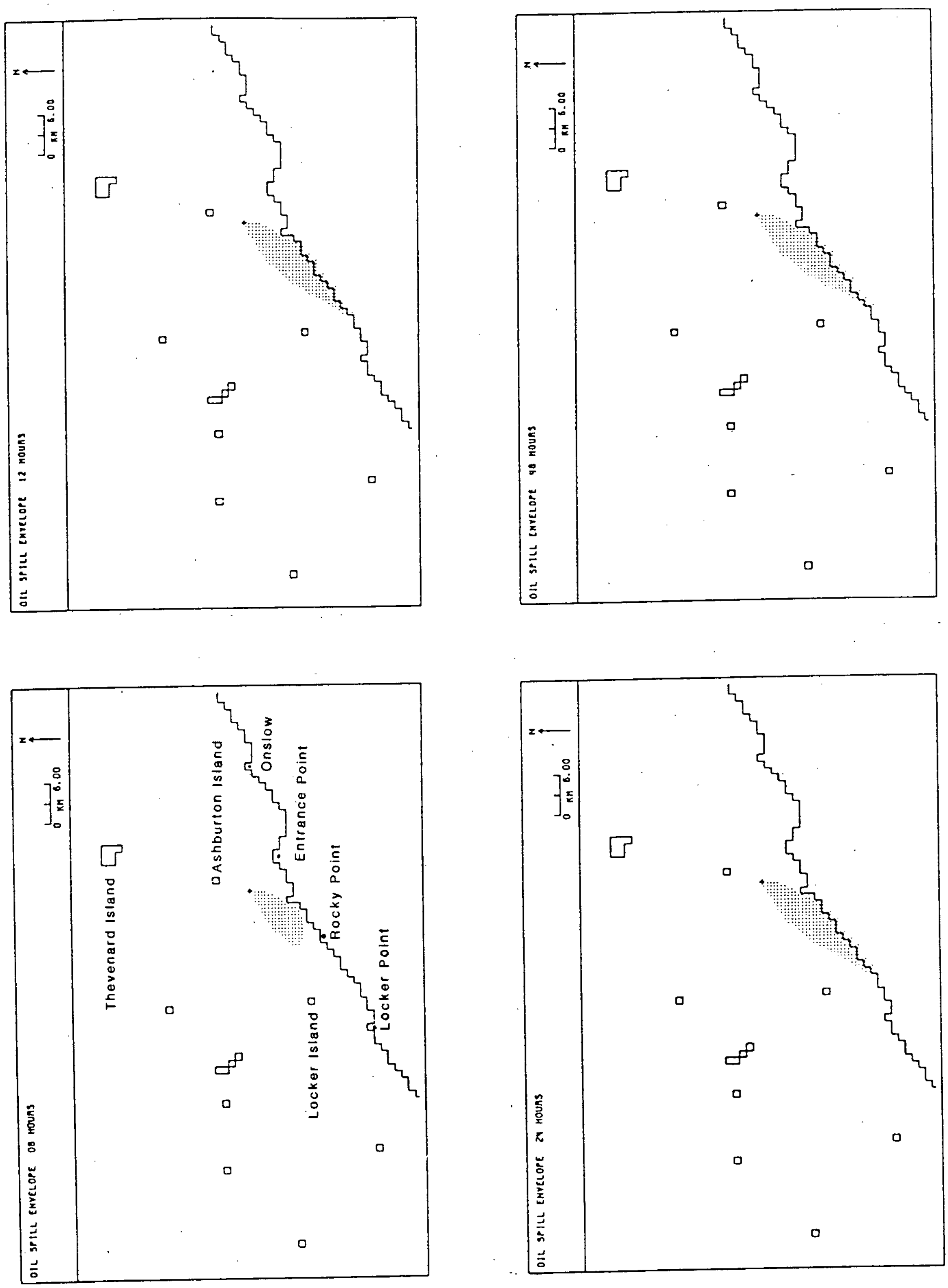

Source: Steedman Science & Engineering (1991)

ROLLER FIELD DEVELOPMENT

OIL SPILL ENVELOPES FOR RELEASE TIMES OF 6, 12, 24 & 48 HOURS FOR THE CASE OF NORTH-EASTERLY WIND DURING SPRING TIDES FOR ROLLER CENTRAL LOCATION.

Figure 6

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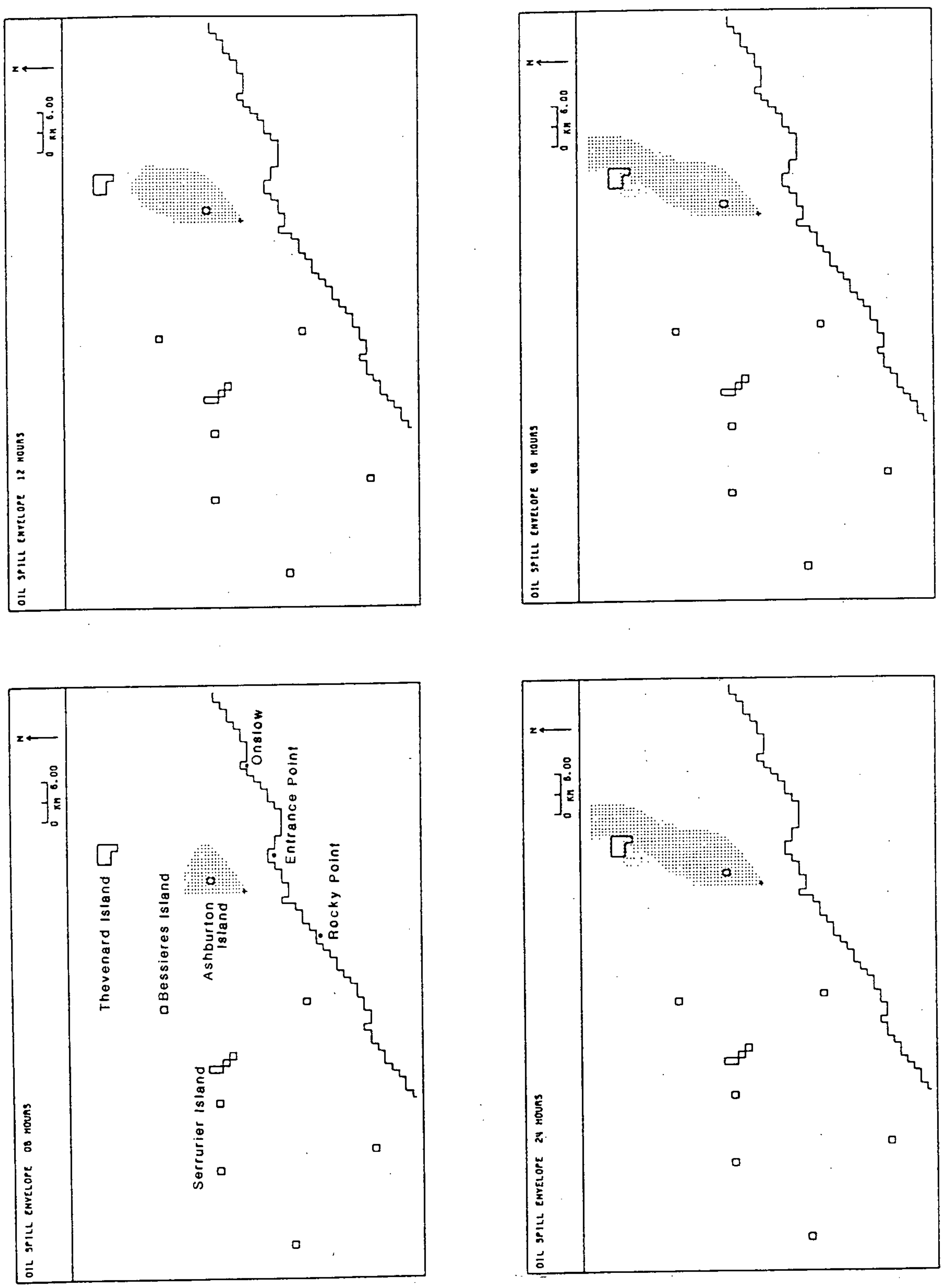

Source: Steedman Science & Engineering (1991)

ROLLER FIELD DEVELOPMENT

OIL SPILL ENVELOPES FOR RELEASE TIMES OF 6, 12, 24 & 48 HOURS FOR THE CASE OF SOUTH-WESTERLY WIND DURING SPRING TIDES FOR ROLLER CENTRAL LOCATION.

Figure 7

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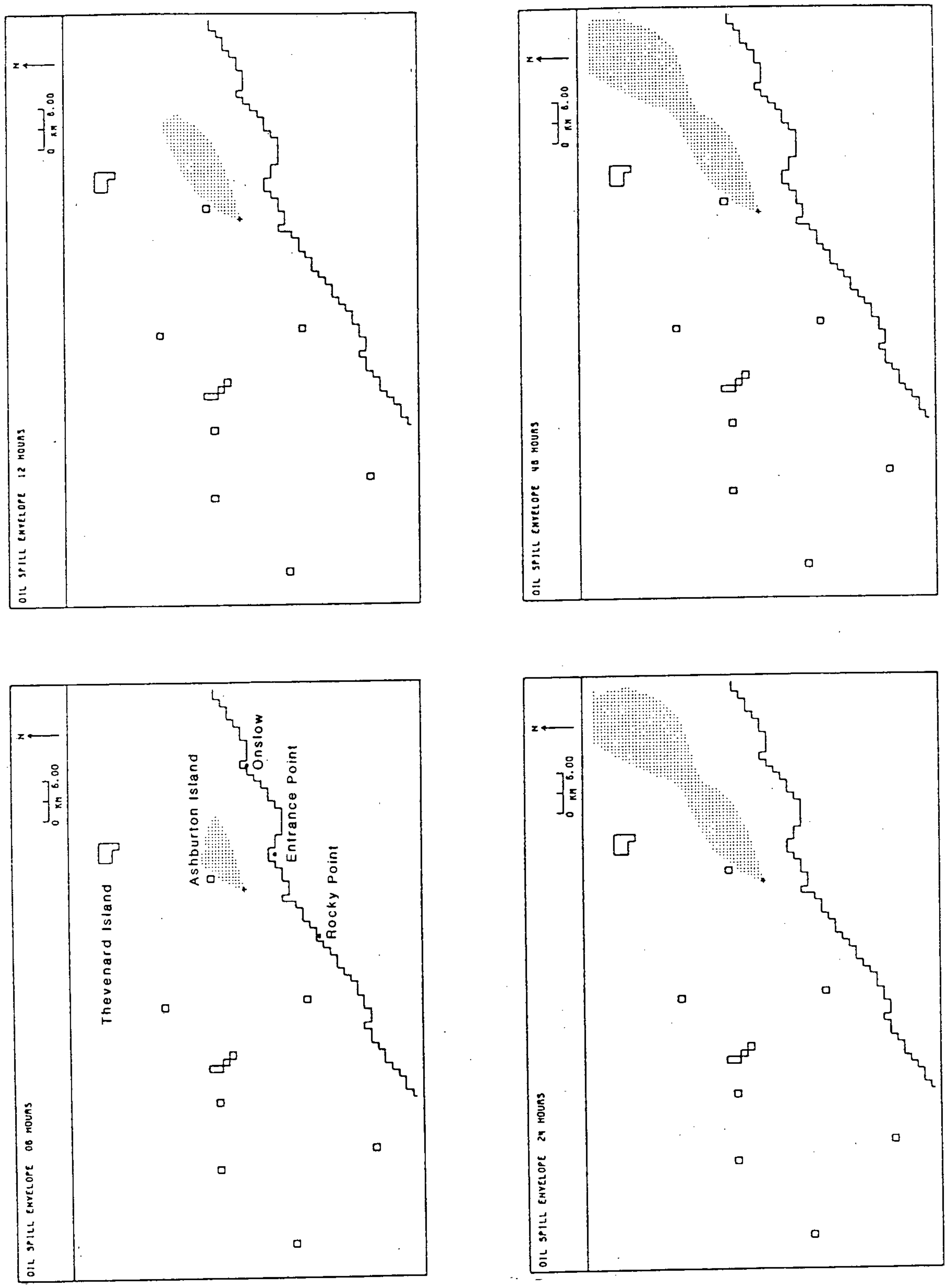

Source: Steedman Science & Engineering (1991)

ROLLER FIELD DEVELOPMENT

OIL SPILL ENVELOPES FOR RELEASE TIMES OF 6, 12, 24 & 48 HOURS FOR THE CASE OF WESTERLY WIND DURING SPRING TIDE FOR ROLLER CENTRAL LOCATION.

Figure **8**

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West Australian Petroleum Pty Limited

Roller Oilfield Development

Consultative Environmental Review

APPENDIX 5

LITERATURE REVIEW ON TOXICITY OF MEDIUM WEIGHT CRUDE TO TROPICAL MARINE ENVIRONMENTS

LEC Ref: J218/R342

LITERATURE REVIEW ON TOXICITY OF MEDIUM WEIGHT CRUDE TO TROPICAL MARINE ENVIRONMENTS

Table of Contents

LITERATURE REVIEW ON TOXICITY OF MEDIUM WEIGHT CRUDE TO TROPICAL MARINE ENVIRONMENTS

1 INTRODUCTION

A comprehensive literature review of the impacts of oil on tropical marine environments was conducted for the Saladin Oilfield Environmental Review and Management Programme (ERMP) (1987). This review was subsequently used as a basis for the assessment of the potential impacts of oil spills on marine resources in the vicinity of the Roller prospect during the preparation of the Roller Notice of Intent (NOI) (LSC, 1989). The assessment was conducted assuming that a very light oil, which is characteristic of the North West Shelf, would be found. The discovery of oil at the Roller prospect showed that the crude was in fact a medium weight oil (API 29°). Based on its gravity the oil more closely resembles Prudhoe Bay, Nigerian and Tijuana crude oils than typical North West Shelf oils.

Initial characterisation of the Roller crude oil suggests that it is composed primarily of hydrocarbon compounds between C_7 (heptanes) and C_{19} (nonadecanes). The remaining 30% (by volume) comprises the C_{20+} (eicosanes plus) fraction that includes the higher molecular weight cyclic and aromatic compounds. The oil is highly biodegraded so its chromatographic trace is characterised by an unidentified complex mixture (UCM), a lack of normal alkanes and a suite of branched and cyclic hydrocarbons. The oil is therefore heavier than an equivalent oil that has not been biodegraded within the reservoir.

Since Roller oil is heavier than had previously been anticipated it was considered necessary to re-assess the potential impacts of the oil on local marine resources, and particularly those having high ecological and commercial value. This review is therefore concerned primarily with the impacts of whole and dispersed medium weight crude oil on mangroves and prawns. A brief review of recent (1987-1990) literature has also been conducted to bring the 1987 Saladin ERMP literature review up to date. This information is included at the end of this review and covers the potential impacts of light and medium weight crude oils on corals and seagrasses.

2 PRAWN FISHERIES

2.1 INTRODUCTION

The potential impacts of an oil spill on a commercial fishery may include:

- loss of access to trawling areas;
- hazard to navigation;
- debris fouling trawl nets; and
- pollution of prawns and gear.

In the event of an oil spill in the vicinity of a commercial trawling ground two major areas of concern have been identified: the toxic impact of the oil on the various life stages of the fishery; and the perception of the consumer with regards to tainting.

2.2 TOXICITY STUDIES

2.2.1 Oil and Prawns

The result of a number of laboratory experiments on the effects of whole oil and water soluble fractions of oil on prawns have indicated that the potential impacts range from none observable to temporary lethargy or death.

Research into the physiological response of marine and estuarine organisms commenced in the early 1970s (Anderson *et al.*, 1974a; Anderson *et al.*, 1974b; Anderson, 1975; Neff & Anderson, 1981; Anderson *et al.*, 1983; Anderson *et al.*, 1987). The research has indicated that the tolerance of all life stages of both estuarine and oceanic shrimps and prawns to the water soluble fraction of a medium weight crude oil were variable (Neff & Anderson, 1981). Furthermore the individual classes of organic hydrocarbons within the oil exhibited different degrees of toxicity based on their solubility. The low molecular weight polycyclic aromatic hydrocarbons (PAH) were toxic at approximately 1 ppm, while PAH of four rings and greater were not toxic at all. In addition alkylated PAH, while less soluble than parental PAH, are also more toxic than parental PAH.

More recently Anderson *et al.* (1987) have identified and isolated the specific compounds in crude oils that cause toxic responses in a species of shrimps. Evidence suggests that toxicity decreases with decreasing total aromatics (benzene, alkylbenzene and naphthalenes). Naphthalenes are the compounds causing significant mortality at the lowest concentration. Benzenes are also toxic, however their comparatively low solubility in water reduces the bio-availability of these compounds. These compounds are also highly volatile and thus disappear from solution and sediments rapidly. Similar tests performed on fish were substantially different to shrimps, with the former being more tolerant than prawns to dispersed oil, particularly the water-soluble fractions. The authors concluded that the effects of water-soluble fractions of the oil were not likely to be significant unless the oil becomes trapped. They noted, however, that latent mortality was evident in tests on cessation of oil exposure, so these findings should be reviewed constantly.

Concern has also been expressed over the possibility of toxic hydrocarbons being bio-accumulated within the food chain. The results of early research suggests however that this does not occur since shrimps contain detoxifying enzymes that allow them to metabolise and flush aromatic hydrocarbons from their system (Neff *et al.*, 1976).

It is therefore apparent that the degree of toxicity of an oil will depend on its molecular composition and in general, medium weight crude oils have a lower percentage of low molecular weight PAH relative to lighter, more toxic oils.

While light, medium and heavy weight oils exhibit variability in the degree of toxicity, similar variability is seen between fresh versus weathered oils. Evaporation removes the more volatile low molecular weight toxic components so a weathered oil is always less toxic than a fresh oil. This concept is supported by a study carried out using the water soluble fraction of a medium weight oil which showed that fresh oil was toxic to test shrimp and caused an immediate and irreversible effect on feeding; while the weathered fraction was less toxic and the effects on feeding was delayed and reversible (Lee, Winters & Nicol, 1978). Recently Kasymov and Gasanov (1987) demonstrated that under static laboratory conditions, oil concentrations of 5 mg/L caused sublethal toxic responses in test shrimp while concentrations of 10-25 mg/L caused mortality of the organism. The study also concluded that larvae were more sensitive than adult life stages. Toxicity testing of local species was conducted following the Ixtoc blowout in the Gulf of Mexico during 1979 and 1980 (Lee, Morris & Boatwright, 1980; Bedinger & Nulton, 1982; Jernelov & Linden, 1981). Larvae and adults of commercial shrimps from spawning grounds in the vicinity of the Ixtoc blowout were found to have an acutely toxic response to 0.1-10 ppm of total oil while weathered Ixtoc oil did not induce any acute toxicity in crustaceans.

2.2.2 Dispersed Oil and Prawns

Laboratory studies on the impacts of dispersed oil on prawn life stages are scarce. However a recent study involving a chemically dispersed light crude suggested that toxic responses occurred rapidly within the first six hours of a spill and that shrimps surviving the first 6-12 hours of exposure usually recovered and survived the ret of the test period (Shuba & Heikamp, 1989). While dispersants will bring a greater proportion of the water column, and thus a greater number of marine organisms that would normally not be affected, into contact with spilled oil they will also enhance the volatilisation of the lighter more toxic aromatics.

2.2.3 Fisheries Impact

Laboratory conditions do not always accurately reflect those observed in the field, so the results of studies following real oil spills are generally a better indicator of the true impacts of oil spills. The majority of these studies suggest that no observable impacts on prawn fisheries have been caused by oil spills (Hester, 1977, and references therein; Blackman & Law, 1980; Boehm & Fiest, 1983; Moller *et al.*, 1989). None of the reviewed literature could definitively state that any impact on commercial fisheries had occurred as a direct result of oil spills and furthermore, most authors conceded that it would be extremely difficult to separate the effects of an oil spill from seasonal variations in catch statistics.

While there are no correlations between oil spills and fluctuations in commercial fishery catch statistics, shrimps caught in the vicinity of an oil slick immediately following a spill may contain measurable concentrations of petroleum hydrocarbons (Teal & Howarth, 1984). However care must be exercised in describing a source for this contamination, since natural sources for petrogenic hydrocarbons do exist (Blumer, Guillard & Chase, 1971; Youngblood & Blumer, 1973; Giam *et al.*, 1976).

Moller *et al.* (1989), while investigating the impacts of oil spills on commercial fishery operations, suggested that free swimming shrimps are rarely affected by oil spills. Moreover they could find no evidence of cases involving proven damage to commercial stocks of free swimming species.

Finally, the Ixtoc blowout of 1979-1980 resulted in a massive intrusion of petroleum hydrocarbons into the waters of the Gulf of Mexico. Approximately half a million tonnes were released into the marine environment which included known prawn trawling grounds. A study by Boehm & Fiest (1983) concluded that:

> "no definitive offshore damage could be associated with the Ixtoc, or other known spills (such as the Burmah Agate) on the epibenthic commercial shrimp population."

2.2.4 Tainting of Prawns

While it is difficult to identify and quantify the chronic and acute impacts of oil spills on crustaceans, it becomes almost impossible to characterise the tainting impacts of oil on commercial seafoods since tainting cannot be easily measured, and is based on subjective rather than objective assessments. Consumer fears of tainted seafood following a spill may cause a greater economic impact on a fishery than the actual oil spill.

The Commonwealth Scientific and Industrial Research Organisation (CSIRO) Food Research Laboratory has identified the five most commonly encountered types of off-flavours. Related studies indicate that the most likely origins of the offending taint-causing compounds may include microbial spoilage, diet and environmental pollution (Whitfield & Freeman, 1983). In the event of petroleum hydrocarbon contamination the compounds that have been identified as being responsible for off-flavours include aromatic hydrocarbons, particularly alkylbenzenes and alkylthiophenes (Kagi *et al.*, 1982; Whitfield, 1988).

Whitfield *et al.* (1987) has also found that off-flavours characteristic of Exmouth Gulf Endeavour prawns are caused by the algae and bryozoa diet of the prawns and thus in this case tainting of the prawns is a natural event.

Of the few studies investigating organoleptic characteristics of marine organisms, only one (McGill *et al.*, 1987) reported a concentration range of petroleum hydrocarbons in tainted fish (0.14-4.6 ppm). This study found that the maximum concentration of petroleum hydrocarbons in taint free samples was 0.30 ppm suggesting that while a sample may be contaminated by petroleum hydrocarbons it must contain the specific compounds that cause off-flavours for the sample to be judged tainted.

A laboratory study by Knieper and Culley in 1975 is the only one from the available literature that assessed the taste threshold for oil in shrimp. The study found that 90 ppm oil in water was the minimum concentration required to cause taste tainting in shrimps.

Due to the difficulties in identifying and quantifying tainting in seafoods this type of data is rarely reported following oil spills. One such study was however conducted following the Eleni V spill off the English coast in 1978. The results indicated that the commercial shrimp samples were free of off-flavours (Blackman & Law, 1980).

2.3 CONCLUSION

The following general conclusions can be drawn from this review of the potential impacts of oil on prawns:

- Generally there has been little or no observable physical impact on commercial fisheries following oil spills.

- Natural fluctuations in fisheries catch statistics may mask any effect caused by an oil spill.

- Medium weight oils containing relatively low concentrations of low molecular weight PAH are less toxic to prawns than light crude oils which often contain a greater proportion of volatile PAH.

- Weathered oils having lost the more toxic volatile components are therefore expected to be less toxic to prawns than unweathered crude oils.

- Shrimps will take up petroleum hydrocarbons however these compounds are not bio-accumulated or bio-magnified since the animal is capable of metabolising these compounds and flushing them from their bodies.

- Young life stages are generally more sensitive to oil than adult organisms.

- Free swimming prawns have a lower potential for exposure to oil floating on the sea surface than to dispersed oil which spreads the oil throughout the water column.

- Natural sources are occasionally responsible for tainting of prawns.

- Aromatic hydrocarbons are generally responsible for petroleum-like off-flavours in seafood.

- There is a potential for a decline in the marketability of seafood following an oil spill because of the public's perception regarding tainting of the product.

3 MANGROVES

3.1 OIL AND MANGROVES

Mangroves are an considered to be an important component of tropical ecosystems as they are:

- nursery areas for a wide range of marine species;
- a source of organic matter and nutrients; and
- shoreline stabilisers.

Until recently mangrove forests have been uniformly assigned the highest sensitivity ranking when compared to other coastal environments. This has been in response to the observed deleterious effects of crude oil on these ecosystems (Baker, 1981).

The deleterious effects may include defoliation, blackening and curling of the leaves, chlorosis, pneumatophore damage and death. There are numerous variations in the response of mangroves to spilled oil and this variability may be caused by factors such as:

- zone of impact;
- the species of mangrove impacted;
- the initial toxicity of the oil;
- the degree of weathering and emulsification that has taken place between spillage and impact;
- prevailing weather and seasonal conditions which influence weathering, emulsification and the position, concentration and retention of oil deposited in mangrove areas; and
- geomorphology of the mangrove area.

This review concentrates primarily on the impacts of medium weight crude oils, either alone or dispersed (usually with Corexit 9527), on the mangroves *Rhizophora* and *Avicennia*.

The following general information is pertinent to this review:

(i) lighter more aromatic crude oils have a higher biological toxicity than medium and heavy weight oils (Wardrop *et al.*, 1987);

(ii) medium weight crude oils will weather moderately rapidly and may leave some residual contamination in water and sediments (Ballou & Lewis, 1989);

(iii) very fine mangrove sediments in low energy environments tend to retain hydrocarbons more than coarse sediments in high energy areas (Vandermeulen cited in Jackson *et al.*, 1989);

(iv) mangrove biota in protected riverine and channel settings are more persistently disturbed than those in open coast settings (Jackson *et al.*, 1989);

(v) the high air and water temperatures of subtropical and tropical marine environments promote evaporative weathering of light - medium weight crude oils.

A comprehensive review of the literature on the impacts of oil spills on mangroves was conducted by Thorhaug (1987). It was concluded that while defoliation of mangroves was a common occurrence, massive mortality was not always the ultimate outcome, suggesting toxicity, but not lethality, of the spilt oil.

Some specific case studies involving spilled oil and mangroves are outlined below.

A spill of approximately 397 kL (2,500 bbl) of oil occurred in the Florida Keys in 1975 (Chan, 1977). A one year survey following the spill indicated that no adverse impact to mature *Rhizophora* trees occurred where oil partially coated prop roots; while the oiling of less than 50% of *Avicennia* pneumatophores did not appear to affect the trees.

This survey did identify extensive mortality of *Rhizophora* seedlings following the oiling of their stems and leaves, and in dwarf black *Avicennia* mangroves with more than 50% oiling of pneumatophores.

Snowden & Ekweozor (1987) studied a spill of medium weight Nigerian crude in a semi-enclosed estuary area which caused defoliation of 500 m^2 of mangroves. Within this area no mortality of mature trees was observed, while seedlings were seen to die as a result of the oiling. Defoliated trees had begun to show new leaf growth within five months of the spill.

A 3,815 kL (24,000 bbl) spill of medium weight Tijuana crude oil washed ashore at Cabo Rojo in Puerto Rico resulted in oiling of the prop roots and submerged roots of *Rhizophora* and *Avicennia* mangroves (Nadeau & Bergquist, 1977). Mortality was restricted to a 1 ha area of mangroves in the months following the spill. A second survey carried out approximately four years after the spill by Page *et al.* (1979), found that the initial mortality was not ongoing and that re-emergence of young trees was occurring in spite of the fact that some of the sediments were still heavily contaminated by oil. The oiled sediments appeared to be no longer toxic to the mangroves, and chemical analyses showed that the one, two and three ring aromatics had been weathered from the oiled sediments. Furthermore, compared with temperate locations, the rate of biodegradation of the oil within the anoxic mangrove sediments was extremely rapid. The study concluded that the recovery potential from an oil spill for a coastal mangrove ecosystem is high.

In synthesising the results of a seven year programme to determine the effects of oil and dispersants on *Rhizophora* and *Avicennia*, Getter, Ballou and Koons (1985) found that *Rhizophora* appeared to be able to exclude oil uptake at the roots while *Avicennia* was only partially capable of this and thus potentially the more sensitive of the two species to oil.

Mangrove response also varied as a function of which part of the tree was oiled; for example root and leaf oilings were more toxic than oiling of the stems. Field studies were carried out by the same researchers who reported defoliation of mangroves without mortality after being exposed to 50 ppm of medium weight crude oil for 24 hours. The acute impacts of the oiling were seen within two weeks of the experimental spill and no further onset of new effects were observed after four months.

In 1986, 7,949 kL (50,000 bbl) of a medium weight crude oil was spilled directly into a sheltered coastal habitat in Panama (Cubit *et al.*, 1987; Jackson *et al.*, 1989). The area affected had been subject to a monitoring programme since a previous oil spill 18 years earlier and thus detailed baseline information was available for impact assessment purposes. The spill caused extensive mortality in the *Rhizophora* mangroves immediately after the spill (Keller, 1989); it is thought that sublethal effects on the *Rhizophora* forests were extensive and that they may be more important in the long-term than the initial mortality (Jackson *et al.*, 1989).

3.2 DISPERSANTS AND MANGROVES

Mangrove substrates are usually composed of fine sediments in low energy areas, so it is generally accepted that mechanical clean-up procedures in those habitats have the potential to render more harm than the oil itself (API, 1985). The alternative has therefore been to treat the oil with chemical dispersants.

Dispersants were first used on a large scale during the Torry Canyon incident in 1967. The extensive ecological damage that resulted from the use of the early dispersant formulations (first generation dispersants) was due to the fact that they were composed primarily of hydrocarbon solvents, containing high concentrations of organic compounds now known to be toxic to marine organisms. These dispersants were applied to the oil undiluted and in large volumes (Brochu *et al.*, 1986/87). The second generation dispersants were water dilutable concentrates which, when diluted, contained lower levels of the toxic hydrocarbons than the first generation types (Franklin & Lloyd, 1986/87). The third generation of dispersants are concentrates that are applied undiluted and, because they are glycol-based, are of a much lower biological toxicity than the two previous types (Franklin & Lloyd, 1986/87).

The dispersant most widely tested and most frequently recommended is Corexit 9527, a third generation concentrate. It has a wide range of applications to various oil types and alone it has a relatively low toxicity to most marine organisms.

Laboratory experiments do not always accurately reflect the behaviour of dispersed oils in the field, so Getter, Ballou and Koons (1985) conducted a 20 month long field experiment with a whole and dispersed medium weight crude oil in Panama. The results of this study clearly indicated that the field application of dispersants to the oil, prior to its exposure to the mangroves, greatly reduced the lethal and sublethal effects on seedlings and adult mangroves. Moreover the application of dispersants greatly reduced the retention of petroleum hydrocarbons in mangrove sediments, reducing uptake by the adult mangroves. Supporting evidence from Ballou *et al.* (1987) indicated that dispersants had a positive effect reducing or preventing adverse impacts to the mangroves, and that seedling sprouting success and survival rates were much higher at dispersed sites than at undispersed sites.

The results of studies involving the lighter, generally more toxic crudes support the results of studies with medium weight crude oils. Locally, a study of dispersed oil in South Australian *Avicennia* stands found that the toxicity of the dispersant oil mixture caused high initial toxicity, however this toxicity decreased with time (Wardrop *et al.*, 1987).

A similar study by Teas, Duerr and Wilcock (1987) provided evidence suggesting that there was no significant difference in deaths of mangroves within dispersed oil and control plots.

As an oil spill management tool, dispersant use on oil prior to its entry to a mangrove forest is recommended by the majority of investigators involved in mangrove research (Getter, Ballou & Koons, 1985; Ballou *et al.*, 1987; Teas, Duerr & Wilcock, 1987; Ballou *et al.*, 1989; Thorhaug, 1989). Dispersants must not, however, be applied after oil enters the mangroves since it produces the same effect as oil alone in mangroves (Thorhaug *et al.*, 1989).

3.3 RESTORATION OF MANGROVES

While mechanical treatment of oil spilled in mangroves is not recommended, restoration of impacted areas has been attempted with some success.

Experiments with the long-term restoration potential of impacted Florida mangroves have indicated that oiled *Rhizophora* seeds placed in clean water will germinate. However, the rate may be lower than control seeds (Chan, 1977).

Seedling sprouting success and survival rates are enhanced in sediments subject to dispersed oil in comparison with sediments exposed to oil only (Getter, Ballou & Koons, 1985).

The largest mangrove restoration project in the world has been initiated in Panama following the rupture of a tank containing a medium weight crude oil (Teas, Duerr & Wilcock, 1989). More than 42,000 nursery-grown seedlings and 44,000 propagules have been planted to restore oil-killed mangrove forests in the area. The restoration programme was initiated soon after the spill and the results of the initial experimental phase suggests that seedlings were successfully replanted six months following the spill, however growth was more rapid if replanting was delayed nine to 12 months after the spill.

3.4 CONCLUSIONS

The conclusions based on review of literature cited in this review are as follows:

(i) The most common response of mangroves to oiling is defoliation, rather than mortality which occurs only rarely.

(ii) Defoliated trees are capable of regrowth within 6-12 months of a spill occurring.

(iii) The low molecular weight aromatics are thought to be responsible for the toxicity of oil to mangroves and the observed defoliation and mortality.

(iv) Residues of weathered medium weight crude oil do not appear to be toxic to mangroves.

(v) Oiling of stems does not appear to cause adverse impact on mangroves However oiling of leaves, prop roots and pneumatophores usually results in defoliation of mangroves.

(vi) Mangroves exposed to dispersed oil exhibit less lethal and sublethal effects than mangroves impacted by crude oil alone.

(vii) Seedling sprouting success and survival rates were much higher at dispersed sites than undispersed sites.

(viii) An oil spill that potentially threatens a mangrove forest should be dispersed prior to it impacting the area.

(ix) Restoration of mangroves impacted by medium weight crude oil is possible and should be initiated approximately one year post spill.

It should be noted, however, that these findings are indicative only of the likely effects under conditions experience on the Western Australian coast, until tests can be performed on mangroves in their natural setting using the Roller oil.

4 CORALS

The most recent information available on the effects of crude oil on corals is provided by Ballou *et al.* (1989); Jackson *et al.* (1989); LeGore *et al.* (1989) and Thorhaug *et al.* (1989).

Intertidal and subtidal reefs were monitored following a spill of medium weight crude oil in Panama. The results indicated that extensive mortality occurred in intertidal and shallow subtidal reefs, however corals growing in waters deeper than 3 m were not affected (Jackson *et al.*, 1989). These results contradict the findings of a large number of researchers who have found little or no adverse impact on corals following oil spills (LeGore *et al.*, 1989 and references therein).

Thorhaug *et al.* (1989) identified a wide variability in response between coral species to various dispersant types and oil. Specifically *Acropora* sp. were far more sensitive to dispersed oil than the shallow water *Diploria* sp. Severe long-term impacts on corals were also noted by Ballou *et al.* (1989) during a field survey on the effects of a dispersed medium weight crude oil on the major tropical habitat types. The authors concluded however that under more realistic conditions, in which floating untreated oil had weathered for several hours and is then dispersed into the water column over a relatively short period of time, it is reasonable to assume that the magnitude of impacts to subtidal environments would not be as severe as that measured during the study. The experimental data for a site exposed to whole, untreated crude oil clearly indicated that the impacts on submerged corals were relatively minor. The report further concluded that the results of this and numerous other studies of oil spills consistently showed that intertidal habitats are exposed to much higher concentrations of oil than subtidal habitats, if no action is taken to prevent the stranding of oil.

Finally, a field study carried out using Arabian light crude (API Gravity between 30° and 48°) indicated that healthy reef corals can tolerate relatively short (one to five days) exposure to floating oil and to dispersed oil with no observable effects. Dispersant related coral mortality may occur if the corals are exposed to other environmental stresses, such as exceptionally high or low water temperatures or cyclone activity (LeGore *et al.*, 1989).

5 SEAGRASSES

Experiments and field observations following spills of medium weight crude oils suggest that seagrasses experience little or no observable adverse impacts as a result of crude oil floating on the sea surface (Ballou *et al.*, 1989; Thorhaug *et al.*, 1989; Jackson *et al.*, 1989; Thorhaug & Marcus, 1987).

Jackson *et al.* (1989) saw a discolouration and heavy algal fouling of seagrasses for several months following heavy oiling of a subtidal seagrass area, however the seagrasses survived these perturbations.

Thorhaug and Marcus (1987) reporting on the use of dispersants on an actual oil spill, found that the results corroborated laboratory and field studies with regards to the low degree of impact caused by the dispersed oil. This study did however identify a variability in toxicities of different dispersants to various seagrasses. *Thalassia* sp. appears to be the most tolerant species tested.

Toxicity testing using light crudes are less common. Thorhaug *et al.* (1989) found that there was a variability in response of *Thalassia, Halodule* and *Syringodium* to oil and dispersed oil, and generally *Thalassia* was the most tolerant species. Dispersed oil appeared to have a slightly greater effect on the seagrasses than oil alone.

6 IMPLICATIONS FOR MANAGEMENT OF SPILLS OF MEDIUM WEIGHT OILS

The Roller crude is a medium weight oil that potentially has lower levels of the toxic PAH than a lighter oil, therefore it is anticipated that a spill of this type of oil will be less toxic to sensitive marine resources than lighter oils.

The following actions are recommended in the event of a spill of medium weight crude oil:

(i) avoid using dispersants over coral or seagrass algae beds,

(ii) apply dispersants to oil prior to the oil impacting mangroves.

It is further recommended that the option of dispersing a medium weight crude should be carried out within approximately six hours of the spill occurring, as evaporative weathering will rapidly remove the light end components leaving a relatively heavy residue. This residue will probably be very viscous and the application of chemical dispersants at this point will have no effect on the oil.

Should the weathered residues of a medium weight crude impact a shoreline then action may be necessary to remove the oil. The residues of a weathered medium weight crude are heavier and more viscous than a light crude and/or its residues, so if the crude makes landfall the primary impacts are expected to be physical rather than chemical. The removal of oil and sediments may be necessary to protect biologically important (turtle and seabird breeding) beaches.

In any event, because of the idiosyncratic nature of major oil spills, the decision to disperse with chemicals must ultimately be made with all conditions and factors prevailing at the time of the spill taken into account.

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West Australian Petroleum Pty Limited

Roller Oilfield Development

Consultative Environmental Review

APPENDIX 6

SUMMARY OF THE OIL SPILL CONTINGENCY PLAN FOR THE ROLLER OILFIELD

LEC Ref: J218/R342

SUMMARY OF THE OIL SPILL CONTINGENCY PLAN

FOR THE ROLLER OILFIELD

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SUMMARY OF THE OIL SPILL CONTINGENCY PLAN FOR THE ROLLER OILFIELD

1 INTRODUCTION

A detailed Oil Spill Contingency Plan (OSCP), covering all drilling and production operations in Permit Area TP/3 Part 1, was submitted to and approved by relevant government departments, including the Environmental Protection Authority, the Department of Mines and the State Combat Committee in early 1990.

This plan has been updated as new information has been obtained and the revised pages distributed to all personnel and government departments that hold copies of the plan.

The purpose of the permit wide contingency plan was to provide a document that could be used for drilling and production operations within the area. The aim of the TP/3 Part 1 OSCP was to avoid the unnecessary repetition and time consuming delays involved in preparation of identical documents for every prospect drilled and for subsequent production operations within the permit area. This appendix on oil spill contingency planning summarises the most important aspects of the detailed TP/3 Part 1 OSCP.

2 OBJECTIVES

The objective of the plan is to provide procedures and guidelines for personnel involved in combating an oil spill such that damage to the environment is either prevented or minimised.

The plan defines priority actions to be taken in the event of a spill and identifies personnel responsibilities, equipment and facilities available for containment, recovery and disposal of spilled oil, and the role of the company and other organisations in responding to an oil spill.

The plan identifies environmental resources in the area requiring special protection and provides information on the influence of local meteorological and oceanographic conditions on marine oil spills. Guidelines are provided for monitoring the impact of oil spills on the environment and for subsequent clean-up procedures. The following sections are summaries of the individual areas covered by the detailed OSCP.

3 ON-SITE OIL SPILL ACTION PLAN - PERMIT AREA TP/3 PART 1

When a reported oil spill or slick is confirmed the following action plan should be used by the West Australian Pty Limited (WAPET) person-in-charge (PIC) to develop appropriate response measures. These response measures are applicable regardless of the size of the spill. This action plan is a summary of the more detailed plan contained in the Permit Area TP/3 Part 1 OSCP.

(1) **Initiate alert procedures**

(a) Evaluate whether required spill response is within the capability of WAPET or whether assistance is needed.

(b) Communication channels are to be monitored continuously during an oil spill response.

(2) **Act to prevent continuing spillage** if possible to do safely. Isolate equipment and materials which may create a fire hazard. Priority consideration must be given to safety of personnel before taking any action.

(3) **Assess spill**

(a) Identify location of spill.
(b) Estimate quantity of oil.
(c) Identify type of oil.
(d) Estimate size of slick.
(e) Observe direction of movement of spill.
(f) Observe weather conditions:
- wind direction,
- wind speed.

(4) **Despatch vessel carrying containment boom equipment**

(5) **Arrange to monitor the movement** of the slick

(6) **Assess the anticipated path** of the slick

(a) Determine current phase of tidal cycle (neap or springs). Refer to tide tables.

(b) Determine wind direction and speed. Weather stations located at Thevenard Island and Barrow Island can provide this information.

(c) Determine likely spill trajectory from oil spill trajectory charts compiled from computer model trajectory results.

(7) **Monitor actual movement** of slick by placing movement indicators (e.g. rubber-backed sponge mat) into the leading edge of the spill. Commence sample collection.

(8) **Determine marine resources at risk** from the path of the spill. The priorities for protection of vulnerable marine resources in the area are summarised below (see Section 8).

High priority

- mangroves;
- sandy beaches (September - May) (turtles and hatchlings);
- tourist beach, Thevenard Island (May - October) (tourist season);
- coral reefs;
- vessel mooring area in Beadon Creek, Onslow.

Low priority

- sandy beaches (June - August) except tourist beach on Thevenard Island;
- seagrass and algae beds.

(9) **Determine appropriate response strategy** to deal with the spill (Fig. 1).

(10) **Initiate clean-up procedures**

(a) Table 1 is a summary of the effects of oil on various shorelines and should be used as a guide to dealing with beached oil.

(b) The preferred course of action for light-medium weight crude oil is to allow any stranded or beached oil to weather and degrade naturally.

(c) If an affected beach is heavily utilised at the time by turtles or seabirds, either:

(i) rake the affected beach areas to increase the rate of weathering and degradation; or

(ii) remove the contaminated sand and dispose of at an approved site on the mainland.

(d) Dispersants are not to be applied to stranded oil.

(11) **Dispose of oil-contaminated wastes** and recovered oil and water

(a) Oily waste and contaminated sand will be sent to one of the following approved sites:

(i) nominated oily waste disposal site at Onslow contact Work Supervisor, Shire of Ashburton, Ph. (091) 84 6001, a/h Ph. (091) 84 6083;

(ii) Karratha "Seven Mile" industrial disposal site, contact Shire of Roebourne, Ph. (091) 86 8555, a/h Ph. (091) 85 2272;

(iii) Karratha existing domestic tip.

(b) Recovered oil and water gathered by skimmers into a barge-mounted tank will be sent to Thevenard Island or Barrow Island and transferred to shore-based tank(s).

Vacuum truck(s) will transfer recovered oil and water to the production processing facilities existing at either site where the oil will be recovered or burned and the water treated prior to disposal.

(12) Initiate environmental monitoring of affected areas.

4 NOTIFICATION PROCEDURES AND INDIVIDUAL RESPONSIBILITIES WITHIN WAPET

These have been summarised in Figure 2 as a flow chart. The level of notification will depend on the size of an oil spill. Notification of government departments will be initiated through the Department of Mines in the event of a spill in excess of 80 L. If a significant spill takes place the following departments will be notified immediately: Environmental Protection Authority (EPA), Department of Conservation and Land Management (CALM), Department of Fisheries, State Combat Committee.

5 OFFSHORE DRILLING OPERATIONS

During the drilling of offshore prospects in Permit Area TP/3 Part 1, the following arrangements will be made with regards to oil spill equipment.

(i) WAPET will place on board the drilling rig 300 m of Jackson net boom, with further 200 m stored at Thevenard Island (part of the WAPET OSCP).

(ii) This boom is stowed in frames designed for rapid deployment. Each frame contains 100 m of boom. Deployment during training exercises took 5-6 minutes per 100 m.

(iii) The boom can be deployed from the following vessels:

(a) supply vessel;
(b) mooring vessel;
(c) fishing vessel.

(iv) In the event of an oil spill, the boom would be transferred from the rig to the standby vessel and rapidly deployed.

(v) A Komara 12K Skimmer Mark 2 would be used for the recovering the spilled oil (12 tonnes per hour). This skimmer would be obtained from Hadson Energy Limited (Harriet Field, Lowendal Islands).

An agreement is currently in place between WAPET and Hadson Energy covering use of the skimmer.

(vi) The Komara Skimmer would be loaded aboard one of the three landing barges under charter to WAPET. Each barge has the capacity to hold 120 tonnes of recovered oil in their cargo fuel tanks.

(vii) A 63.6 kL (400 bbl) frac tank is available at Barrow Island. This tank can be loaded onto a barge for additional storage. Hose connections and pump have all been allocated for this contingency.

(viii) Dispersant availability

1,200 L of Corexit 9527 dispersant is held on Barrow Island, Thevenard Island and the currently contracted standby supply vessel at all times. A company-owned, helicopter-mounted dispersant spray bucket is held at Thevenard Island or Barrow Island at all times.

(ix) Response times

(a)	Loading boom onto a supply vessel	15 minutes
(b)	Deploying boom	20 minutes
(c)	Additional 200 m of boom at Barrow to Permit Area TP/3 Part 1	1 hour
(d)	Komara Skimmer and power pack to site by helicopter	5 hours
(e)	Barge to site	0 to 6 hours
(f)	Dispersant spray bucket	1 hour

6 TELEPHONE LIST

A regularly updated telephone list is included in the plan. It lists contact details for the following personnel:

(i) WAPET;
(ii) Other local oilfield operators;
(iii) State Combat Committee;
(iv) State Departments (CALM, EPA, Department of Mines, Department of Marine & Harbours);
(v) Local Government - Shire of Ashburton;
(vi) Local Government - Shire of Roebourne;
(vii) Bird Rehabilitation Volunteer Group;

(viii) Regional Emergency Groups;
(ix) Federal Authorities.

7 REPORTING REQUIREMENTS

All oil spills will be reported to the WAPET (PIC).

Any oil spills less than 80 L (0.5 bbl) will be logged by the WAPET (PIC). The log details:

(i) time and place of spill;
(ii) type of oil spilt;
(iii) estimated amount of oil spilt;
(iv) actions taken.

The log will be forwarded to the Operations Superintendent in Perth immediately.

All spills in excess of 80 L will be reported by the Operations Superintendent to the Department of Mines immediately.

The Operations Superintendent will prepare a written report to the Department of Mines and the EPA detailing:

(i) time and place of spill;
(ii) type of oil spilt;
(iii) estimated amount of oil spilt;
(iv) cause of spill;
(v) action taken to control spill;
(vi) damage assessment.

8 ENVIRONMENTAL CONSIDERATIONS

Details concerning the distribution of marine habitats within the permit area are included in the plan and are updated as the results of ongoing biological surveys are obtained.

To date biological habitat surveys have been conducted for:

(i) Serrurier Island;
(ii) Bessieres Island;
(iii) Bowers Ledge;
(iv) Tortoise Island;
(v) Ashburton Island;
(vi) Direction Island;
(vii) Thevenard Island;
(viii) Ashburton River delta;
(ix) Locker Island;

(x) Intertidal habitats - Turbridgi Point to Beadon Creek.

The islands (i) to (viii) have also been surveyed on a biannual basis as part of the ongoing Saladin Oilfield Development Marine Biological Monitoring Program. This program involves the monitoring of seagrass and algae, corals and sediment hydrocarbon levels. A similar program will be instigated for the mainland coast between Turbridgi Point and Beadon Creek, including the Ashburton River Delta and Locker Island for the Roller Development.

Habitat distribution studies have been conducted for the Roller development and details are contained in Section 4 of the Roller Consultative Environmental Review (CER). The TP/3 Part 1 Contingency Plan also contains a brief review of the impact of crude oil and dispersed oil on local marine resources and an assessment of priority allocations for the protection of sensitive resources in the vicinity of WAPET's various exploration and development activities within the permit area. This information is summarised in Table 2.

Particular consideration has been given to the potential impacts of an oil spill on the mangroves of the mainland coastline adjacent to the Roller development, on the commercial recreational vessels that use Beadon Creek (Onslow) as a mooring area, and on the proposed Onslow Salt development. These resources have been assigned a high priority for protection and methods for achieving this have been considered.

9 MARINE AND TERRESTRIAL CONTROL MEASURES AND CLEAN-UP PROCEDURES

Details concerning the available clean-up options and where they should be used are given in the contingency plan. Options discussed include:

- containment and recovery with boom and skimmer;
- dispersant application;
- diversion with booms;
- agitation on water surface;
- raking of beaches;
- physical removal of beached oil;
- natural degradation.

The control measures and clean-up procedures used will depend on the time and size of the spill, the prevailing metocean conditions and the oil type. The preferred options recommended by the EPA are:

- contain and recover at sea;
- divert with booms;
- allow to weather naturally;
- use chemical dispersants (only with EPA authorisation).

10 ENVIRONMENTAL MONITORING PROCEDURES

An existing marine monitoring program has collected baseline and post-commissioning data for the Saladin Oilfield development.

Baseline habitat surveys have also been conducted at Locker Island, Ashburton River delta (east), Turbridgi Point and Urala Creek as part of the environmental monitoring program for the Roller Oilfield Development. The habitat maps derived from these surveys are shown as Figures 14-17 of the Roller CER and will also be included in the TP/3 Part 1 OSCP as a function of the regular updating of the plan.

In the unlikely event of an oil spill, these sites will be monitored to assess the extent and impact of oil and the time it takes for the system to recover. This information will be promptly reported to the Department of Mines and the EPA.

11 SEASONAL METOCEAN CHARACTERISTICS

This information is used by personnel combating the oil spill in conjunction with the computer simulated oil spill trajectories to assess the likely weathering behaviour and direction of travel taken by a spill. The contingency plan details seasonal meteorological and oceanographic characteristics of the development area.

Computer modelled oil spill trajectories have been conducted for Roller, Thevenard Island tanker mooring and Saladin A, B and C (Thevenard Island).

12 EXTERNAL RESOURCES AVAILABLE FOR COMBATING LARGE MARINE OIL SPILLS

In the event of a marine oil spill incident which requires a level of response beyond the immediate capability of WAPET to provide, assistance may be called upon from external sources. These include:

(i) the Australian Institute of Petroleum (AIP) Marine Oil Spill Action Plan (MOSAP);
(ii) the West Australian State Counter Disaster Plan;
(iii) National Plan to Combat Pollution of the Sea by Oil.

These plans can provide equipment and manpower to the company in the event of an oil spill. Contact number and equipment available is detailed in the WAPET TP/3 Part 1 plan.

13 LOCALLY AVAILABLE OIL SPILL EQUIPMENT AND DISPERSANTS

A wide range of equipment and dispersants are available within Western Australia and can be accessed by WAPET either directly or through the MOSAP Regional Industrial Controller at Karratha.

The TP/3 Part 1 OSCP lists equipment available from the following sources:

(i) WAPET;
(ii) Western Mining Corporation;
(iii) Woodside Offshore Petroleum - King Bay;
(iv) Hadson Energy Limited;
(v) AIP equipment at King Bay.

An inventory of this equipment is given below. The contact details necessary to mobilise this equipment in addition to miscellaneous equipment held by various private companies are listed in detail in the plan.

WAPET FACILITIES AND EQUIPMENT

BWI = Barrow Island
TVI = Thevenard Island
ONS = Onslow

	Equipment	Location
1.	**Vessels**	
	1 Tug "Mary Ann Tide", has fire monitors and dispersant booms. Bigadda 1 x 16.5 m launch capable of deploying Jackson net boom and carrying 2,200 L Corexit 9527 dispersant, fitted with spray facilities.	BWI/ONS
	"Osprey" 1 x 19 m launch capable of deploying Jackson net boom and carrying 2,200 L Corexit 9527 dispersant, spray facilities.	TVI
	"Miss Barrow" 1 x 10 m launch with capacity for 800 L Corexit 9527 dispersant.	BWI
	2 x landing barges, loaded draught 1.8 m, deck cargo space 160 m, capacity 150 tonnes.	BWI/TVI/ ONS
	"Saladin Scout" 1 x 9.9 m launch capable of deploying Jackson net boom and carrying 30 L Corexit 9527 dispersant for immediate use, spray facilities (as from December 1989).	TVI

A further 1000 L of dispersant is stored on Thevenard and can be carried on board four drums at a time.

2. Booms

300 m Jackson net boom	TVI
200 m Jackson net boom	TVI

3. Dispersant

1,200 L Corexit 9527	BWI
1,000 L Corexit 9527	TVI
1,000 L Corexit 9527	Vessel
2 x 44 gallon dispersant on each of the supply vessels (WAPET Drilling)	

4. Helicopter spray unit TVI

5. Aviation services

1 x twin engine aircraft, nine person STOL capability.	BWI

6. Miscellaneous equipment

5 x front-end loaders	BWI
1 x front-end loaders	TVI
1 x grader	BWI
1 x bulldozer	BWI
1 x tractor	BWI
1 x tractor	TVI
2 x vacuum trucks	BWI
1 x vacuum tank trailer (10.9 kL)	TVI
Various mobile tanks (up to 79.5 kL)	BWI/TVI
Various mobile pumps and bases	BWI/TVI

7. Miscellaneous equipment

During offshore drilling operations the above equipment is supplemented by the following:

(a)	Vessels - 2 x supply/support vessels	BWI
(b)	Helicopters - 1 x PUMA	TVI
	1 x Bell 206B	

WESTERN MINING CORPORATION LIMITED, PETROLEUM DIVISION EQUIPMENT

Equipment and dispersants available immediately are:

- one vessel "Marella"
- one 1,620 foot Petrel TXB - 50 air-filled oil boom
- 10 x 200 L Corexit 9527

WOODSIDE OFFSHORE PETROLEUM PTY LTD - KING BAY

Tugs

Four vessels - LOA: 33.0 m
speed: 12 knots 50 ton bollard pull
fire fighting: Class B waterborne fire fighting
support vessels fitted with dispersant booms and fire/foam monitors

Oil spill equipment

600 m Jackson net
200 m Hoyle Shore guardian
100 m Gamlem boom
20 bags Drizit for absorbent boom
200 L BP 1100WD
Komara Mini Skipper (BP)
Vikoma Coastal Pack (BP)

HADSON ENERGY LIMITED

Launches 1

- Length - 25 m
- Speed - 10 knots
- Radio fitted - yes
- Equipment - spray system
- Dispersant - 2,000 L Corexit 9527, 2,000 L Baroid Surflo OW1

Boom - 300 m Jackson boom
Spray equipment - Simplex helicopter dispersant spray bucket unit
Helicopters - 1 x S76
1 x 206
Skimmer - 1 Komara MKII 12K

APP EQUIPMENT HELD AT KING BAY

Two spray units for vessels, including power pack and spray booms.
12 ton Shell dispersant.

TABLE 1

A SUMMARY OF THE EFFECTS OF OIL ON SHORELINES

SHORELINE TYPE	COMMENTS	METHODS OF, AND SUSCEPTIBILITY TO, CLEANUP
Exposed rocky headlands and eroding wave-cut platforms	Wave reflection will keep some oil offshore. Landed oil weathers rapidly.	No attempt should be made to clean by artificial means.
Fine-grained sand beaches	Light grade oils penetrate deeply. Asphalt-like pavement may develop, and persist for many years on a low energy beach. On a high energy beach oil may be weathered and removed rapidly, or buried and removed more slowly.	Depending on priority rating, beached oil may be left to weather naturally or, alternatively, hand or mechanical removal of oily sand may be necessary.
Coarse-grained sand beaches	Light grade oils can sink in rapidly and deeply. Under moderate to high wave energy, oil can be removed rapidly. Buried oil may persist in low energy beaches.	Depending on priority rating, beached oil may be left to weather naturally or, hand or mechanical removal of oily sand may be necessary.
Mixed sand and gravel	Oil may undergo rapid penetration and burial. Under moderate to low energy conditions buried oil may persist for years. Under high energy conditions, oil can be removed rapidly.	Depending on priority rating, beached oil may be left to weather naturally or, hand or mechanical removal of oily sand may be necessary.
Sheltered rocky coasts and sand beaches	Areas of low wave energy. Oil may persist.	Allow to weather naturally. May be protected by dykes if mangroves present. Booms should be used to keep oil offshore.
Mangroves	Extremely low energy environment. In muddy sediments little penetration of the substrate occurs. Oil is not rapidly removed and is very persistent. In sediment with a large sand component, oil may penetrate the sediments and persist for years.	Diversion of oil offshore with booms, etc. a high priority. Extremely sensitive area. May be necessary to disperse prior to landfall. Mechanical removal must not be attempted.
Intertidal limestone pavement with or without sand veneer	Landed oil should weather rapidly. May collect in pools and be redistributed on rising tide.	Natural weathering will remove oil with time. Dispersants not recommended, will cause loss of shoreline plants and animals.

Refs: Healey, B.O., 1987. The role of the scientific co-ordinator. In: *Spillcon, 1987, Proceedings Australian National Oil Spill Conference, Melbourne, 1987.*

IMCO/UNEP, 1982. *The Status of Oil Pollution and Oil Pollution Control in the West and Central African Region.* Regional Seas Report and Studies No. 4, UNEP.

The International Tanker Owners Pollution Federation Ltd, 1983. *Technical Information Papers: 1-10.*

TABLE 2

THE EFFECTS OF OIL ON TROPICAL MARINE HABITATS AND POPULATIONS AND MANAGEMENT OPTIONS

HABITAT/ POPULATION TYPE	DAMAGE AND TYPE OF EFFECT	SENSITIVITY TO OIL AND RECOVERY RATES FOLLOWING DAMAGE	TREATMENT OPTIONS	WHAT TO AVOID
CORAL REEFS	Impacts range from no affect (particularly on corals in deep, well flushed areas) to mortality of entire assemblages in shallow water (dispersed oil). Abortion effects have been reported, direct coating is lethal and corals are expected to be highly sensitive during mass spawning.	Sensitive. Behavioural effects temporary. Recovery rates poorly known. Corals have been observed self cleaning after an acute exposure.	Booms can be used to deflect oil around shallow reef areas.	No dispersants in shallow (less than 10 m) deep water.
SEAGRASS BEDS	Some species show short-term local denuding. Dispersed oil causes severe damage to intertidal organisms and produces higher sediment hydrocarbon concentrations than in undispersed areas.	Moderately sensitive. Recovery may be rapid after short-term impact. Retention of oil in sediments may cause long-term damage.	Booms can be used to deflect oil around shallow seabed area.	No dispersants increases residence time of oil in sediments.
MANGROVES	Highly susceptible to even light oiling resulting in defoliation and death. Faunal mortalities leading to decrease in population density.	Very sensitive. Diversion of spill the highest priority. Estimates from 10s-100s of years to attain a mature forest. Retention of oil in sediments may cause long-term problems.	Dispersants should be applied to oil that is approaching mangroves. Best treatment is to leave stranded oil alone to weather naturally.	Dispersants should not be used on oil stranded in mangroves. Mechanical clean-up methods must not be attempted in mangroves.
INTERTIDAL MUD AND SAND FLATS	These areas support a great variety of marine flora and fauna and often are spawning or nursery grounds, and fish and bird feeding areas. The above components are all highly susceptible to the impacts of oil. Turtles mating in shallow nearshore waters may be seriously affected.	Sensitive. Recoveries vary from rapid (months to years) to slow (10s of years) depending on the degree of oil retention and availability of recolonising species.	Booms can be used to deflect oil away from area possibly onto a beach for later clean-up.	Dispersants should be avoided.

TABLE 2 (Cont'd)

THE EFFECTS OF OIL ON TROPICAL MARINE HABITATS AND POPULATIONS AND MANAGEMENT OPTIONS

HABITAT/ POPULATION TYPE	DAMAGE AND TYPE OF EFFECT	SENSITIVITY TO OIL AND RECOVERY RATES FOLLOWING DAMAGE	TREATMENT OPTIONS	WHAT TO AVOID
ROCKY INTERTIDAL	Little or no effect. Organisms hardy. Damage caused by coating leading to suffocation or loss of purchase on substrate.	Low sensitivity. Fast recovery. Rapid recolonisation by more species.	None required.	
OPEN WATERS	Surface dwelling organisms may suffer (birds, mammals, plankton). Sublethal to lethal effects on fish. Tainting of fish or prawn flesh may occur.	Some components sensitive. Unknown. Birds severely impacted. Local breeding populations of larval fish and shellfish may take a long time to recover. Plankton is expected to recover rapidly.	If there is a potential for landfall, disperse oil in deep water. If not, leave alone.	
BENTHIC COMMUNITIES	Mortalities lead to decrease in population density and age distributions. Change in species abundance and distribution, imbalance between interacting populations.	Some components sensitive. Immigration from surrounding areas are expected to speed up recovery.	None identified.	
BIRDS	Very easily damaged, oiling of plumage and ingestion of oil result in large mortalities.	Very sensitive. Damage to breeding population will cause slow recovery.	Clean-up of birds may be attempted, it is rarely successful.	Trampling nests above high tide line of sandy beaches.
SANDY BEACHES	Severe impact on egg laying turtles and hatchlings, feeding and breeding wading birds and intertidal fauna.	Some components very sensitive on a seasonal basis. Recovery of fauna will depend on the time it takes for the sandy beach to be cleansed of oil. Affected breeding populations will be slow to recover.	Beaches should be raked to promote evaporation. Mechanical or manual removal may be necessary on nesting beaches.	Dispersants should never be applied to a sandy beach. Avoid trampling of the beach and dune areas.

TABLE 2 (Cont'd)

THE EFFECTS OF OIL ON TROPICAL MARINE HABITATS AND POPULATIONS AND MANAGEMENT OPTIONS

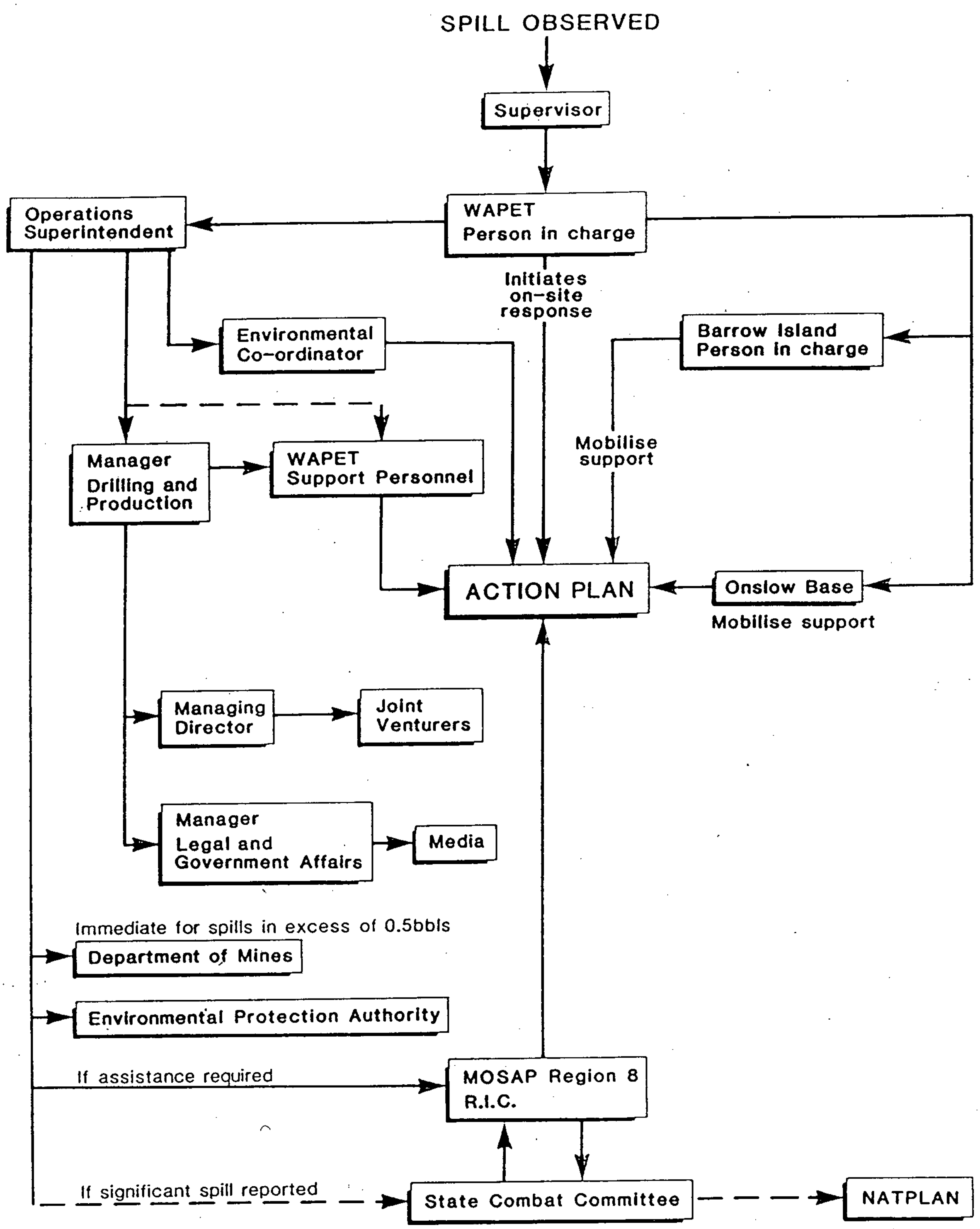
HABITAT/ POPULATION TYPE	DAMAGE AND TYPE OF EFFECT	SENSITIVITY TO OIL AND RECOVERY RATES FOLLOWING DAMAGE	TREATMENT OPTIONS	WHAT TO AVOID
FISH	Possible for them to avoid spills. Mortality and tainting of flesh can occur. Greatest danger to breeding populations in confined waterways or benthic fish in heavily polluted substrates.	Moderate sensitivity. Fast to moderate recovery rates. Fast immigration of larvae and adults.	Dispersants will make oil more available to the fish, however, its use may be necessary to protect higher priority habitats.	
MAMMALS	Chances of impact reduced by low abundance of mammals and ability to escape the area impacted. Conclusive evidence of death due to oil is rare. Possible effects include ingestion of oil during grooming, loss of thermal insulation and/or water-proofing and eye irritation. Indirect effects include destruction of food sources.	Unknown sensitivity. Slow if population is seriously affected.		

Refs: Dicks, B., 1984. Oil pollution in the Red Sea. Environmental monitoring of an oilfield in a coral area, Gulf of Suez. *Deep Sea Research* 31 (6-8A): 83.

Hyland, J.L. & Schneider, E.D., 1977. *Petroleum Hydrocarbons and Their Effects on Marine Organisms, Populations, Communities and Ecosystems. Sources, Effects and Sinks of Hydrocarbons in the Aquatic Environment.* American Institute of Biological Science, Washington, D.C., pp. 463-506.

Knap, A., 1987. The effects of oil spills on reef systems. In: *Proceedings Australian National Oil Spill Conference, Melbourne, 7-9 October 1987.*

Thorhaug, A., 1987. The effect of oil and dispersed oil on global tropical seagrass and mangroves. In: *Proceedings Australian National Oil Spill Conference, Melbourne, 7-9 October 1987.*

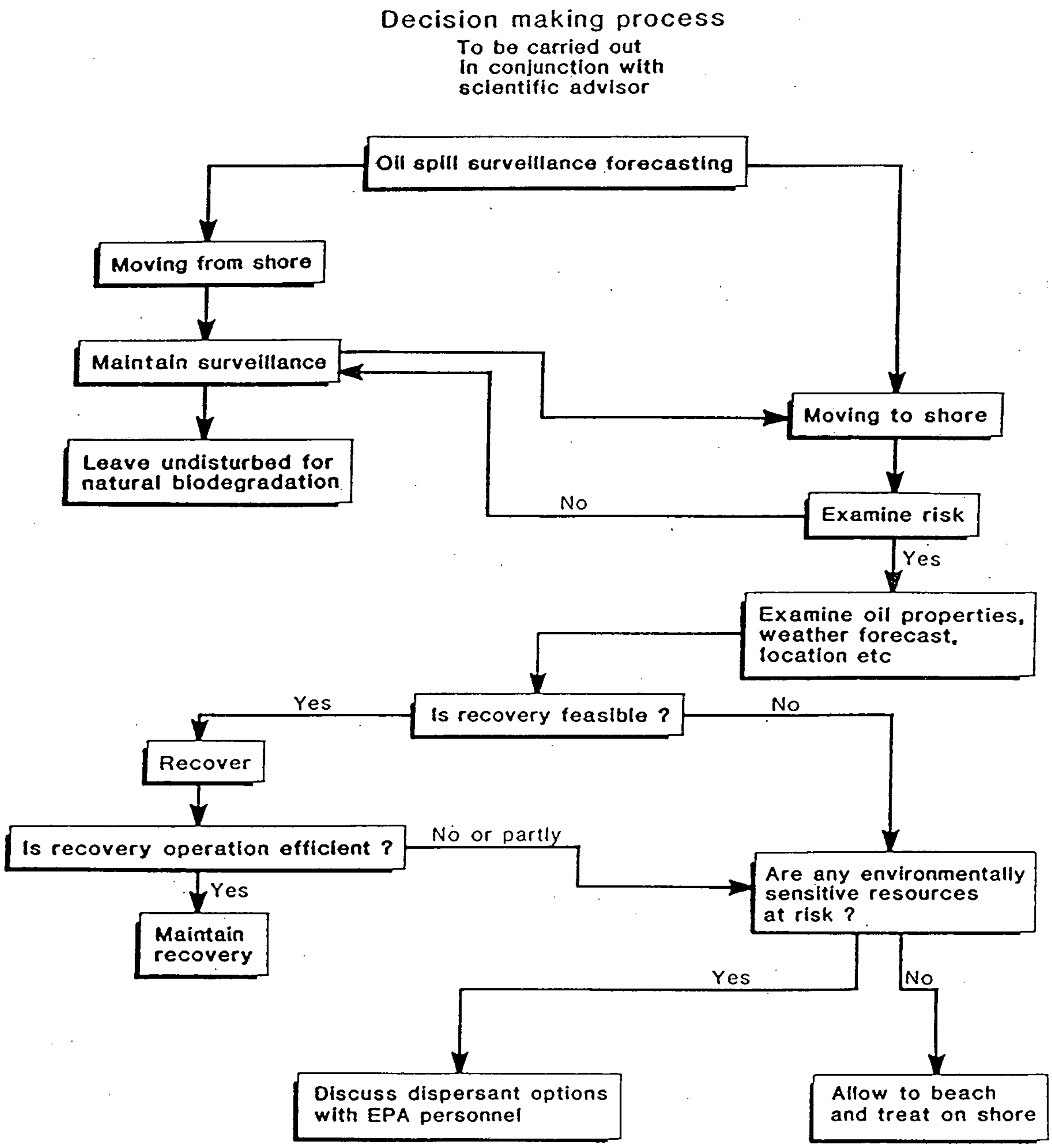


ROLLER FIELD DEVELOPMENT

FLOWCHART OF NOTIFICATION PROCEDURES

SEPTEMBER 1989

Figure **1**



ROLLER FIELD DEVELOPMENT

Figure 2

OIL SPILL TREATMENT

SEPTEMBER 1989

West Australian Petroleum Pty Limited

Roller Oilfield Development

Consultative Environmental Review

APPENDIX 7

LIST OF COMMITMENTS

LEC Ref: J218/R342

LIST OF COMMITMENTS

West Australian Petroleum Pty Limited (WAPET) undertakes to abide by all of the commitments made in the Roller Oilfield Development Consultative Environmental Review (CER), and in all cases will fulfil those commitments to the satisfaction of the appropriate statutory authority(s).

The major commitments given within the CER are listed in the following sections.

ENVIRONMENTAL MONITORING AND EDUCATION

(1) The existing Marine Biological Monitoring Programme for the Saladin Field will be expanded to ensure that important marine resources that could be affected by the either development or operation of the Roller field are covered by the monitoring programme.

(2) Before commencement of their duties, each worker or contractor (including workboat and supply vessel crews) will be given an induction including advice on the sensitive nature of the environment in which the drilling rig and oilfield is located.

SAFETY AND OIL SPILL CONTINGENCY

(1) Operation and maintenance procedure manuals based on WAPET's experience of the Barrow Island and Saladin Fields will be prepared and made available for review by relevant statutory authorities prior to project commissioning. These manuals will cover normal and emergency procedures.

(2) To improve operational safety, commercial and recreational vessels will not be permitted closer than 500 m to the drilling rig during the construction phase.

(3) The drilling rig to be contracted will be capable of withstanding cyclonic wind and wave conditions. Detailed procedures which set out the various levels of responses to cyclones will be contained in the operator's Emergency Procedures Manual.

(4) The existing Permit Area TP/3 Oil Spill Contingency Plan (OSCP) will be expanded with insertion of relevant information for the Roller field. WAPET will abide by all procedures detailed in the OSCP, as summarised in Section 6.4.2 of the CER.

(5) An oil spill containment boom will be present at the site during drilling. A stand-by vessel will be in the vicinity of the drilling rig at all times to deploy the boom and skimmer in the event of an oil spill.

(6) During any spill event, WAPET would make available oil spill equipment, vessels, aircraft and personnel to help with containment and clean-up measures.

(7) Existing WAPET procedures for cyclone response will be followed to safeguard the wells, rig, offshore structures, vessels and personnel.

(8) With regard to any oil spill or discharge resulting from the drilling of any well in the Roller Oilfield or production of petroleum therefrom WAPET makes the following commitments:

   (a) to be fully responsible for the cost of operations conducted by it or any Governmental agency aimed at containing or dispersing or recovering any such petroleum or cleaning-up any areas polluted by such petroleum;

   (b) to promptly pay to any person, company or Government (Federal, State or Local) any damages to which any of those entities is lawfully entitled from WAPET.

DRILLING RIG OPERATIONS

(1) Prior to spudding in, the rig operator will conduct surveys and tests in accordance with Department of Mines regulations to ensure stability of the rig and to minimise the risk of abnormal penetration of the seabed during storm conditions.

(2) The blowout preventer (BOP) stack will be tested in accordance with Department of Mines regulations after the surface casing has been installed.

(3) All casing strings installed below the BOP stack will be pressure tested in accordance with Department of Mines regulations before drilling is resumed.

(4) Drilling fluids used will be those approved for offshore use by the Department of Mines.

(5) Chrome lignosulphonates will not be used in any drilling fluids.

(6) Drill cuttings will be disposed of into the ocean after separation from the drilling fluid through solids control equipment.

(7) Drilling fluid residue will be disposed of into the ocean at controlled intervals, under the direction of the drilling superintendent.

(8) Deck drainage will be disposed of into the ocean after passing through an oily water separator. Lubricating oil wastes will be collected and transported to a designated land site for disposal.

(9) Sanitary wastes from the kitchen, showers and laundry will be passed through a sewage treatment plant for comminution and disinfection before being discharged overboard. Solid food waste will be macerated before disposal overboard. Biodegradable detergents will be used for cleaning functions. Combustible materials will be burnt on the rig. All non-combustible material will be returned to the shore base for disposal at an approved land site.

PIPELINES AND OFFSHORE STRUCTURES

(1) Surveyors and divers contracted for pipe laying operations will be informed that the discovery of any new shipwreck must be promptly reported to the Marine Department at the Western Australian Museum in accordance with the *Marine Archaeology Act 1973*.

(2) All subsea lines will be stabilised. Pipelines will be trenched where they cross commercial trawling grounds lying between Roller A and Ashburton Island. If Option 2 is selected, the various lines between the monopod at Roller D and the modified jack-up rig will run along a piperack bridge.

(3) A marine exclusion zone will be required around the monopods and the subsea pipelines (where they cannot be buried). The location and width of the exclusion zones will be determined by consultations between WAPET and the appropriate government authorities.

(4) Flowlines transmitting unseparated product (two-phase or three-phase) will be hydrostatically tested, with the test waters disposed of through the production plant at Thevenard Island.

(5) Corrosion control of subsurface structures will be by paints, cathodic protection or by a continuous external coating to standards cited by Government codes.

THEVENARD ISLAND FACILITIES

(1) No additional temporary accommodation is likely to be needed for the construction and drilling workforce, other than that currently deployed on Thevenard Island for the Cowle and Yammaderry development, and such

accommodation will not be installed without first obtaining approval from the Department of Conservation and Land Management (CALM).

(2) No additional terminal storage or tanker facilities will be required on Thevenard Island.

(3) In the event that the total amount of discharged water at Thevenard Island is likely to exceed the existing total oil and water treatment capacity of the Thevenard Island facility, then additional equipment will be installed to comply with (4) below.

(4) The quality of all produced water discharged from the Thevenard Island outfall will comply with Clause 616 of the *Specific Requirements as to Offshore Petroleum Exploration and Production 1990* [issued under the provisions of the *Petroleum (Submerged Lands) Act 1987*].

(5) Gas will be flared either offshore beside Roller D (Option 2), or from the ground flare presently located on Thevenard Island.

(6) Existing procedures on Thevenard Island for fire control, workforce movements, island flora and fauna protection, custody transfer of produced crude to tankers will be maintained.

OPERATION OF VESSELS AND AIRCRAFT

(1) Helicopter pilots will be instructed not to overfly islands.

(2) Regular crew transfers between Roller, Thevenard Island and Perth will use existing routes involving helicopter/light aircraft transfers to Barrow Island, and chartered commercial flight direct to Perth.

(3) All refuelling operations for the supply vessels will be conducted in accordance with strict Port Authority requirements, including continuous visual monitoring and the use of reinforced hoses and fail-safe valves and fittings.

(4) It will be a contractual requirement for the various vessels and barges to comply with all State and Commonwealth legislation for the control of pollution and dumping at sea.

(5) Masters of barges and supply vessels will be instructed not to allow crew to disturb islands or wreck sites, nor to anchor close to coral reefs.

FIELD CLOSURE

(1) The wells will be plugged and sealed with concrete and cut off at 4 m below the surface of the seafloor, as is presently required by the Department of Mines for the abandonment of dry wells.

(2) No subsurface structure will be left protruding from the seabed so as to cause a hazard to navigation or fishing operations.

(3) Subsea flow and gas-lift lines will be flooded with seawater and left *in situ*, unless specific requirements deem their removal in certain areas.