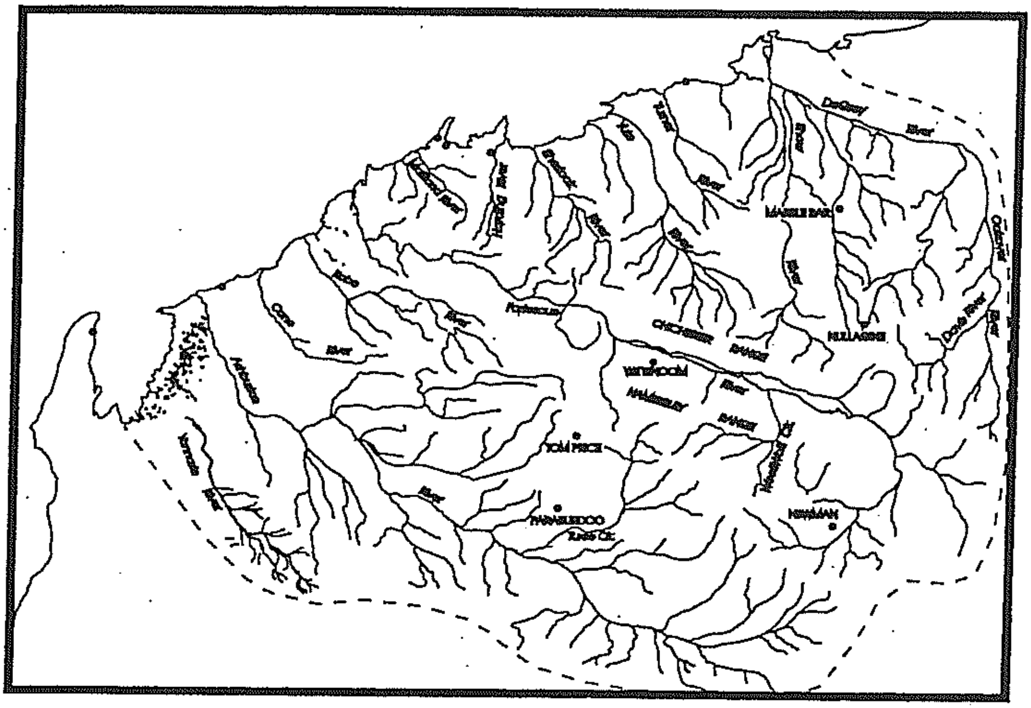
Wetlands of the Pilbara Region:
description, consanguineous suites, significance



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Summary

The Pilbara Wetland Region is defined by Precambrian rocky ranges, and its various drainages. It is bordered sharply to north and northeast by the Great Sandy Desert, largely devoid of drainage, and to east and southeast by the Little Sandy Desert and Gibson Desert. Geological materials in the region are assigned to five main settings: the Archaean Pilbara Craton; the layered Proterozoic sequences; the Proterozoic intrusive igneous rocks; Cainozoic coastal plain and riverine deposits, and coastal Quaternary deposits. These form the foundations to various groundwater zones, with their various mechanisms of hydrodynamics, and to the landforms host to the wetlands.

As there is a large number of wetlands in the region, the approach in this project was to identify consanguineous suites to typify wetland styles. This enables rapid discrimination between different wetland types, and grouping vast numbers of wetlands into natural sets. A geomorphic classification of *inland wetlands*, based on their host landform and hydroperiod, identifies the following main wetland types in the Pilbara: playa, dampland, lake, sumpland, creek, river, wadi, floodplain, barlkarra. The coastal marine "wetlands" are: tidal mud flats, tidal sand flats, tidal creek complexes, beaches. Significant wetlands have been identified on one or several criteria, viz., avifauna, flora, aquatic fauna, geoheritage values, and types of mangrove stands. Wetlands are assessed as International, National, State-wide, or Regional in significance. The inland wetlands of the Hamersley Ranges and Millstream are assessed as International. Many of the mangrove wetlands also are assessed as Internationally significant.

Wetlands of the Pilbara Region: description; consanguineous suites; significance

1.0 Introduction

1.1 Preamble

The National Heritage Trust (NHT) through the Water & Rivers Commission (WR&C) funded the V & C Semeniuk Research Group (VCSRG) to undertake a study to describe the wetland systems in the Pilbara Region (Figure 1), and to provide a preliminary identification of the wetlands of significance in this region. Though it is in an arid climate, the Pilbara Region, in fact, contains a range of arid zone wetlands, and has a varied assemblage of wetland types in terms of consanguineous suites. It is the objective of this document to provide a preliminary report on these wetlands. In this context, this report is structured as follows:

- Scope and Methods this Study
- Classification and Terminology
- The Definition of the Pilbara Wetland Region
- Regional Setting
- Geological Framework useful for wetland delineation
- Wetland Subregions, and their consanguineous suites
- Flora of the Pilbara Wetland Region
- Avifauna of the Pilbara Wetland Region
- Aquatic invertebrate fauna of the Pilbara Wetland Region
- Aquatic fish fauna of the Pilbara Wetland Region
- Criteria for selecting significant wetlands
- Significant wetlands of the Pilbara Region
- Management recommendations

A description of the Philosophy of Approach in this report is provided in this Introduction. Brief summaries of previous work are provided in the relevant sections throughout the report.

1.2 Acknowledgements

This study was undertaken with funding from the National Heritage Trust (NHT) under the Wetlands Research Programme. This contribution is gratefully acknowledged. In-kind contribution was provided by VCSRG directly during the time of the study as contributions in fee-for-time in a ratio of approximately 1:1, and in addition, providing access to R&D information collected between 1980 and 1995.

Staff from Water & Rivers Commission were helpful in this study, namely Alan Hill, Jeni Alford, and Roy Stone, in providing literature and commentary.

Cate Tauss, Lorna Charlton, and Julie Raines provided assistance, information, or documents/reports in the fields of flora, aquatic fauna, and avifauna, respectively. Their help in this context also is gratefully acknowledged.

1.3 Philosophy of approach

The prevailing emphasis in conservation in the literature to date has been on "biodiversity". However, recently, there has been recognition of the need for conservation on the basis of "geodiversity" in its own right, and for conservation of "geodiversity" through its links to "biodiversity". In the first case, conservation of purely physical phenomena of scientific and heritage value is viewed as a valid and legitimate target in its own right, and in the second case, biodiversity can be commonly seen to be linked to, or underpinned by geodiversity. This report, however, firstly focuses on the physical settings of wetlands to explain the diverse types and to describe the suites of wetlands that occur in this region, and uses a framework of consanguineous wetland suites to assess the diversity of wetlands. Thus, the emphasis initially in this study is on geodiversity of wetlands. This would form the basis later for the description and assessment of wetlands for their habitats and their biodiversity.

While there are numerous examples of areas containing a high degree of biodiversity because they are situated in an inherently biologically rich biogeographic region, in many situations the high degree of biodiversity may be the result of the region's geodiversity. That is, the variability in geology, geomorphology and soils result in varying biotic responses, and hence biodiversity. The reason for this is that biotic systems, and especially vegetation, are strongly linked to habitats, and variable landforms, soils, and hydrologic processes result in variable habitats. Where fauna are linked to vegetation types, or to soil types, then diversity in vegetation and landscape/soils may result in faunal diversity. For these reasons, the geodiversity and physical aspects of the wetlands leading to recognition of consanguineous suites as well as the biological aspects that lead to an appreciation of biodiversity are both described as a basis for conservation and selection for investiture in a conservation estate, or listing on the Register of the National Estate.

As there is a large number of wetlands scattered in the region, and all could not be visited in the field, and the information on them was often limited and unequal in quantity, value and category, the approach in this project was to identify consanguineous suites as the basis to typifying wetlands in the region. The approach provides a method for rapidly discriminating between different wetland types, and for grouping into natural sets vast numbers of wetlands that would otherwise require extensive and intensive fieldwork to obtain sufficient data to separate them.

Once systems of consanguineous wetlands are identified, it is a simple matter to choose typical and well preserved wetlands within a suite as being representative of that suite, thus ensuring that diversity of wetland types are captured in the conservation selection process.

A consanguineous suite of wetlands means "a related suite of wetlands that occur in the same region, within the same setting, that have formed because of similar related factors" (Semeniuk 1988). This would imply such a group of wetlands would have similar features and functions. The fundamental factors of wetland development and maintenance are hydrology, geomorphology, wetland maintenance, and wetland origin. When these factors are similar for any group of wetlands, there exists a relationship between wetlands which is termed consanguinity. Within any one consanguineous suite, wetlands exhibit essentially similar characteristics such as geometry, wetland type, hydroperiod, water quality, sediments, and vegetation assemblages. In comparing wetlands between consanguineous suites, these characteristics will be disparate. Thus, identification of consanguineous suites is a practical and rational method of sorting an array of variable wetland systems based on fundamental causative factors and physical setting. As there is a strong correlation between consanguinity of wetlands and physiographic divisions within a region, an understanding of the regional setting, regional geomorphic processes and regional hydrology was the focus for description of the consanguineous suites of this study.

2.0 Scope & Methods, this study

Desk studies formed a major part of this project, and involved topographic maps, aerial photographs, orthophotographs, published and unpublished reports from State Government Agencies and mining companies (where publicly available), inventories, scientific literature, and VCSRG in-house R&D data. However, field surveys were conducted in order to verify aerial photographic interpretation, collect information not currently available through existing resources, ascertain the geomorphic framework underpinning the occurrence of consanguineous wetlands, and to upgrade information where resources were not available in enough detail. In detail, this study involved several tasks. The tasks were:

1. review of published literature on regional features
2. review of VCSRG in-house R&D data
3. preliminary identification of consanguineous wetland suites
4. field study of wetlands (traverses, transects, site descriptions)
5. literature review of wetlands in the Pilbara region
6. literature review to collate information on biota
7. data reduction and data analyses
8. assessment of conservation status.

Task 1: available literature was accessed to determine its relevance to this study at the scale that this study was being undertaken. This involved desk study of climate, geology, hydrology, geomorphology, and any relevant wetland work, as well as topographic maps and aerial photographs.

Task 2: VCSRG in-house R&D data involved some 25 years of previous research on the inland wetlands, and the coastal plain and mangroves of the Pilbara Coast between Exmouth and Pardoo (some of which has been published in Semeniuk 1983 and Semeniuk 1993), amounting to some 50 months of fieldwork (= 15,000 hours), as well as information on geomorphology collected by VCSRG between 1980-1987, amounting to 14 months (= 4200 hours). Study sites are shown in Figures 2 & 3.

Task 3: Wetlands were related to the physiographic units in which they occur, and physiographic/geomorphic information was used as a basis for preliminary identification of consanguineous suites on the following criteria:

- geomorphic setting
- similar phototone
- proximity,
- similarity in wetland size and shape,
- recurring pattern of wetland forms or alternatively, heterogeneous pattern representing a spectral range of inter-related wetland forms.

Task 4: Three field surveys were undertaken specifically for this study, as follows:

- November 1998: 4 weeks, 1 senior wetland scientist and two assistants
- June 1999: 1 week, 2 senior wetland scientists
- July 1999: 4 days, 1 senior wetland scientist and 1 assistant

The survey in November 1998 was during the dry season to describe wetlands in the dry phase of their seasonal cycle. The survey in June 1999 was immediately after significant rains to investigate wetlands during the wet phase of their seasonal cycle. The survey in July 1999 was to ascertain the longevity of the effects of the wet phase, particularly in the channel wetlands, as observed in the previous month.

Field study of the wetlands included visiting wetlands in their geologic/ geomorphic setting to determine their origin, the nature of the hydrologic mechanisms maintaining them, drilling/augering wetlands to determine the nature of the sedimentary fill, sampling water to determine its salinity, and sampling relevant biota). Areas of interest, specific transects, road traverses, and study sites visited in the Pilbara Region upon which this report is based are shown in Figure 4. The traverses involved vehicle travelling north-south in a zigzag manner from the eastern part of the Pilbara to the western part, following all major roads and secondary roads. In the field, the following information on the natural features for each suite of wetlands was obtained:

- geomorphic and stratigraphic setting
- hydrologic setting and water salinity
- hydrological dynamics if readily discernible
- wetland vegetation

Task 5: In this stage, literature review of wetlands, and collation of information on biota was undertaken to develop a preliminary model of ecosystem function of the wetlands within a consanguineous suite. This was based on an analysis and integration of baseline natural history information on flora, invertebrate fauna, and vertebrate fauna such as waterfowl. Functions of wetlands were categorised as ecological, social, and cultural. In this study, the emphasis was on ecological functions. Again, the sources were field work, and some literature review.

Task 6: In this stage, literature review of wetlands, and collation of information on biota was undertaken to develop a preliminary model of biodiversity, and ecosystem function of the wetlands within a consanguineous suite. This was based on an analysis and integration of baseline natural history information on flora, invertebrate fauna, and vertebrate fauna such as waterfowl. Functions of wetlands were categorised as ecological, social, and cultural. In this study, the emphasis was on ecological functions. Again, the sources were field work, and some literature review.

Task 7: This involved data reduction, data analysis, identification of biota collected from field work.

Task 8: This involved integrating information on consanguineous suites and geodiversity, and evaluating wetland suites on status or condition, regional significance, representativeness, scarcity, diversity, and ecological functions to recommend selection of wetland suites or parts of suites for conservation.

A note on water quality: Information on water quality can be useful as a lower level criterion in defining wetland suites. Information on water quality in this area is derived from three sources: 1. the Water Authority of Western Australia, 2. selected research publications, and 3. fieldwork in this study. A brief description of water quality is provided later, but most of the information is used in the description of the appropriate suites, where relevant. The data on water quality from the Water Authority pertain to stream salinity, and will be discussed only within the context of individual suites, where appropriate. The data from research publications cover a diverse and often single sampling event for parameters such as pH, total dissolved solids (TDS), phosphorous and nitrogen. Field sampling for this study also was often a single measurement during either November 1999, and was restricted to water salinity (TDS) only.

3.0 Wetland classification and terminology

Some explanation of terms for wetland classification, description and evaluation used in the report is required before proceeding.

Generally, in the first instance, wetlands are classified as to being inland, estuarine, or coastal marine. In this study area, the main wetland types are inland and coastal marine. Previous classifications, and the classifications and terms utilised in this study for inland coastal marine wetlands are briefly outlined as follows:

- previous wetland classifications
- geomorphic classification for inland wetlands
- coastal marine wetlands
- vegetation classification
- water classification
- general terms

3.1 Previous wetland classifications

A previous comprehensive study of Pilbara wetlands was undertaken by Massini (1988), and it involved identifying types of wetlands, describing them as to landform setting, vegetation, and fauna. Massini (1988) identified nine wetland types, viz., spring, primary river pools, headwater streams and drainage channels, primary river channel, adjoining pools, ephemeral claypans, semi-permanent claypan, tidal reaches, and man-made wetlands. While this classification is not used primarily to categorize Pilbara wetlands in this report, it is presented below to provide both a contrast in style of classification used previously, and a description of the range of wetlands from a colloquial perspective. Descriptions of wetland types from Massini (1988) is as follows:

Wetland type	Description
spring	generally upland seepage sites; springs vary with season and site characteristics: in the Hamersley and Chichester Ranges, both sets of springs examined consisted of a series of interconnected pools (up to 4.5 m deep in Eera Baranna), with water flowing from one to the next down a medium to steep gradient. Fed by associated aquifers, springs provide permanent sources of water for their associated biota in all but extended drought conditions.

primary river pools	deep permanent and semi-permanent river pools tend to occur on the outer edge of meanders, or where a river is confined in a narrow section. In both cases active erosion during flood flows results in river bed scouring; the pools are initially filled by river flows but are sustained after flow ceases by water inputs either from localised bank storage or by a direct link with the water table; the permanence of the pools depends on the relationship between pool depth and the water table; during dry periods the water table may decline (permanent pools occur where pool depth exceeds the limit of decline of the water table, or where pool volume exceeds annual evaporation losses)
headwater streams and drainage channels	draining relatively small catchment, headwater streams and drainage channels are generally quite narrow and shallow, have relatively steep bed gradients and are fast flowing; the streams usually drain relatively small catchments and cumulatively, supply water to primary river channels
primary river channel	primary river channels are the large channels in the regions, and they cope with spasmodic influxes of large volumes of water and hence are often quite wide (up to 1 km); for most of the year these channels are usually dry (e.g., Fortescue River channel, dry section); shallow ephemeral pools often occur in the river beds but these are subject to frequent changes in position and profile due to changes in location of river bed sediments during river flow
adjoining pools	pools adjoining the primary river channels are ephemeral to intermittent, occupying depressions adjacent to rivers which are subject to flooding; these depressions include cut off meanders and wind deflation hollows between vegetation hummocks; once saturated, the fine sediments of these areas may retain moisture for considerable periods after surface water has gone
ephemeral claypans	claypans generally are areas of fine-grained soils where sheet runoff may collect after rains; although characterised by small, shallow depressions (<0.2 m deep), ephemeral claypans may occupy wide areas where there are large expanses of relatively flat land with no definite drainage patterns (e.g., the De Grey River floodplain)

semi-permanent claypan	semi-permanent claypans are quite shallow, with low permeability and low through-flow; located within better-defined drainage channels than the ephemeral claypans, they are usually deeper and more persistent, but occupy a smaller area
tidal reaches	tidal reaches of the Pilbara rivers experience large diurnal fluctuations in water depth and area, particularly if the channels have gently sloping banks; active erosion and deposition within many tidal creek systems leads to constantly changing stream channels (e.g., Fortescue River, Post Office Pool System)
man-made wetlands	man-made wetlands are inland waters created by anthropogenic activities (e.g., dams, sewerage ponds); they vary in area and depth according to their function

3.2 Geomorphic classification for inland wetlands

A geomorphic classification of *inland wetlands* is used here, based on their host landform and hydroperiod (Semeniuk & Semeniuk 1995). In the first instance, wetlands are classified as to whether they are self-emergent or non-emergent, *i.e.*, whether they form positive emerging structures through accumulation of sediment, precipitates, or peat accumulation, or whether they conform to, or fill a landform (Semeniuk & Semeniuk 1995). The latter wetlands are then classified as to their landform settings.

Subdivision on emergence or non-emergence	**Further subdivision**
non-emergent	further subdivided on landform setting and hydroperiod (see below)
self-emergent	peat mounds spring mounds (travertine; carbonate) sinter mounds

Landforms of wetlands include: basins, channels, flats, slopes and hills/highlands. Hydroperiod includes: permanent, seasonal or intermittent inundation, and seasonal waterlogging. Combining landform with hydroperiod, for wetlands, globally, thirteen primary types of common wetlands are recognized:

1.	permanently inundated basin	= LAKE;
2.	seasonally inundated basin	= SUMPLAND;
3.	seasonally waterlogged basin	= DAMPLAND;
4.	intermittently flooded basin	= PLAYA;
5.	permanently inundated channel	= RIVER;
6.	seasonally inundated channel	= CREEK;
7.	seasonally waterlogged channel	= TROUGH;
8.	intermittently flooded channel	= WADI;
9.	seasonally inundated flat	= FLOODPLAIN;
10.	seasonally waterlogged flat	= PALUSPLAIN;
11.	intermittently flooded flat	= BARLKARRA;
12.	seasonally waterlogged slope	= PALUSLOPE;
13.	seasonally waterlogged hill	= PALUSMONT.

Of these, the main wetland types in the Pilbara Region are:

1.	intermittently flooded basin	= PLAYA
2.	(seasonally) waterlogged basin	= DAMPLAND
3.	permanently inundated basin	= LAKE
4.	seasonally inundated basin	= SUMPLAND
5.	seasonally inundated channel	= CREEK
6.	permanently inundated channel	= RIVER
7.	intermittently flooded channel	= WADI
8.	seasonally inundated flat	= FLOODPLAIN
9.	intermittently flooded flat	= BARLKARRA
10.	seasonally waterlogged slope	= PALUSLOPE

A correlation between the wetland categories of Massini (1988) and the classification of Semeniuk & Semeniuk (1995) is presented below.

Wetland type of Massini (1988)	**Wetlands of Semeniuk & Semeniuk**
spring	paluslope
primary river pools	creeks, rivers
headwater streams, drainage channels	wadis, creeks, paluslopes
primary river channel	creeks, rivers
adjoining pools	sumplands, playas
ephemeral claypans	sumplands, playas
semi-permanent claypan	playas
tidal reaches	not classified
man-made wetlands	not classified

The wetland types of Semeniuk & Semeniuk (1995) may be further categorised according to scale. For basins and flats, the categories of geomorphic scale for wetlands developed therein are (after C A Semeniuk 1987):

- Megascale : Very large scale wetlands larger than a frame of reference 10 km x 10 km;
- Macroscale: Large scale wetlands encompassed by a frame of reference 1000m x 1000m to 10 km x 10 km;
- Mesoscale : Medium scale wetlands encompassed by a frame of reference 500m x 500m to 1000m x 1000m;
- Microscale: Small scale wetlands encompassed by a frame of reference 100m x 100m to 500m x 500m;
- Leptoscale: Very small scale wetlands encompassed by a frame of reference < 100m x 100m

For channels, a definitive width to length relationship is used to separate size of channel wetlands:

- Macroscale: Large scale channels 1 km and greater wide, by several to tens of kilometres long;
- Mesoscale : Medium scale channels hundreds of metres wide, by thousands of metres long;
- Microscale: Small scale wetlands tens of metres wide, hundreds of metres long;
- Leptoscale: Fine scale channels several metres wide, tens of metres long.

3.3 Coastal marine wetlands

The Ramsar Bureau (the International Convention for the protection of wetlands especially as a waterfowl habitat) identifies marine coastal systems as types of wetlands. For purposes of this report, this procedure is followed here, in that tidally exposed coastal zones are noted as a type of wetland. In this context, there are several types of marine coastal systems that function as "wetland", though it should be noted that there are emergent dry parts of these coastal systems that are not wet or tidally inundated.

The term "marine coastal wetland" will be used to denote those parts of the shore exposed at low tide, and hence are the "marine wetted" part of the continent. Barrier dunes, and emergent sandy spits, islands surrounded by tidal zones, and rocky cliffs and headlands are not part of this assignment. The main coastal marine "wetlands" are:

- tidal mud flats
- tidal sand flats
- tidal creek complexes
- beaches

The tidal mud flats may be vegetation-free (e.g., low tidal mud flats, or high tidal salt flats), or vegetated by mangroves or samphires. Tidal sand flats are usually broad low gradient low tidal flats. Tidal creek networks are permanently tidally inundated to low-tidally exposed channel systems. Beaches are usually steep gradient sandy shore surfaces.

3.4 Wetland vegetation classification

Wetland vegetation for basin wetlands has been classified on the areal extent and pattern of distribution of vegetation cover over the wetland and the internal organization of that vegetation in plan (Semeniuk *et al.*, 1990). While this classification was developed for on the Swan Coastal Plain, this approach can also be applied to basin wetlands of the Pilbara Region. Vegetation cover is divided into 3 intergradational classes: peripheral, mosaic and complete. Complexity of wetland vegetation is divided into 3 classes: homogeneous, zoned and heterogeneous. The combination of cover and internal organization results in the recognition of 9 basic wetland categories: periform, paniform, latiform, zoniform, gradiform, concentriform, bacataform, heteroform, and maculiform.

3.5 Water classification

Water in a wetland may be described in terms of salinity and consistency of salinity. Salinity terms are (Hammer 1986):

- fresh : <1000 ppm salinity
- subhaline : 1000-3000 ppm salinity
- hyposaline : 3000-20000 ppm salinity
- mesosaline : 20000-50000 ppm salinity
- hypersaline : 50000-100000 ppm salinity
- brine : >100000

Wetlands that are seasonally variable in salinity are categorised by the salinity state existing for the major part of the year. Water salinity consistent throughout the year, remaining totally within a given salinity field, is termed stasohaline. Water quality markedly fluctuates throughout the year is termed poikilohaline.

3.6 Consanguinity: The concept and its usefulness

Consanguineous wetlands are inter-related wetlands. As defined by Semeniuk (1988), they may have a similarity because they occur in the same geomorphic, geologic, and hydrologic setting, or because they have been formed by the same underlying process. The notion of consanguineous suites essentially recognises that there are different types of wetlands residing in different settings. Recognition of these differences is important for comparative, for management, and for representative conservation purposes. Thus the identification of consanguineous suites is a powerful first step to comparing similar or "like" wetlands for evaluation and assessment procedures

In general, seven criteria used to establish wetland consanguinity (Semeniuk 1988):

1. *Wetlands should occur in reasonable proximity*
2. *Wetlands should be similar in size and shape*
3. *A recurring pattern of similar wetland forms or a spectral range of inter-related wetland forms resulting from a dynamic process*
4. *Wetlands should have a similar stratigraphy*
5. *Wetlands should have similar water salinity regimes*
6. *Wetlands should have similar hydrological dynamics*
7. *Wetlands should have similar origin*

Limited data were obtained from in-house drill core data and field investigations. However, in this project, due to constraints of time and budget, information obtained from the literature was used to apply some of the criteria, in lieu of more extensive field investigations. One of the criteria, pertaining to water salinity, was not applied, because of the incomplete data set.

The extent to which the criteria were applied, and the sources of data, are explained below.

1. *Wetlands should occur in reasonable proximity*
   Fully applied.

2. *Wetlands should be similar in size and shape*
   Fully applied.

3. *There should be a recurring pattern of similar wetland forms or a spectralrange of inter-related wetland forms resulting from a dynamic process*
   Fully applied. Information was obtained from geomorphic setting.

4. *Wetlands should have a similar stratigraphy*
   Information was obtained from the following sources: published geology and soils maps, some in-house data, and field investigations.

5. *Wetlands should have similar water salinity regimes*
   This information was not consistently applied for all wetlands.

6. *Wetlands should have similar hydrological dynamics*
   Limited data was obtained from geomorphic setting, field investigations of selected wetlands and in-house data.

7. *Wetlands should have similar origin*
   Limited data were obtained from in-house drill core and field investigations.

3.7 General terms

Holocene and Pleistocene, used throughout this report, are geologic terms for time periods within the Quaternary Epoch. Holocene refers to that period of the geological time scale within the Quaternary Period between 10,000 years and the present. Pleistocene refers to that period of geological time within the Quaternary Period between 2,00,000 years and 10,000 years ago. Precambrian refers to the period > 550 x 10^6 years, Proterozoic is the younger part of the Precambrian between 550 x 10^6 and 2000 x 10^6 years, while Archaean is the older part of the Precambrian between 2000 x 10^6 and 4600 x 10^6 years. Other general geologic and geomorphic terms used in this report are defined in Bates & Jackson (1980).

In this report, the terms "value" and "function" are used as follows. The term "value" refers to the importance, merit, or worth given to a wetland after it has been evaluated. Evaluation results from assessing the importance of a range of attributes that a wetland possesses and the functions that it performs. To illustrate with one example: if the wetland provides a regional drought refuge for avifauna, and for trans-equatorial migrators, then it has a high value. The term "function" refers to the role that a wetland performs in its natural setting. Thus a wetland may perform the following functions, amongst others:

- local water source for fauna
- local food source for fauna
- drought refuge for avifauna,
- breeding ground for avifauna,
- hydrological discharge zone,
- collection point for a range of ephemeral drainage lines,
- habitat for biota.

4.0 Description of wetland types in the Pilbara region

This section describes inland wetlands and coastal wetlands, and deals with channel-form terrain that may be perceived or mistaken to be wetlands but actually is not wetland.

4.1 The inland wetlands of the Pilbara

The main inland wetlands that occur in the Pilbara Region are: playas, damplands, lakes, sumplands, creeks, rivers, wadis, floodplains, and barlkarras. Typical description of these, and their settings is presented below:

Wetland	Description	Main setting and features
playa	intermittently flood basin, round to irregular; usually macroscale to mesoscale; vegetated by low grass; commonly underlain by mud	on plains of floodplains; and on the low gradient drainage basins; commonly only flooded on passage of infrequent cyclones
dampland	seasonally waterlogged basin, round to irregular; usually mesoscale; vegetated by grasses; underlain by sand and mud	on plains of floodplains; and on the low gradient drainage basins
lake	permanently flooded basin, usually round; mesoscale; vegetated by sedges and rushes; underlain by sand and mud	on plains of floodplains
sumpland	seasonally flooded basin, usually round; mesoscale; vegetated by sedges and rushes; underlain by sand and mud	on plains of floodplains
creek	seasonally flooded channels; channels are sand-floored, gravel-floored, or rocky; leptoscale to microscale; lined by Coolibah or paperbark; along their length there may be riffles and pools; pools are developed by scour in channel sand deposits, or are scoured from rock	common throughout the region dissecting the terrain, and on the plains

river	permanently flooded channels; channels are sand-floored, gravel-floored, or rocky; macroscale to mesoscale; lined by Coolibah or paperbark; along their length there may be riffles and pools; pools are developed by scour in channel sand deposits, or are scoured from rock	locally in tracts along the Fortescue River
wadi	intermittently flooded channels; leptoscale to microscale; lined by wattles or mulga, Coolibah or paperbark; wadis are commonly underlain by sand	common throughout the region dissecting the terrain, and on the plains; flooded usually for a period after passage of cyclones
floodplain	seasonally flooded channels; mainly macroscale to mesoscale; underlain by mud, sand, or gravel sheets; vegetated by wattles or mulga, or grasses	common throughout the region on the plains and adjoining rivers
barlkarra	intermittently flooded channels; mainly macroscale to mesoscale; underlain by mud, sand, or gravel sheets; vegetated by wattles or mulga, or grasses	common throughout the region on the plains and adjoining rivers

4.2 The coastal wetlands of the Pilbara

The marine coastal systems that function as "wetland" in the Pilbara Region, *i.e.,* those parts of the shore that are exposed at low tide, and hence are the "marine wetted" part of the continent, are :

- tidal mud flats
- tidal sand flats
- tidal creeks
- beaches

Tidal mud flats may be vegetation-free (e.g., low tidal mud flats, or high tidal salt flats), or vegetated by mangroves or samphires. Tidal sand flats are usually broad low gradient low tidal flats. Tidal creeks are permanently inundated to low-tidally exposed channel systems. Beaches are steep gradient sandy shores.

4.3 What is not a wetland in the Pilbara

In the Pilbara Region there are many channel-forms throughout the dissected landscape that are conduits for water but that are not wetlands. These shallow channel-forms flood for periods of several hours to about one day, after torrential rainfall, particularly after a cyclone passing, and serve as conduits for water within the drainage basin, feeding the wadis, creeks, and rivers in the Region. The short term flooding may be of sufficient current magnitude to mobilise sand shoals and gravel banks, and cause massive bank erosion. However, the water carriage is a very short term event, viewed within the context of a year, and the water passage does not develop hydrophilic soils or hygrophilous vegetation. Since the channel-ways are commonly situated to some height above the regional water table, they generally are not waterlogged or close to being waterlogged. These types of channel-ways are abundant in the Pilbara, and from aerial photographic mapping, they dominate the dissected terrain of the Pilbara Region, comprising the small-scale headwater regions of the drainage basins, but they are not considered in this report to be wetlands in the Pilbara.

4.4 Variability along channel wetlands in the Pilbara

There is variability and arrays of "wetland" forms along creeks and rivers. For instance, along a given valley tract, and a single channel form, in systems such as the Robe River, or the Fortescue River, there may be a variety of hydrologic regimes, at different scales. Consider these two situations along the Fortescue River valley tract near Millstream:

Feature and scale of along-channel form	Interpretation of the tract	Comments
a 100-m to 200-m tract of channel underlain by sand, with 10-m diameter scours in the bedload excavated to the water table exposing temporary pools; the main channel floods yearly	channel tract is a creek, flooding annually, and pools represent small scale longitudinal variability along channels; pools could be viewed as "sumplands" but should be more appropriately viewed as pools along a channel	at this scale, within the domain of 100-200m, the pools are viewed as temporary exposures to a water table, that will dry out over the drier months, and hence are part of the normal variability of a creek channel morphology
a 10,000-m tract of channel at Millstream, underlain by sand, mud, and rock, with a pool permanently inundated, 100-200 m wide, and fed by groundwater springs and seepage	channel tract is a river, with a permanent inundation and flow within valley tract of the Fortescue River; additionally, the tract floods annually; this pool represents large scale longitudinal variability along the regional river tract; the pool could be viewed as a "lake" but should be more appropriately viewed as part of the Fortescue channel way, though here permanently inundated, and hence a local "river"	at this scale, within the domain of 10,000 m, the pools is viewed as a permanent system that will not dry out over the drier months, being independently fed from the drainage basin system of the main Fortescue River channel, and hence is not part of the normal variability of a creek channel morphology

In this report, smaller scale temporary to permanent pools developed as part of the natural geomorphic and sedimentologic variability along the channel-ways of the creeks throughout the region are viewed as part of the creek system , and not as "lakes", "sumplands" and "damplands" along valley tracts. However, larger permanent pools, fed by groundwater independently of the main drainage basin supply, can be viewed as "river", or "lake" systems along a given valley tract.

5.0 Definition of the Pilbara Region

In this study, the definition and boundaries of the Pilbara Region rests on a number of inter-related criteria, essentially linking upland and coastal landforms through the connectedness of natural drainage, the criteria are:

- occurrence of Precambrian high relief terrain and its array of drainage,
- the down-stream coastal products of this upland terrain, and
- further delimitation of upland boundaries based on the defined extent of the Pilbara Coast by tracing rivers from the coast to upland source.

Thus, the Pilbara Region is defined by Precambrian rocky ranges (Pilbara Massif), and its various drainages (Figure 5). This Region is bordered sharply to north and northeast by the lower terrain of the Great Sandy Desert, which is largely devoid of drainage, and to east and southeast by the Little Sandy Desert and (stony) Gibson Desert. Its southern boundary is defined in relation to its southerly located drainage (see below).

The down-stream expression with the coast of all the drainage lines deriving from the uplands determines the character of the Pilbara Coast (Figure 5). The coast is a product of interaction of rivers with coastal processes, producing coastal forms such as deltas, relict deltas, and barriers (Semeniuk 1993). Thus, the Pilbara Coast, dominated by a range of rivers and creek lines emanating from Precambrian uplands, is delineated as the coastal tract occurring between the De Grey River to the north and the Yanrey River to the south. All rivers in this coastal tract are directly flowing from the uplands and debouching along the coast, influencing coastal form. In detail, the Pilbara Coast is defined as the coastal tract between the northern part of the De Grey River Delta (at Pardoo) and the southern shore of Exmouth Gulf (Bay of Rest). Pardoo, a carbonate dominated coast, also defines the southern margin of the Canning Coast, the next major coastal type to north (Semeniuk 1993a,b). To south of Bay of Rest, the coast is dominated by tectonically uplifted ridge-and-basin structures of Cape Range, Cape Cuvier, and Peron Peninsula that are part of the next major coast type to south, the Carnarvon Coast (Semeniuk 1993a). The Minilya and Lyndon Rivers, deflected from the coast by tectonic uplift, are part of the Carnarvon Coast, and the next southerly river, the Gascoyne, flowing directly east to west, also is part of the Carnarvon Coast; its headwaters are outside of the upland Pilbara Region, and thus the southern margin of the Pilbara Region is defined by drainage of the Ashburton and Yannerie Rivers (Figure 5).

6.0 Regional setting, formative processes

The Study Area in this project, the Pilbara Region, mostly centered on the Pilbara Massif, is located in tropical northwestern Australia, and comprises one of the driest regions of Western Australia. The Study Area stretches from the to Ashburton River Valley tract in the south, to the edge of the Great Sandy Desert and the (stony) Gibson to the north, northeast and east, and borders the Northwest Shelf of the Indian Ocean to the northwest. It contains megascale landform units of rocky ranges, valley tracts, inland plains, and coastal plains, the latter containing a range of smaller scale landform units such as relict/stranded coastal flats, mangrove coasts, tidal flats, coastal dunes, and rocky shores, amongst others.

In the Study Area of this project, there are a range of regional physical features and patterns which are important to understanding the development of wetland types and their distribution; they are:

- climate;
- geology and geomorphology;
- hydrologic patterns.

In addition to the features mentioned above, there also are key terrain features such as drainage patterns and aeolian landforms.

6.1 Climate

Climate affects the development of wetlands, and determines the style of development/characteristics of wetland regions through its affect on landform, hydrology, water salinity, and vegetation. Key features of the regional climate in development of landforms, hydrology and wetlands are rainfall, evaporation, and wind. Climate parameters are presented in The Bureau of Meteorology (1973, 1975) and Beard & Webb (1974).

Rainfall influences development of landforms and wetlands through run-off and erosion, recharges the groundwater aquifers, and maintains wetland hydrology. Evaporation influences wetland formation by increasing wetland salinity, and through salt-weathering. Wind influences evolution of landform and wetlands though development of aeolian landforms (e.g., linear dunes), development of deflation flats, and in the formation of beach ridges and lunettes that fringe and/or isolate wetlands.

The Study Area may be subdivided into two climatic regions; these are:

- the coastal zone
- the rocky ranges zone

Climatic zone	Characteristics
coastal zone	arid, tropical, ~ 300 mm rainfall annually, > 3000 mm of annual evaporation
rocky ranges zone	arid, tropical, <250 mm rainfall annually, > 3000 mm of annual evaporation

The rocky ranges zone represents the extreme in climate for this region, with < 250 mm/yr rainfall and > 3000 mm/yr evaporation is > 4000 mm/yr, and winds strongly influenced by deserts to the east. Wind is not important in development of wetlands in this system. The coastal zone represents the most humid climate for this region, with rainfall ~ 300 mm/yr, evaporation 3200 mm/yr, and winds strongly influenced by the landbreeze and seabreeze systems. Wind in the coastal zone is important in developing marine and coastal landforms such as coastal dunes, and their associated wetlands.

6.2 Geology and geomorphology

Through lithology and structure, geology controls how the regional geomorphology evolves, and this determines the setting for development of landforms that are host to wetlands. Geology through its expression of varied rock types, formational aquifer properties, plan geometry of formations and hence geometry of landforms, and in structures such as faults, joints, also influences hydrology in development of aquifers, seepage points, discharge zones, perching patterns, drainage patterns, etc.

Geological materials in the Pilbara region can be assigned to five main settings; from oldest to youngest, these are (Figure 6):

1. those occurring in the Pilbara Craton;
2. those within the layered Proterozoic sequences;
3. the Proterozoic intrusive igneous rocks
4. those in Cainozoic coastal plain and riverine deposits, and
5. those Quaternary deposits in the coastal zone

The Pilbara Craton, an Archaean granite-and-greenstone complex exposed over 60,0000 km^2 of the northern Pilbara (Hickman, 1975, 1981, 1983, 1984), contains the oldest (3.6-2.8 Ga) and best-exposed granite-and-greenstone terrain in Australia. The greenstones include metamorphosed basalt, sandstone, shale, chert, banded ironstones, and felsic volcanics, as well as mafic-ultramafic schist. Granitoid rocks constitute 60% of the terrain, generally occupying anticlinal domes, up to 120 km across, separated by greenstones in synclinal structures. Granitic batholiths, or in the terms of some authors, "granitoid complexes", are conspicuous in the Pilbara Craton as evident on aerial photographs (Figure 7), forming ovoid bodies up to 120 km across in the northern Pilbara granite-greenstone terrain. The granitic batholiths generally occupy anticlinal domes, whereas the greenstones occur in adjacent synclinal structures.

The layered Proterozoic sequences comprise supracrustal rocks up to 10,000 m thick, and cropping out over an area of 100,000 km^2 south of the Archaean Pilbara Craton. The sequences are composed of a range of layer-parallel sequences of volcanic rocks, lavas, shales, cherts, banded ironstones, and dolomites, with volcanic rocks occurring towards the base of the sequence, ironstone, dolomite and shale in the middle of the sequence, and shale, sandstones and dolomite towards the top of the sequence. The rocks are assigned to three Groups as follows (MacLeod, 1966):

the Turee Creek Group (top)
the Hamersley Group
the Fortescue Group (base)

The Fortescue Group, with a total thickness of 6000 m, comprises 60% of the outcrop of the Proterozoic sequence, and is composed of mafic volcanics and volcaniclastic rocks, some subordinate felsic rocks, and sandstone, conglomerate, and dolomite. The Hamersley Group, with a total thickness of 2500 m, comprises nearly 30% of the outcrop of the Proterozoic sequence, and is characterised by well layered banded ironstones, shale, and dolomite. A significant thickness of the Hamersley Group, totalling about 1000 m is composed of intrusive sills (see later). The Turee Creek Group, with a total maximum local thickness of 1200 m, comprising about 10% of the sequence, crops out only locally, and is composed of fine grained greywacke, sandstone and siltstone, dolomite, and quartzite.

The entire succession of the Archaean to Proterozoic craton and Proterozoic layered sequence in the Pilbara Region is intruded by younger igneous rocks (the Proterozoic intrusive igneous rocks system). These include dolerite and gabbroic dykes, quartz dykes, small to medium sized dolerite sills, large scale gabbroic to dolerite sills, dolerite plugs, and young granitic batholiths.

The coastal plain and river deposits are underlain by Cenozoic deposits. The coastal plain front the upland ranges forming an extensive ribbon to apron unit descending to sea level. The plain is underlain by a variety of deposits that include gravel, sand and mud sheets, lateritised sedimentary deposits, limestone sheets, pedogenic sheets, and calcrete. The river deposits reside in valley tracts and gorges, and are underlain lenses, ribbons and wedges of gravel, sand and mud, lateritised sediment and calcrete.

The Quaternary coastal deposits are complex, and are comprised of shoestrings, ribbons, sheets, wedges, and lenses of Pleistocene to Holocene sediments and sedimentary rock. The materials include Pleistocene limestones, red sand, red muddy sand, conglomerates, fossil soils, and Holocene, beach sands, dune sands, spit/chenier sands, tidal flat gravel, tidal plat sand, tidal flat mud, high tidal alluvial fan deposits, colluvial gravels and sands, and soils.

The fundamental geomorphic units in the Pilbara Region are:

- plateaux, tabletops, mesas
- deeply dissected plateaux (= plateaux and gorges)
- rocky ridges
- high relief undulating terrain
- low relief undulating terrain
- valley tracts

The relation between geology and geomorphology is tabled below:

Geological Unit	Geomorphologic expression
Archaean Pilbara Craton	
granitoid complexes	extensive, grass-covered low plains
junction between granitoids and greenstones	narrow creek-lines etching out the contact
greenstone belts	upstanding high and regionally narrow ridges
Layered Proterozoic sequence	
Fortescue Group	undulating terrain and rocky ranges, with dendritic drainage resulting in moderate internal relative relief
junction between Fortescue and Hamersley Groups	broad valley tract of the Fortescue River
Hamersley Group	deeply dissected to undulating terrain cut into a plateau, and rocky ranges, dissected by rectilinear to dendritic drainage resulting in moderate internal relative relief, deep gorges, broad valley tracts
Turee Group	undulating terrain and rocky ranges, dissected by dendritic drainage resulting in moderate internal relief
Proterozoic igneous intrusions	
mega-sill at Dampier	large resistant rocky range
sills	local rocky ridges
dykes	local rocky ridges
granite batholiths	extensive low plains
plugs	upstanding local rocky knoll

Cenozoic coastal plain and river deposits	
coastal plain	extensive shore-parallel low plain
large rivers	low valley tracts with incised narrow channel
small rivers	low valley tracts with incised narrow channel
Quaternary coastal deposits	
deltas and relict deltas	deltoid low coastal plain with distributary channels, sandy barriers, tidal creeks, and tidal flats
sandy barriers	shore-parallel sandy beach and dune barriers
limestone barriers	shore-parallel, multi-splayed limestone barriers
ria coastal deposits	mainly tidal flats, tidal creeks, and sand bars occupying re-entrants in an indented ria coast
embayment coasts	mainly tidal flats and tidal creeks occupying broad low energy embayments

6.3 The Pilbara Region rivers and creeks: their flood dynamics and fluvial discharge magnitudes

Numerous rivers and creeks drain the uplands of the Pilbara Region. In terms of magnitude of discharge, these may be subdivided into 3 types:

1. large rivers that discharge considerable water during their floods (usually in excess of 200 million cubic metres annually); these rivers have extensive catchments; rivers of this magnitude are the Ashburton River, Fortescue River and the De Grey River;

2. medium rivers that discharge moderate amounts of water during their floods (usually less than 200 million cubic metres annually, many less than 10 million cubic metres annually); these rivers have less extensive catchments than the three mentioned above; rivers of this magnitude are most of the systems that have their headwaters in the Pilbara uplands, and they include the Maitland River, the Robe River, the Nickol River, the Harding River, amongst others;

3. small rivers and creeks that discharge limited amounts of water during their floods; these rivers do not have extensive catchments, and most have their headwaters extending only a limited extent into the hinterland from the coast; most rivers and creeks of this magnitude are unnamed.

This subdivision of rivers and creeks in the Pilbara Region is important in that it provides a perspective of the relative size and longevity of drainage lines inland (i.e., large rivers with large volumes may be expected to support wetlands along their valley tracts for longer periods into the dry season following any given flood), while smaller creeks may be short lived wetlands), and the relative importance of rivers and creeks in generating deltaic landforms at the coast (i.e., large rivers will deliver large volumes of sediment to the coast and hence build extensive delta-lands).

6.4 Hydrology

Groundwater occurs in confined and unconfined aquifers of the Pilbara region, which consist of several drainage basins as described by Allen (1990), Balleau (1972, 1973), PWD WA, (1975) and WRC (1996). There are two categories of water resources, surface water and groundwater. The main catchment areas of unconfined and confined groundwater occur along the major river systems and their associated tributaries. Unconfined groundwater is contained within underlying sediments of alluvium, colluvium, calcrete, iron goethite as Robe pisolite and bedrock consisting of dolomite and granite. The main focus of this review is on unconfined groundwater aquifers.

Observations of meteorology and hydrology in the Pilbara region have been carried out for over 100 years, with the first 50 years consisting mainly of annual precipitation and flow rates of major regional rivers (PWD WA, 1975). Exploration of ground water resources in the last 50 years has occurred due to the demand for water to support the region's towns and associated industries.

Hydrological information has been recorded on a number of catchment systems in the Pilbara region (Balleau 1972, 1973; Dames and Moore 1978; Barnett 1980; Robe River Mining 1999; Leech 1997; Geological Survey of Western Australia 1976, 1996; PWD 1975, 1981; WAWA 1991). These catchments include the, Fortescue River Basin, Port Hedland Coastal Basin, DeGrey River Basin, Millstream aquifer, Ashburton River Basin and the Onslow Coastal Basin. These systems are described as having similar aquifers of alluvium, colluvium, calcrete and goethite, and that they rely on precipitation and runoff from the Hamersley and Chichester ranges for recharge. Recharge is dependent on annual rainfall and is controlled by the nature of the underlying sediments, topography and runoff. The aquifers typically comprise unconsolidated sediments and pedogenic rock below the ground surface and have expressions of surface water in pools, wetlands and river systems. In confined aquifers, the groundwater is contained between impermeable rock formations such as calcrete, siltstone and claystone. Information on hydrology of these catchments is presented below.

Hydrological information of Pilbara groundwater resources

Basin	Occurrence surface area (km^2)	Depth water table below surface (m)	Thickness of aquifer (m)	Stratigraphic setting/ Formation	Salinity mg/l	Reference:
Fortescue River	55,000	6-10 average up to 30 on flanks	not clear	alluvial; calcrete	1 600	Balleau (1972) PWD (1975)
DeGrey River	56,500	7-10	20-75	alluvial	5790-15100	PWD (1975) Leech (1997)
Ashburton / Turee creek		40-50	50	alluvial; calcrete	220-700	RRM (1999)
Millstream	600	20-25	26	calcrete	900-1000	PWD (1981)
Port Headland Coast / Yule R		18-20	20-50	alluvial	600	WAWA (1991
Onslow Coast / Cane River	16, 400	10-30	6-22	alluvial	57-560	Balleau (1973)

Note: The range between unit measurement is given for the average variation of particular sections within each separate system, where minimum and maximum values apply.

For purposes of this study of wetlands in the region, the hydrology of the Pilbara Region has been divided into seven zones (Figure 8):

- Zone 1: that centred on Archaean Precambrian bedrock wherein mainly fresh groundwater resides at depth within bedrock, and to some extent in the alluvial deposits, *i.e.*, the region of the granitoid-and-greenstone terrain;
- Zone 2: that under rocky ranges of Proterozoic Precambrian volcanic bedrock (*i.e.*, the Chichester Ranges), wherein mainly fresh groundwater resides at depth in the bedrock, and again, to some extent in the alluvial deposits;
- Zone 3: the broad valley complex of the Fortescue River
- Zone 4: that under rocky ranges of Proterozoic Precambrian ironstone, dolomite and shale bedrock wherein mainly fresh groundwater resides at depth within the bedrock, and again, to some extent in the alluvial deposits;
- Zone 5: that under rocky ranges of Proterozoic Precambrian sandstone, shale, and dolomiticbedrock (*i.e.*, the Capricorn Ranges, Minnierra Range, Kenneth Range, Barlee), wherein mainly fresh groundwater resides at depth in the bedrock, and again, to some extent in the alluvial deposits, and there is perched water on claypans developed on shale;
- Zone 6: a coastal plain, where fresh to saline groundwater is located in various coastal plain aquifers;
- Zone 7: a coastal zone, where saline to fresh water is located in Quaternary (Pleistocene and Holocene) tidal zone sediment and sedimentary rock units.

Descriptions of specific areas in each of these designated zones are provided by Kriewaldt (1964), Kriewaldt & Ryan (1967), Low (1965), Davidson (1968, 1974), Mann & Horwitz (1979), Sanders (1973), GSWA (1976). Additional information has been accessed from VCSRG in-house R&D data.

In an overview perspective, when reading the ensuing text, and integrating it with the description of wetland hydrology, it is important to bear that groundwater in the Pilbara Region mainly occurs in main levels: 1. in the fracture porosity or vugular porosity of Precambrian rocks, thus constituting the main regional groundwater system; 2. within valley tract sediments and rocks (e.g., sands and gravels, and brecciated calcrete, respectively), as groundwater either perched above the regional groundwater, or communicating with it; valley-tract base flow, and the water exploited by industries in the region are examples of this category; and 3. perched in the near-surface, or locally at the surface (ponding of water by clay pans are an example of this type).

The main hydrologic processes in the Pilbara Region are as follows:

1. run-off after rain forms overland flow, valley tract flows, or channel flows; flash floods result in creeks rising to 3-4 m depths within hours;
2. meteoric infiltration through the fractured rock of the uplands to recharge the groundwater residing in fractured bedrock;
3. meteoric infiltration into valley tracts to infiltrate into the floor of valley fills, recharging the perched aquifers of the valley fill
4. meteoric infiltration into alluvial fans and plains of the coastal plains, recharging the aquifers therein
5. meteoric infiltration into dunes, limestone ridges, and chenier, along the coastal zone, recharging the aquifers therein
6. infiltration from surface water, or perched groundwater within any channel-confined hydrologic system, into the underlying fractured rock of the uplands to recharge groundwater in fractured bedrock;
7. lateral percolation of vadose water, by baseflow, to infiltrate into the floor of valley fills, recharging the perched aquifers of the valley fill stratigraphic pile; these sedimentary piles are unconsolidated sediments, or earlier Cenozoic sedimentary rock;
8. along-valley-axis groundwater flow through alluvial fans and buried channels to infiltrate into tidal flats;
9. lateral percolation of vadose water, along preferred pathways due to fracture configuration or due to relatively impermeable rock layers, to form seepage (springs) on slopes, valley walls, and gorge walls;
10. daily, fortnightly or yearly seawater recharge into tidal flats, and into the margins of cheniers, spits, limestone ridges, dunes, beaches;
11. storage of freshwater occurs in fractured Precambrian rock aquifers, vugular (karst) Precambrian dolomite aquifers, in valley tract calcretes, coastal sand bodies, as perched bodies in valley tract alluvial sediment ribbons, within river delta wedges, and in various limestone formations;
12. where inland aquifers have watertables close to ground surface and subject to evaporation, the groundwater may become salinised.

In relation to these hydrologic settings, wetlands in the region are maintained by: 1. surface water flows from fluvial drainage; 2. water table rise in unconfined surficial aquifers; 3. ponding/perching of meteoric water by near-surface hardpans; 4. seepage from uplands (e.g., from limestone ridges into tidal zones, from upland rocky ranges into valley tracts, or from upland ranges into the walls of a bedrock valley); and 5. by locally upward leakage from formational waters.

Description of the groundwater zones of the Pilbara Region.

Groundwater Zone	Description
Zone 1: Archaean granitoid-and-greenstone terrain where mainly fresh groundwater resides at depth, and to some extent in alluvial deposits	meteoric water sheets off the granitic/gneissic terrain forming creek run-off, or infiltrates groundwater to reside in fractures and joints of the rock; in the greenstone ridges, meteoric water sheets off the terrain forming run-off and waterfalls, or infiltrates to reside in fractures and joints of the rocks; meteoric water and run-off infiltrates alluvial deposits recharging shallow groundwater; groundwater in Zone 1 is fresh because of the rapid recharge of meteoric water deeply into the fractured rock aquifer beyond the effects of evaporation and hence salinisation
Zone 2: volcanic bedrock rocky terrain wherein mainly fresh groundwater resides at depth, and again, to some extent in alluvial deposits	there are two types of materials host to groundwater, viz., volcanic rock and alluvium; the volcanic bedrocks form thick massive fractured sequences; the alluvium is sand, gravel, and muddy sediments; meteoric water sheets off the rocky terrain forming creek run-off or waterfalls, or infiltrates deeper to reside as groundwater in bedrock fractures and joints; on the broader alluvial tracts, which are underlain by sand and gravel, meteoric water and inflowing run-off from upstream infiltrate to recharge the shallow groundwater; groundwater throughout Zone 2 is mostly fresh because of the rapid recharge of meteoric water deeply into the fractured rock aquifer beyond the effects of evaporation and hence salinisation

Zone 3: broad valley complex of the Fortescue River, incorporating valleys of bare rock walls, cemented Cenozoic sediment fills, calcrete-fills, and alluvial sediment-fills	this zone is complicated: along the one valley tract, it has components of unconsolidated sedimentary alluvial fill of gravel, sand and mud, or cemented Cenozoic alluvial fill, or calcrete deposits along the valley tract, or high level calcrete, or where there is bedrock (where sediment has been flushed out) bare rock valleys cut into ironstone, valley underlays of karstic dolomite, or fractured quartz breccia; on the broader alluvial tracts, which are underlain by mud, sand and gravel; meteoric water and inflowing run-off from upstream infiltrate to recharge the shallow groundwater; there is recharge/seepage from adjoining uplands (north and south) into the valley tract; and there is water flow within the karst system of the regional dolomites into the valley tract and into the dolomites that underlie the valley; depending on location, extent of infiltration of meteoric waters, and extent of exposure to solar radiation, groundwater throughout Zone 3 varies from fresh to saline; groundwater is fresh where it has penetrated in the aquifer deeply enough to be out of reach of evaporative processes, and becomes salinised where it is sufficiently near the surface to be subject to evaporation
Zone 4: rocky ranges of the Proterozoic layered sequence of ironstones, shale, volcanics, and dolomite wherein mainly fresh groundwater resides at depth within the bedrock, and again, to some extent in the alluvial deposits	there are five types of materials that are host to groundwater, viz., four types of rock associations and alluvial material; the rocks are layered ironstones, shales, volcanics, and dolomites, and these are interlayered, or form thick sequences in different parts of the region; the alluvial materials are sand, gravel, and muddy sediments; meteoric water sheets off the rocky terrain forming creek run-off or waterfalls, or infiltrates to the deeper groundwater to reside in fractures and joints of the bedrock; complex layering in the sequence causes perching and groundwater flow diversion, resulting in seepage from walls of gorges, and local springs; in the broader alluvial tracts, which are underlain by sand and gravel, meteoric water and inflowing run-off from upstream infiltrates the alluvium to recharge the shallow groundwater; groundwater throughout Zone 4 is mostly fresh because of the rapid recharge of meteoric water deeply into the fractured rock aquifer beyond the effects of evaporation and hence salinisation

Zone 5: sandstone, shale, and dolomiticbedrock, wherein mainly fresh groundwater resides at depth in the bedrock, and again, to some extent in the alluvial deposits, with localperched water on claypans	three types of rock are host to groundwater (sandstone, quartzite, and greywacke; shale; and dolomite); the rocks form thick massive fractured sequences; the alluvium is sand, gravel, and muddy sediments; meteoric water sheets off the rocky terrain forming creek run-off, or infiltrates deeper to reside as groundwater in bedrock fractures and joints; on the broader alluvial tracts, which are underlain by sand and gravel, meteoric water and inflowing run-off from upstream infiltrate to recharge the shallow groundwater; groundwater throughout Zone 5 is mostly fresh because of the rapid recharge of meteoric water deeply into the fractured rock aquifer beyond the effects of evaporation and hence salinisation; locally the nearsurface is subartestian welling up through fractures; where there are clay pans developed on the weathered shale terrain, perched rain water evaporates, and the waters become saline
Zone 6: a coastal plain section, where fresh to saline groundwater is located in various coastal plain aquifers;	three types of materials are host to groundwater (local bedrock knolls/outcrops, Cenozoic deposits of colluvium, alluvial fan material, and alluvium, and younger alluvium located along valleys; the local bedrock knolls/outcrops act hydrologically in a similar manner to bedrock described above; the alluvial material in valley tracts acts hydrologically in a similar manner to alluvial settings described above; the vast majority of the coastal plain is underlain by a Cenozoic sequence of alluviam, alluvial fans, pedogenic deposits; this sequence is host to groundwater recharged by infiltrating rainfall, upland seepage, and inflow from creeks; groundwater in Zone 5 is varies from fresh to brackish, becoming more saline coastally
Zone 6: a coastal zone section, where saline to fresh water is located in Quaternary (Pleistocene and Holocene) tidal zone sediment and sedimentary rock units.	this zone is very complicated: it is recharged by rainfall, by marine waters, and by hinterland seepage, and because groundwater is frequently at very shallow depths, it is subject to extreme evaporation resulting in hypersalinity; the spatial distribution of groundwater types thus is complicated because of the array sedimentary units (e.g., tidal flats, and sand bars) and stratigraphic types (e.g., delta wedges, or limestone ridges); as a result, there is a mosaic of various water body chemistries and water body shapes, with salinity varying from fresh to brackish to saline to hypersaline; commonly there also is a gradient in salinity from saline to hypersaline to fresh in response to shore gradients

7.0 Wetland subregions and consanguineous suites

7.1 Preamble

Applying the approach of consanguineous suites of C A Semeniuk (1988) to the wetlands of the Pilbara Region was not a straightforward exercise, as will be discussed later. The wetlands in the Pilbara Region created two types of problems in classifying them from a perspective of their larger scale groupings. Thus there is a need to describe, discuss and resolve the issues underlying the complex classification problems identified.

This section firstly deals with a new concept, viz., that of a wetland subregion. It then describes the geological framework useful for delineating wetland subregions and consanguineous suites. This is followed by a discussion of the problems of delineating consanguineous suites and defining their boundaries, and then by a practical example of the problem using a contrast between two landscape settings (viz., the Fortescue River Valley Tract and the Marble Bar area). Finally, the wetland subregions and their consanguineous suites in the Pilbara Region are delineated and described.

7.2 The concept of a wetland subregion

Recognising the Pilbara as a "Region" carried with it some inherent problems. Clearly, the Pilbara uplands stand out distinct as a "region" separate from the Yilgarn system to the south, the Great Sandy Desert to the north, and the Gibson Desert to the east and southeast. However, the smallest scale of "systems", the delineation of consanguineous suites, occurs in distinct tracts of landforms in the Pilbara Region. These landform tracts also influence the types and styles of wetlands developed therein sufficiently distinctly to be identified as regional landform types. For instance, the Hamersley Ranges contain consanguineous wetland suites and the terrain north of the Chichester Ranges contains another set of consanguineous suites. These "subregional" terrains within the Pilbara Region also qualify to be identified because of their influence on landscape and development of wetland type, but they are at a scale above consanguineous and below that of "Region".

Therefore, it is clear that in the Pilbara Region, with its more complex geology and greater range of landforms deriving from it, there is another tier of landform classification required to deal with the wetlands there. This problem does not occur in the regions of the Swan Coastal Plain, Scott Coastal Plain, or Great Sandy Desert, but the widely contrasting rock types in the Pilbara, forming distinct geological tracts, and hence geomorphic tracts, necessitate another tier for landscape classification, that of a "subregion". In this context, the concept of a wetland "subregion" is proposed. This is a term for a terrain or land system forming distinct tracts at scales smaller than a wetland region (*i.e.,* a wetland region may contain a number of wetland "subregions"), but is larger than the domain of a consanguineous suite. While this approach is necessary and workable in the Pilbara Region, it does not imply that all wetland regions can be subdivided into "subregions". Such a subdivision will depend on the complexity of geology and landforms within a given region.

7.3 Geological framework useful for delineating wetland subregions and consanguineous suites

Given the linkage between geology, landscape and hydrology, geology forms a logical first tier framework for delineating wetland systems at the largest scale. The Pilbara Region, for purposes of delineating wetland subregions, and ultimately identifying a framework for consanguineous suites, can be divided into nine main geological zones or subregions:

1. Archaean Precambrian terrain, with local Cenozoic riverine deposits,
2. Proterozoic Precambrian terrain, centred on the Chichester Ranges, with local cover of Cenozoic riverine deposits,
3. the valley tract of the Fortescue River, with fill of Cenozoic riverine deposits, occurring between the Chichester and Hamersley Ranges,
4. the Proterozoic Precambrian terrain, centred on the Hamersley Ranges, with local cover of Cenozoic riverine deposits,
5. the Proterozoic Precambrian terrain, centred on the igneous rock sill of the Burrup "Peninsula", with local cover of Cenozoic riverine deposits,
6. Proterozoic Precambrian terrain, centred on the Ashburton River Valley tract, with local cover of Cenozoic riverine deposits,
7. near-coastal tablelands and plains, mainly of Cenozoic deposits,
8. coastal plains, mainly of Cenozoic deposits, and
9. coastal zone, mainly of Quaternary deposits.

Geomorphology and wetlands of the subregional scale units

Subregional scale units	**Description of unit, and wetland types developed**
Archaean rock terrain, with local cover of Cenozoic riverine deposits	flat plains, oval to round in plan, tens of kilometres across, underlain by eroded granite, with ridges of greenstone forming high and relatively narrow ridges circumferential to the granites, and locally with narrow igneous rock ridges (dykes, plugs, sills); wetlands developed as shallow/broad creeks and wadis on the plain, incised creeks with semi-permanent to permanent pools cutting through ridges, and creeks with semi-permanent to permanent pools along the contact of plains and ridges
Proterozoic rock terrain, centred on the Chichester Ranges, with local cover of Cenozoic riverine deposits	undulating terrain and rock ranges, and broad valley tracts, underlain by volcanic rock and alluvium, respectively; wetlands developed as shallow/broad creeks and wadis, and creeks, floodplains and barlkarras on the broad valley tracts
the valley tract of the Fortescue River, with fill of Cenozoic riverine deposits, occurring between the Chichester and Hamersley Ranges	variable terrain along the length of the River; headwaters are dissected with low relative internal relief; eastern tract is broad 20 km wide alluvial plains; Millstream sector is incised into layered bedrock; western sector is narrow bedrock valley; deltaic plain comprising low plains with incised channel; in all sectors there are creeks, tributary creeks and wadis, and pools within channels; on the plains of the headwaters, eastern sector, western sector and deltaic plain sector, there are also floodplains and barlkarras; in the Millstream sector there are the river, creeks, wadis, floodplains and barlkarras

Proterozoic Precambrian terrain, centred on the Hamersley Ranges, with local cover of Cenozoic riverine deposits	variable terrain dependent on the type of geologic setting; dissected ironstones develop rugged ranges and gorges (incised creeks); volcanic and shale terrain develop undulating terrain and broad valley tracts; igneous sills and dykes develop local rocky ridges; wetlands include incised creeks and wadis, with pools within the channels; broad valley tracts and undulating terrain develop wetlands such as creeks, wadis, floodplains and barlkarras
Proterozoic Precambrian terrain, centred on the Burrup "Peninsula", with local Cenozoic riverine deposits	dissected terrain with creeks and wadis following fracture lines, and igneous sills and dykes developing the upland rocky ridges; wetlands include incised creeks and wadis, with pools within the rocky channels, and ribbon floodplains and barlkarras
Proterozoic terrain, centred on Ashburton River Valley tract, with local cover of Cenozoic riverine deposits	dominant shale and dolomite develop undulating terrain with broad valley tracts; wetlands include incised creeks and wadis with local floodplains and barlkarras; playas locally formed on floodplains
near-coastal tablelands and plains, mainly of Cenozoic deposits	mesas and tablelands capped by gravelly Cenozoic ironstone (Robe River Pisolite), upstanding above a broad and extensive plain (flat to low undulating terrain) with creek lines, and local floodplains and barlkarras
coastal plains, mainly of Cenozoic deposits	flat to undulating terrain with creek lines, and local floodplains and barlkarras
coastal zone comprised mainly of Quaternary deposits	diverse coastal morphology of deltas, barriers, beaches/dunes, rias, embayment coasts, with marine wetlands of tidal flats, beaches, sand flats (see Semeniuk 1996)

Contacts between the geologic units described above have generated settings for specific wetland types. For example, the contacts between the Proterozoic rock terrain of the Chichester Ranges and the Fortescue River Valley, and the Hamersley Ranges and the Fortescue River is a zone of southerly and northerly shedding alluvial fans, laterally coalescing. It is also a zone of groundwater discharge between the uplands and the valley tract, with the development of wadis, and seepage zone wetlands.

7.4 Delineating consanguineous suites, and defining their boundaries: discussion of a problem

While the approach of classifying wetlands regionally into "inter-related" suites, or consanguineous suites, has been successfully applied in a number of areas in southwestern and southern Western Australia and globally, there have been problems with applying the concept to the Pilbara wetlands. The approach so far has been successfully applied to the wetlands elsewhere in Western Australia (viz., the entire length of the Swan Coastal Plain between Dongara and Busselton, the Scott Coastal Plain, the D'Entrecasteaux Region, the area between Walpole and Esperance, the Great Sandy Desert, amongst others; cf. C. A Semeniuk 1988; V & C Semeniuk Research Group 1991, 1992, 1993, 1996, 1997, 1998, 1999), to the wetlands in Southern Africa (V & C Semeniuk Research Group 1992), and to wetlands in Britain, France and Canada (VCSRG R&D data).

The main problem is the dilemma between either being practical or applying criteria in a purist manner (being consistent). While it is possible to rapidly derive a workable practical classification, it may only superficially deal with the natural variability of the wetlands. The objective of classification from a purist scientific viewpoint is to identify and generate categories that as closely as possible parallel natural grouping. The approach of identifying consanguineous suites attempts to identify natural grouping and associations of wetlands.

- A digression is provided to illustrate the problem: there is a contrast in drainage expression, and landscape style between the Fortescue River Valley Tract and the De Grey River drainage basin (headwaters) in the area north of Marble Bar. Both systems are dominated by drainage, but there are differences that clearly delineate one as a distinct suite along its whole length and the other as part of a landscape system.

As outlined earlier, the Fortescue River has a number of clearly defined tracts along its length: a headwater region, a mid tract of broad flats, another tract incised into rock where it is permanently spring-fed, a further tract where it crosses dissected terrain with occasional entrenchment, a coastal plain tract, and a delta. The river is well demarcated regionally, and has clearly defined valley-filling deposits that further define it. In effect there is one clear well defined valley tract.

The De Grey River, in contrast, has a headwater system and tributary system similar to the headwaters of the Fortescue River, but its entire drainage basin is of this character. The sediments within the channel are in transit, and the system does not produce a sedimentologically and geomorphologically as distinct a system as the Fortescue River valley tract. Where it nears the coast, the De Grey River forms a distinctive subaerial deltaic plain, and at the coast a large and distinctive delta.

If the criterion is applied that all wetlands along the distinctive drainage tract of the Fortescue River constitute a consanguineous suite, it could be argued that all drainage basins similarly constitute "suites". However, the various main channels and the tributaries range from well defined and large (as for the Fortescue River) to diffuse. The problem of delineating consanguineous suites in this context is illustrated diagramatically in Figure 9.

The resolution is that if a river valley tract is sufficiently distinct from the surrounding uplands, and has a clear sedimentologic signature, then it is sufficiently distinct to be identified as a consanguineous suite along its entire length.

In this context, the drainage basins of the De Grey, the Yule, the Turner, and numerous other rivers are not consanguineous suites in their own suites, but that the Fortescue River valley Tract is sufficiently diagnostic to be separated as a suite that crosses the Pilbara Region.

Note that once a river meets and interacts with the coast and forms deltas, it belongs to the coastal suite. Here, marine processes rather than riverine processes become dominant.

7.5 Wetland subregions and their consanguineous suites in the Pilbara Region

The eight main geological zones form the framework to identifying wetland subregions in the Pilbara. In the context of the control of the Precambrian geology and Cenozoic geology on developing distinctive wetland subregions, it is proposed here to formally name these subregions (Figure 10):

Regional scale units	Name of Subregion
Archaean rock terrain, with local cover of Cenozoic riverine deposits	Marble Bar Subregion
Proterozoic rock terrain, centred on the Chichester Ranges	Chichester Range Subregion
Proterozoic rock terrain, located between the Chichester Ranges and Hamersley Ranges, *i.e.*, the valley of the Fortescue River	Fortescue River Valley Tract
Proterozoic Precambrian terrain, centred on the Hamersley Ranges	Hamersley Range Subregion
Proterozoic Precambrian terrain, centred on the Burrup "Peninsula"	Burrup Subregion
Proterozoic Precambrian terrain, centred on the Ashburton River Valley tract,	Ashburton River Drainage Basin
Cenozoic tableland and plains	Nanutarra Subregion
Cenozoic coastal plains	Abydos-Onslow Plain Subregion
Quaternary coastal zone	Pilbara Coastal Zone

Contacts between the Proterozoic rock terrain of the Chichester Ranges and the Fortescue River Valley, and that of the Hamersley Ranges and the Fortescue River are interface zones. They are later afforded status as consanguineous suites, but not formally identified at the scale of subregion.

Within each of these subregions, there are suites of wetlands, and these are noted and described below. The criteria for recognising consanguinity are:

- types of wetlands associated together, e.g., creeks with floodplains, and playas on the floodplain
- style of wetland development, e.g., creeks in broad valley tracts versus creeks incising plateaux to form gorges
- size and shape of the wetlands
- inter-relatedness of wetlands, e.g., various wetland forms developed along the same riverine valley tract.

The wetland suites, in relationship to the subregions are:

Name of Subregion	**Consanguineous wetland suite**
Marble Bar Subregion	Yule River Suite Shaw Batholith Suite Coppin Gap Suite Gorge Range Suite
Chichester Range Subregion	Chichester Range Suite
between Chichester Range Subregion and Fortescue River Valley tract	Roy Hill Suite
Fortescue River Valley tract	Ethel Creek Suite Fortescue Marsh Suite Millstream Suite Dogger Gorge Suite Mardie Suite
between Fortescue River Valley tract and Hamersley Range Subregion	Maddina Pool Suite
Hamersley Range Subregion	Hamersley Gorge Suite Turner Creek Suite
Burrup Subregion	Burrup Suite

Ashburton River Valley tract	Capricorn Range Suite Ashburton Downs Suite
Nanutarra Subregion	Robe River Suite
Abydos-Onslow Plain Subregion	De Grey River Plain suite South Hedland Suite Karratha Suite Burbunman Flat Suite Yannarie River Suite
Pilbara Coastal Zone	De Grey Delta Suite Yule-Turner Delta Suite Port Hedland Suite Balla Balla Suite Dampier Archipelago Suite Fortescue-Robe Delta Suite Onslow Suite Ashburton Delta Suite East Exmouth Suite

A description of these suites, in terms of their wetlands, and the mechanisms of hydrologic maintenance is presented in the two Tables following.

7.6 Difficulty with mapping of the consanguineous suites

There is a plethora of wetland suites in the Pilbara Region spread over a quite extensive area, and it has not been possible with the photographic and topographic resources avaibale at present to fully map them. There would also need to be more extensive field surveys specifically to locate/map suites throughout the region, and this was beyond the scope and budget of this project. This type of procedure, viz., mapping consanguineous suites, has been carried out successfully in other regions by the Semeniuk Research Group (viz. V & C Semeniuk Research Group 1991, 1995, 1996, and Hill et al., 1996), in the Guraga area, Scott Coastal Plain, and Swan Coastal Plain, but these latter areas are smaller regions than the Pilbara, and more accessible to vehicles. While the description in the Table below serves to define and categorise the various consanguineous suites, the task of locating all the occurrences of the suites must be left to future work. However, the descriptions of the suites within the context of wetland subregions (which are located on Figure 10) should enable the reader to obtain a reasonable picture of a given suite.

Description of the wetland consanguineous suites

Subregion	**Consanguineous suite**	**Description of wetland types therein**
Marble Bar	Yule River Suite	valley tract with main channel and tributary creek and wadis, floodplains and barlkarra; local pools
	Shaw Batholith Suite	plains with wadis and barlkarras
	Coppin Gap Suite	creek with pools developed along interface between plain and ridge
	Gorge Range Suite	incised creek, steep walled, with pools, and fed by run-off and seepage
Chichester Range	Chichester Range Suite	valley tracts and tributaries of creeks and wadis, locally with pools
Contact: Chichester Range and Fortescue River Valley	Roy Hill Suite	gravelly alluvial fan complexes with wadis, and seepage into the valley tract along toe of the fans
Fortescue River Valley	Ethel Creek Suite	creeks/wadis in the Fortescue River headwaters
	Fortescue Marsh Suite	broad, low-relief weakly incised main creek, subsidiary meandering flood-way creek, broad and extensive floodplains and barlkarras underlain by mud, local playa basins on the plains
	Millstream Suite	permanently flooded channel cut into bedrock and Cenozoic deposits; system bordered locally by floodplains and barlkarras; where channel crosses terrain of lower relief, creeks have local pools
	Dogger Gorge Suite	valley incised into bedrock, with areas of relatively lower internal relief; local pools
	Mardie Suite	creek incised into coastal plain; local polls, and floodplains and barlkarras

Contact: Fortescue River Valley and Hamersley Range	Maddina Pool Suite	alluvial fan complexes with wadis, and seepage into the valley tract along the toe of the fans
Hamersley Ranges	Hamersley Gorge Suite	incised creek developing gorges, with pools developed in rocky settings and sand floored sectors along the creek length; local seepage from the walls of the creek
	Turner Creek Suite	valley tracts and tributaries of creeks and wadis, locally with pools
Burrup "Peninsula"	Burrup Suite	incised channels developing rocky floored creeks and wadis, sediment filled valley tracts of creeks, wadis, and associated ribbon-like floodplains and barlkarras; sediment filled valley tracts are comprised of gravelly, sandy and muddy deposits, and calcrete; there is local seepage from the walls of the creek
Ashburton River Valley tract	Capricorn Range Suite	valley tracts and tributaries of creeks and wadis, locally with pools
	Ashburton Downs Suite	zones of mud-floored playas
Nanutarra subregion	Robe River Suite	valley tracts of creeks and wadis, and local pools
Abydos-Onslow Plain	De Grey River Plain Suite	deltaic plain with tributary creeks, wadis, local playas
	South Hedland Suite	plains of red sand with local wadis, and playas
	Karratha Suite	plains of red gravel with local wadis, and playas
	Burbunman Flat Suite	Robe and Fortescue delta plains (alluvial to deltaic plains of red sand and gravel) with local wadis
	Yannarie River Suite	network of inter-connected playas

Pilbara Coastal Zone	De Grey Delta Suite	delta complex of tidal flats and channels
	Yule-Turner Delta Suite	delta complex of tidal flats, barrier sand ridges and channels
	Port Hedland Suite	barrier of limestone ridges with protected tidal flats, embayments, and tidal creeks
	Balla Balla Suite	broad mud-filled embayments, tidal flats, and eroding limestone barriers
	Dampier Archipelago Suite	ria coast complex of tidal flats, tidal creeks, spits/cheniers, tidal alluvial fans
	Fortescue-Robe Delta Suite	gravel-dominated barrier complex within a deltaic setting
	Onslow Suite	barrier beach/dune systems with barred linear lagoons
	Ashburton Delta Suite	delta complex of tidal flats, sand ridges & channels
	East Exmouth Suite	laterally extensive, insular-peninsular prograded wide tidal flat system

Hydrologic maintenance of wetlands within the consanguineous suites

Consanguineous suite	**Description of hydrologic mechanisms within the wetlands**
Marble Bar subregion	
Yule River Suite	valley tract with main channel and tributary creek and wadis, floodplains and barlkarra; local pools: run-off after rain forms overland flow, valley tract flows, or channel flows; flash floods result in creeks rising rapidly within hours; meteoric infiltration into valley tracts to infiltrate into the floor of valley fills, recharging the perched aquifers of the valley fill stratigraphic pile, and infiltration through the valley floor recharges the groundwater residing in underlying fractured bedrock; exposure of the perched water table in the valley tract sands creates local pools; along-valley-axis groundwater flow-through; where inland aquifers have watertables close to ground surface and subject to evaporation, the groundwater may become salinised
Shaw Batholith Suite	plains with wadis and barlkarras: run-off after rain forms overland flow flooding the plains and barlkarras; watertable rise under the barlbarrras within the broader setting of their position within a valley tract keeps the barlkarra surface for a period within the zone of water table capillary rise after the flood waters have subsided; flash floods result in wadis rising rapidly within hours
Coppin Gap Suite	creek with pools developed along interface between plain and ridge: run-off after rain forms channel flows; flash floods result in creeks rising rapidly; meteoric infiltration through fractured rock of the uplands to recharge the groundwater residing there; meteoric infiltration into creek floor, recharging the perched aquifers of the valley fill; percolation of vadose water, by baseflow, to infiltrate into the floor of valley; karst derived seepage zones on valley walls; storage of freshwater occurs in fractured Precambrian rock aquifers, local vugular (karst) dolomite aquifers, in calcretes, as perched bodies in alluvial sediment; groundwater close to ground surface may become salinised

Gorge Range Suite	incised creek, steep walled, with pools, and fed by run-off and seepage: run-off after rain forms channel flows; flash floods result in creeks rising rapidly within hours; meteoric infiltration through the fractured rock of the uplands recharges groundwater residing in fractured bedrock; meteoric infiltration into creek infiltrates into the floor of valley fills, recharging the perched aquifers there; percolation of vadose water, by baseflow, infiltrates into the floor of valley fills, recharging the perched aquifers of the valley fill stratigraphic pile; lateral percolation of vadose water, along preferred pathways due to fracture configuration or due to relatively impermeable rock layers, to form seepage zones (springs) on gorge walls; storage of freshwater in fractured Precambrian rock aquifers, local vugular (karst) Precambrian dolomite aquifers, in valley tract calcretes, as perched bodies in alluvial sediment ribbons; where valley baseflow groundwater has a watertable close to surface and subject to evaporation, the groundwater may become salinised
Chichester Range subregion	
Chichester Range Suite	valley tracts and tributaries of creeks and wadis, locally with pools: run-off after rain forms overland flow, valley tract flows, or channel flows; flash floods result in creeks rising rapidly within hours; meteoric infiltration into valley tracts infiltrates into the floor of valley fills, recharging the perched aquifers, and infiltration through the valley floor recharges the groundwater residing in underlying fractured bedrock

Contact: Chichester Range and Fortescue River Valley	
Roy Hill Suite	gravelly alluvial fan complexes with wadis, and seepage into the valley tract along toe of the fans: run-off after rain forms overland flow, valley tract flows, or channel flows; flash floods result in creeks rising rapidly within hours; meteoric infiltration through the gravel fans recharges the groundwater residing under there; along-valley-axis groundwater flow through alluvial fans and buried channels to seep out at the toe of fans
Fortescue River Valley subregion	
Ethel Creek Suite	creeks/wadis in the headwaters: run-off after rain forms overland flow, valley tract flows, or channel flows; flash floods result in creeks rising rapidly within hours; meteoric waterinfiltrates the floor of valley fills, recharging the perched aquifers there, and infiltrates through the valley floor to recharge the underlying fractured bedrock aquifer; exposure of the perched water table in the channel sands creates local pools; watertables close to ground surface, subject to evaporation, may become salinised
Fortescue Marsh Suite	broad, low-relief weakly incised main creek, subsidiary meandering flood-way creek, broad and extensive floodplains and barlkarras underlain by mud, local playa basins on the plains: run-off after rain forms overland flow, valley tract flows, or channel flows; flash floods result in creeks rising rapidly within hours; perching of rain water and overland flow on the mud fill of the valley tract; meteoric infiltration into valley tracts to infiltrate into the floor of valley fills, recharging the perched aquifers there; storage of freshwater occurs in fractured and vugular (karst) Precambrian dolomite, and in calcretes; where groundwater is close to surface and subject to evaporation, it may become salinised

Millstream Suite	permanently flooded channel cut into bedrock and Cenozoic deposits; system bordered locally by floodplains and barlkarras; where channel crosses terrain of lower relief, development of creeks with local pools: run-off after rain forms overland flow, valley tract flows, or channel flows; flash floods result in creeks rising rapidly within hours; meteoric infiltration through the fractured rock of the uplands to recharge the groundwater residing in fractured bedrock; meteoric infiltration into valley tracts to infiltrate into the floor of valley fills, recharging the perched aquifers of the valley fill stratigraphic pile; lateral percolation of vadose water, by baseflow, to infiltrate into the floor of valley fills, recharging the perched aquifers of the valley fill stratigraphic pile; these sedimentary piles are unconsolidated sediments, or earlier Cenozoic sedimentary rock; along-valley-axis groundwater flow; lateral percolation of vadose water, along preferred pathways due to fracture configuration or due to relatively impermeable rock layers, to form seepage zones (springs) on slopes, valley walls, and gorge walls; storage of freshwater occurs in fractured Precambrian rock aquifers, vugular (karst) dolomite aquifers, in valley tract calcretes; where watertables are close to ground surface and subject to evaporation, the groundwater may become salinised
Dogger Gorge Suite	valley incised into bedrock, with areas of relatively lower internal relief; local pools: run-off after rain forms overland flow, valley tract flows, or channel flows; flash floods result in creeks rising rapidly within hours; meteoric infiltration into valley tracts to infiltrate into the floor of valley fills, recharging the perched aquifers there, and infiltration through the valley floor recharges the groundwater residing in underlying fractured bedrock; exposure of the perched water table in the valley tract sands creates local pools; along-valley-axis groundwater flow through; where watertables are close to ground surface and subject to evaporation, the groundwater may become salinised

Mardie Suite	creek incised into coastal plain; local polls, and floodplains and barlkarras" run-off after rain forms overland flow, valley tract flows, or channel flows; flash floods result in creeks rising rapidly within hours; meteoric infiltration through the fractured rock of the uplands to recharge the groundwater residing in gravel deposits; along-valley-axis groundwater flow through gravel deposits; where watertables close to ground surface and subject to evaporation, the groundwater may become salinised
Contact: Fortescue River Valley and Hamersley Range	
Maddina Pool Suite	alluvial fan complexes with wadis, and seepage into the valley tract along the toe of the fans: run-off after rain forms overland flow, valley tract flows, or channel flows; flash floods result in creeks rising rapidly within hours; meteoric infiltration through the gravel fans recharges the groundwater residing under there; along-valley-axis groundwater flow through alluvial fans and buried channels to seep out at the toe of fans
Hamersley Ranges subregion	
Hamersley Gorge Suite	incised creek developing gorges, with pools in rocky settings, and sand floored sectors along the creek length; local seepage from walls of the creek: run-off after rain forms channel flows; flash floods result in creeks rising rapidly within hours; meteoric infiltration into into the floor of valley fills, recharging the perched aquifers there, and infiltration through the valley floor recharges the groundwater residing in underlying fractured bedrock; exposure of the perched water table in the valley tract sands creates local pools; along-valley-axis groundwater flow through; where watertables close to ground surface and subject to evaporation, the groundwater may become salinised

Turner Creek Suite	valley tracts and tributaries of creeks and wadis, locally with pools: run-off after rain forms overland flow, valley tract flows, or channel flows; flash floods result in creeks rising rapidly within hours; meteoric infiltration into valley tracts to infiltrate into the floor of valley fills, recharging the perched aquifers there; infiltration through the valley floor recharges the groundwater residing in underlying fractured bedrock; exposure of the perched water table in the valley tract sands creates local pools; along-valley-axis groundwater flow through; where watertables close to ground surface and subject to evaporation, the groundwater may become salinised
Burrup "Peninsula" subregion	
Burrup Suite	incised channels developing rocky floored creeks and wadis, sediment filled valley tracts of creeks, wadis, and associated ribbon-like floodplains and barlkarras; sediment filled valley tracts are comprised of gravelly, sandy and muddy deposits, and calcrete; there is local seepage from the walls of the creek: run-off after rain forms overland flow, valley tract flows, or channel flows; meteoric infiltration into floor of valley fills, recharging the perched aquifers there; infiltration through the valley floor recharges the groundwater residing in underlying fractured bedrock; exposure of the perched water table in the valley tract sands creates local pools; along-valley-axis groundwater flow through; where watertables close to ground surface and subject to evaporation, the groundwater may become salinised

Ashburton River Valley subregion	
Capricorn Range Suite	valley tracts and tributaries of creeks and wadis, locally with pools: run-off after rain forms overland flow, valley tract flows, or channel flows; flash floods result in creeks rising rapidly within hours; meteoric infiltration into valley tracts to infiltrate into the floor of valley fills, recharging the perched aquifers there and infiltration through the valley floor recharges the groundwater residing in underlying fractured bedrock; exposure of the perched water table in the valley tract sands creates local pools; along-valley-axis groundwater flow through; where watertables close to ground surface and subject to evaporation, the groundwater may become salinised
Ashburton Downs Suite	zones of mud-floored playas: run-off after rain forms overland flow, valley tract flows, or channel flows; flash floods result in creeks rising rapidly within hours, and filling of clay-lined pans
Nanutarra subregion	
Robe River Suite	valley tracts of creeks and wadis, and local pools: run-off after rain forms overland flow, valley tract flows, or channel flows; flash floods result in creeks rising rapidly within hours; meteoric infiltration into valley tracts to infiltrate into the floor of valley fills, recharging the perched aquifers there; infiltration through the valley floor recharges the groundwater residing in underlying Cenozoic sediments; exposure of the perched water table in the valley tract sands creates local pools; along-valley-axis groundwater flow through; watertables close to ground surface and subject to evaporation, may become salinised

Abydos-Onslow Plain subregion	
De Grey River Plain Suite	deltaic plain with tributary creeks, wadis, local playas: run-off after rain forms overland flow, valley tract flows, or channel flows; flash floods recharge creeks; meteoric infiltration into valley tracts recharges the perched aquifers there; lateral percolation of vadose water, by baseflow, to infiltrate into the floor of valley fills, recharging the perched aquifers of the valley fill stratigraphic pile; these sedimentary piles are unconsolidated sediments, or earlier Cenozoic sedimentary rock; along-valley-axis groundwater flow through alluvial fans and buried channels; where watertables close to ground surface and subject to evaporation, the groundwater may become salinised
South Hedland Suite	plains of red sand with local wadis, and playas: run-off after rain forms overland flow, valley tract flows, or channel flows; flash floods result in creeks and basins rising rapidly within hours; meteoric infiltration into sand plain, recharging the aquifers therein; where watertables close to ground surface and subject to evaporation, the groundwater may become salinised
Karratha Suite	plains of red gravel with local wadis, and playas: run-off after rain forms overland flow, valley tract flows, or channel flows; flash floods result in creeks and basins rising rapidly within hours; meteoric infiltration into sand plain, recharging the aquifers therein; where watertables close to ground surface and subject to evaporation, the groundwater may become salinised

Burbunman Flat Suite	Robe and Fortescue delta plains (alluvial to deltaic plains of red sand and gravel) with local wadis: run-off after rain forms overland flow, valley tract flows, or channel flows; flash floods recharge creeks; meteoric infiltration into valley tracts recharges the perched aquifers there; lateral percolation of vadose water, by baseflow, to infiltrate into the floor of valley fills, recharging the perched aquifers of the valley fill stratigraphic pile; these sedimentary piles are unconsolidated sediments, or earlier Cenozoic sedimentary rock; along-valley-axis groundwater flow through alluvial fans and buried channels; where watertables close to ground surface and subject to evaporation, the groundwater may become salinised
Yannarie River Suite	network of inter-connected playas: run-off after rain forms overland flow, valley tract flows, or channel flows; flash floods result in creeks rising rapidly within hours, and filling of clay-lined pans; where watertables close to ground surface and subject to evaporation, the groundwater may become salinised

Pilbara Coastal Zone	
De Grey Delta Suite	complex of tidal flats and channels: groundwater flow through alluvial fans and buried channels infiltrates tidal flats; storage of freshwater in coastal sand bodies, in valley tract alluvial sediment, within river delta wedges, and in various limestone formations; seawater recharge on a daily, fortnightly or yearly basis into tidal flats, and into the margins of cheniers
Yule-Turner Delta Suite	complex of tidal flats, barrier sand ridges and channels: groundwater flow through alluvial fans and buried channels infiltrates into tidal flats; storage of freshwater in coastal sand bodies, in valley tract alluvial sediments, within river delta wedges, and in various limestone formations; seawater recharge on a daily, fortnightly or yearly basis into tidal flats, and into the margins of cheniers
Port Hedland Suite	barrier of limestone ridges with protected tidal flats, embayments, and tidal creeks: storage of freshwater in limestone formations and cheniers, which then seeps onto the tidal flat; seawater recharge on a daily, fortnightly or yearly basis into tidal flats, and into the margins of cheniers
Balla Balla Suite	broad mud-filled embayments, tidal flats, and eroding limestone barriers: storage of freshwater in limestone formations and cheniers, which then seeps onto the tidal flat; seawater recharge on a daily, fortnightly or yearly basis into tidal flats, and into the margins of cheniers
Dampier Archipelago Suite	ria coast complex of tidal flats, tidal creeks, spits/cheniers, tidal alluvial fans: along-valley- groundwater flow through alluvial fans and buried channels to infiltrate into tidal flats; storage of freshwater in valley tract calcretes, coastal sand bodies, as perched bodies in valley alluvial sediment, within alluvial fan wedges, and in various limestone formations; seawater recharge on daily, fortnightly or yearly basis into tidal flats, and into margins of cheniers

Fortescue-Robe Delta Suite	gravel-dominated barrier complex within a deltaic setting: groundwater flow through alluvial fans and buried channels to infiltrates tidal flats; storage of freshwater in coastal sand bodies, as perched bodies in valley tract alluvial sediment ribbons, within river delta wedges, and in various limestone formations; seawater recharge on a daily, fortnightly or yearly basis into tidal flats, and into the margins of cheniers
Onslow Suite	barrier beach/dune systems with barred linear lagoons: storage of freshwater in dune sand ridges, spits, and cheniers, which then seeps onto the tidal flat; seawater recharge on a daily, fortnightly or yearly basis into tidal flats, and into the margins of cheniers
Ashburton Delta Suite	complex of tidal flats, sand ridges & channels: groundwater flow through alluvial fans and buried channels to infiltrates onto tidal flats; storage of freshwater in coastal sand bodies, as perched bodies in valley tract alluvial sediment, within river delta wedges, and in various limestone formations; seawater recharge on a daily, fortnightly or yearly basis into tidal flats, and into the margins of cheniers
East Exmouth Suite	laterally extensive, insular-peninsular prograded wide tidal flat system: seawater recharge on a daily, fortnightly or yearly basis into tidal flats, and into the margins of cheniers

8.0 Flora of the Pilbara wetlands

A compilation of specimens occurring in the Pilbara Region is held at the WA Herbarium (FloraBase 1998), and records from Jessop (1981), Buckley (1982) and since some Kimberley flora extends into Pilbara wetland locations, Wheeler *et al* (1992) on the "Flora of the Kimberley" is relevant as well. The species are listed as to family, and described as to habitat occurrence. At present there is no dedicated published flora of the Pilbara..

From the literature, the following flora species are considered to be diagnostic of wetland environments in the Pilbara Region:

Rush and sedge species:

Bulbostylis barbata
Byblis liniflora
Crinium flaccidum
Cyperus bifax)
Cyperus spp (about 8 species)
Eleocharis geniculata
Eleocharis sphacelata
Eleocharis spp..
Fimbristylis spp
Nymphaea gigantea (possibly introduced)
Psilotum nudum (possibly)
Schoenoplectus dissachanthus
Schoenoplectus lateriflorus
Schoenoplectus littoralis
Triglochin spp
Typha domingensis

Woody and tree species:

Eucalyptus camaldulensis
Eucalyptus coolabah
Melaleuca glomerata
Melaleuca leucodendran
Melaleuca linophylla
Sesbania cannabina
Sesbania formosa

This section on the flora of the Pilbara wetlands is presented in four parts, viz.,

1. information from Massini (1988)
2. listings from the CALM database of wetland plants, known to occur in wetlands
3. grouping of the wetland plant species within broader wetland habitats
4. listing of priority vegetation species in the Pilbara

8.1 Information from Massini (1988)

Massini (1988) recorded more than 250 plant species from 38 wetland areas in the Pilbara region. Massini (1988) also determined species richness for the different wetland habitats such as springs, headwater streams and adjoining pools, permanent/semi-permanent pools, and so on, identified as part of that study, and found that the species richness data corroborated the physical wetland classification system. The high species richness characteristic of spring systems (average 36 species), headwater streams (average 33 species) and adjoining pools (average 39 species) largely reflects a high habitat diversity, since more species are able to survive because of the relative stability of the permanent/semi-permanent water availability and diverse habitat of these systems. Ephemeral soaks (average 9 species) with relatively flat topography, with little habitat diversity, have potential only for annual wetland plants, and species richness is low. Tidal areas have the lowest species richness (average 4 species). Habitats with the highest species richness also are the most variable in species number.

Since physiology and physiognomy of wetland plant species are related to their habitats, and the presence or absence of those species known to be confined to specific habitats can be used as indicators of certain environmental variables, Massini (1988) found some wetland species useful in differentiating between types of inland waters. In particular, analysis of the flora, and a knowledge of the physiology of specific plant species, allowed recognition of situations related to water tables, persistence and periodicity of inundation characteristic of particular inland water types (see Table immediately below).

Some of the key tree wetland species, their physiology and physiognomy, and their environmental significance are described in the Table below

Species/Genera	Physiology and physiognomy	Environmental significance and comments
Melaleuca leucadendran (the cajeput);	shallow platform root system occupying a large area, with developed aerenchyma and ability to cope with waterlogging for extended periods; it is apparently dependent on water table levels depths of between 1 and 2 m	according to bush-lore, large, thick-trunked cajeputs are indicative of permanent water; consistent with the ecophysiology, *M. leucadendran* is restricted to inland wetland types 1, 2, 3, 4
Melaleuca glomerata	shallow platform root system occupying a large area, with developed aerenchyma and ability to cope with waterlogging for extended periods; it is apparently dependent on water table levels depths of between 1 and 2 m	*M. glomerata* is restricted to inland wetland types 1, 2, 3, 4
Melaleuca linophylla	shallow platform root system occupying a large area, with developed aerenchyma and ability to cope with waterlogging for extended periods; it is apparently dependent on water table levels depths of between 1 and 2 m	*M. linophylla* were restricted to inland wetland types 1, 2, 3, 4

Eucalyptus coolabah (the coolabah)	moving flood waters, and water tables below 2 m appear to favour the growth and survival of this eucalypt	susceptible to long periods of static flooding, but can withstand drought for long periods; prefers being near water during early growth and establishment; occurs in same locations as cajebuts, with the addition of semi-permanent claypans and adjoining pools; river gums and coolabahs usually occupy distinct but overlapping zones in relation to water with coolabahs predominantly in the drier areas
Eucalyptus camaldulensis (the river gum)	moving flood waters, and water tables below 2 m appear to favour the growth and survival of this eucalypt	susceptible to long periods of static flooding, but can withstand drought for long periods; prefers being near water during early growth and establishment; occurs in same locations as cajebuts, with the addition of semi-permanent claypans and adjoining pools; river gums and coolabahs usually occupy distinct but overlapping zones in relation to water, with river gums predominantly in the wetter areas
Sesbania (*Sesbania formosa* and *S. cannabina*)	cork-like aerenchyma in the root, stem and nodules of the legumes *Sesbania formosa* and *S. cannabina* allow establishment of seedlings along high water zones and enables mature plants to survive waterlogging	*S. cannabina* is often found on steep banks cut by river or stream flow (e.g., Mulye Pool) and road verges; *S. formosa* may reach 7 or 8 m in height, and large plants are found only near permanent water (e.g., Eera Baranna)

8.2 Wetland taxa from CALM's Priority Flora List (Atkins, 1997).

The following taxa have been extracted from the Pilbara records in the Priority Flora list because they occur at or near a known wetland site (e.g., Weeli Wolli Spring), or belong to a family or genus (e.g., *Fimbristylis*) which is often associated with wetlands or have a specific name with wetland connotations.

Approximately 170 taxa were found with recorded inland wetland habitat including 9 naturalized aliens. The largest families in the survey were Cyperacea (39 spp), Myrtaceae (13spp), Mimosaceae (11spp), Poaceae (10spp), Asteraceae (10spp), Chenopodiaceae (7 spp), Schrophulariaceae (6 spp).

* Naturalized alien taxa

Species name	Habitat notes
FILICOPSIDA (Ferns)	
Adiantaceae	
Adiantum capillus -veneris	damp cliffs and floors gorges (Hamersley Range)
Ceratopteris thalictroides	near creeks, swamps, in pools or wet ledges of waterfalls
Cheilanthes brownii	in rock crevices and sometimes shallow soil near seepage areas
Cheilanthes contigua	seasonally wet soils
Ophioglossaceae	
Ophioglossum lusitanicum	shallow soil subject to flooding, amongst rocks or on streamlines
Ophioglossum polyphyllum	as above
Marsileaceae	
Marsilea drummondii	claypans, waterholes, rivers, swamps
Marsilea hirsuta	salt flats, claypans, waterholes, rivers, swamps
Marsilea mutica	pools, watercourses, mud on creek banks

Pteridaceae	
Pteris vittata	rocks and damp floors of gorges
Thelypteridaceae	
Ampelopteris prolifera	moist habitats (Hamersley Range)
MAGNOLIOPSIDA (Angiosperms)	
Aizoaceae	
Mollugo molluginea	seasonal wetlands
Trianthema triquetra	claypans, seasonal marshes
Amaranthaceae	
Amaranthus pallidiflorus	creek beds and sand along creeks
Arecaceae	
Livistona alfredii	river banks
* *Phoenix dactylifera*	river banks
Asteraceae	
* *Bidens bipinnata*	creek lines
Centipeda minima	margins of lakes, streams
Chrysogonum trichodesmoides	near watercourses
Flaveria australasica	near watercourses
Pluchea rubelliflora	seasonally wet swamps, claypans, rivers
Pluchea tetranthera	near seasonally wet claypans
* *Sonchus oleraceus*	watercourses
Sphaeranthus indicus	seasonally flooded creeks
Streptoglossa odora	near claypans
Streptoglossa tenuiflora	on mud or clay near water
Boraginaceae	
Trichodesma zeylanicum	watercourses, floodplains
Brassicaceae	
Lepidium pholidogynum	drainage channel

Byblidaceae	
Byblis liniflora	in swamps and along watercourses, sand, muddy sand skeletal soils over sandstone pavements
Caesalpiniaceae	
**Parkinsonia acuelata*	along watercourses
Campanulaceae	
Wahlenbergia queenslandica	seasonally wet depressions
Chenopodiaceae	
Atriplex cinerea ssp. rhagodioides	riverine
Dysphania glomulifera ssp eremaea	alluvial flats, river/creek banks
Dysphania plantaginella	coastal and alluvial flats
D. rhadinostachya ssp rhadinostachya	drainage lines
Halosarcia auriculata	salt marshes
Halosarcia indica ssp. leiostachya	salt marshes
Salsola kali	salt marshes
Commbretaceae	
Terminalia platyphylla	often in sand associated with creeks
Commelinaceae	
Commelina ensifolia	floodplains, seepages
Convolvulaceae	
Ipomea polymorpha	creek lines and moist depressions

Cyperaceae	
Baumea rubiginosa	Kalamina falls
Bulbostylis barbata	watercourses, low lying flats
Bulbostylis burbidgeae	cliff bases, granite
Bulbostylis turbinata	watercourses, depressions, rock holes
Cyperus betchei ssp. commiscens	river beds and sandy banks
Cyperus bifax	creek banks, floodplains
Cyperus blakeanus	claypans, creek floodplains, alluvial fans
Cyperus bulbosus	mudflats, creek banks
Cyperus concinnus	swamps, creeks, pools
Cyperus dactylotes	creek beds, damp areas
Cyperus difformis	watercourses
Cyperus iria	drainage lines, watercourses
Cyperus ixiocarpus	sandy creeks
Cyperus pygmaeus	watercourses, claypans
Cyperus rigidellus	watercourses, claypans, floodplains
Cyperus squarrosus	drainage lines, claypans
Cyperus vaginatus	pools, rivers
Eleocharis atropurpurea	along watercourses, swamps, lakes
Eleocharis dulcis	pools, billabongs, lagoons
Eleocharis geniculata	in and around watercourses, margins of permanent pools
Eleocharis sphacelata	in and around swamps, pools
Fimbristylis depauperata	seepages, swamps, along watercourses
Fimbristylis dichotoma	creek banks, claypans
Fimbristylis microcarya	claypans, swamps, watercourses, drainage lines
Fimbristylis oxystachya	swamps, red sand dunes
Fimbristylis rara	watercourses, claypans
Fimbristylis Shay Gap	sandy drainage lines
Fimbristylis sieberiana	watercourses, muddy levees
Fuirena ciliaris	swamps, claypans, pools, along watercourses
Fuirena incrassata	claypans, semi saline lakes, swamps, creeklines
Gahnia trifida	swamps, creeks
Lipocarpha microcephala	watercourses, rock holes, claypans
Schoenoplectus dissacharanthus	rivers, creeks, pools, swamps
Schoenoplectus laevis	rivers, creeks, swamps
Schoenoplectus lateriflorus	billabongs, watercourses
Schoenoplectus littoralis	pools, in and around swamps
Schoenoplectus subulatus	pools, swamps, streams
Schoenus falcatus	damp habitats

Droseraceae	
Drosera burmannii	near creeks, swamps and seepages
Drosera indica	damp areas besides creeks, swamps and seepages
Elatinaceae	
Bergia pedicellaris	clay soils usually near watercourses
Bergia trimera	damp soil
Eriocaulaceae	
Eriocaulon cinereum	wet sand, creek lines, swamps
Frankeniaceae	
Frankenia ambita	saline mud flats, tidal marshes
F. cordata	saline flats, floodplains
F. setosa	saline flats, floodplains
Goodeniaceae	
Goodenia lamprosperma	seasonally wet depressions, swamps, near watercourses
Haloragaceae	
Myriophyllum verrucosum	stagnant or slow flowing water or damp mud
Hydrocharitaceae	
Ottelia ovalifolia	stagnant or fresh running water
Vallisneria spiralis	pools
Vallisneria annua	shallow running water or ephemeral pools
Vallisneria nana	freshwater pools
Juncaceae	
Juncus kraussii	saline habitats
Lamiaceae	
Mentha australis	watercourses
Teucrium racemosum	along creeks, claypans

Lentibulariaceae	
Utricularia australis	shallow pools, lakes
Lobeliaceae	
Lobelia quadrangularis	watercourses
Lythraceae	
Rotala mexicana	swamps, shallow water
Malvaceae	
Abelmoschus ficulneus	seasonally wet areas, alluvial flats, irrigation ditches
Menispermaceae	
Tinospora smilacina	riverine flats
Mimosaceae	
Acacia ampliceps	around watercourses, salt flats
Acacia citrinoviridis	river/ creek lines
Acacia coriacea ssp pendens	around rivers and creeks
Acaica farnesiana	river/creek lines
Acacia holosericea	often around rivers and creeks
Acacia pyrifolia	drainage lines
Acacia spondylophylla	drainage lines, rocky ground around watercourses
Acacia stenophylla	drainage lines
Acacia stipuligera	floodplains, sand dunes
Acacia trachycarpa	watercourses
Neptunia dimorphantha	near creeks rivers
Molluginaceae	
Glinus lotoides	edge of billabongs, watercourses and other wetlands
Glinus oppositifolius	watercourses
Glinus orygioides	claypans
Myoporaceae	
Eremophila maculata ssp brevifolia	river floodplains, claypans
Eremophila. maculata ssp maculata	claypans , floodplains, dongas
Myrtaceae	

Eucalyptus camaldulensis	watercourses
Eucalyptus Marandoo aff. coolibah var. rhodoclada M Trudgen 10362	no information available
Eucalyptus microtheca (Coolabah)	seasonally waterlogged flats, along watercourses, around swamps
Eucalyptus papuana (Ghost Gum)	floodplains and watercourses
Eucalyptus patellaris	levees and alluvial flats
Eucalyptus victrix	floodplains, flats
Melaleuca acacioides	saline habitats including salt marshes
Melaleuca bracteata	small watercourses
Melaleuca argentea	watercourses, swamps, sand, sometimes clay
Meleuca glomerata	rocky river beds, low lying areas
Melaleuca lasiandra	creek lines
Melaleuca linophylla	creek lines
Melaleuca nervosa	watercourses, damp depressions
Najadaceae	
Najas graminea	fresh water
Najas marina	fresh or brackish waters
Najas tenuifolia	fresh or brackish, still or slow flowing water
Nyctaginaceae	
Boerhavia repleta	creek lines
Nymphaceae	
Nymphaea gigantea	pools (possibly introduced)
Onagraceae	
Ludwigia perennis	edges of creeks, pools and swamps
Papilionaceae	
Indigofera hirsuta	creeklines swamps
Sesbania cannabina	areas subject to seasonal waterlogging
Sesbania formosa	creeks, rivers margins of swamps
Vigna lanceolata	watercourses, seasonally waterlogged areas
Zornia muelleriana	near creeks
Poaceae	
* *Cenchris ciliaris*	variety of habitats including watercourses
Dactyloctenium radulans	marshes, seasonal swamps, floodplains
Diplachne fusca	claypans, irrigation channels

Elytrophorus spicatus	in damp soil beside rivers
Phragmites karka	watercourses, seepages
Sporobolus actinocladus	coastal samphire flats
Sporobolus australasicus	floodplains , coastal flats
Sporobolus mitchelli	floodplains
Sporobolus virginicus	salt marshes
Urochloa gilesii	clay in watercourses
Passifloraceae	
**Passiflora foetida var. hispida*	river/creek banks
Polygonaceae	
Persicaria attenuata	besides creeks and rivers
** P. lapathifolia*	floodplains, margins of pools
Portulacaceae	
Calandrinia quadrivalvis	near creeks and swamps
Potamogetonaceae	
Potomageton crispus	fresh flowing water
Potamogeton javanicus	lakes creeks
Potamageton pectinatus	as above
Potamageton tricarinatus	still or slow flowing fresh water
Sapindaceae	
Atalaya hemiglauca	creek lines, floodplains
Dodonea lanceolata var. lanceolata	watercourses
Scrophulariaceae	
Mimulus clementii	no information available
M. gracilis	claypans wet areas
M. uvedaliae	wet areas
Peplidium muelleri	moist red clay or sand
Peplidium sp C (NT Burbidge & A Kanis 8158)	margins of creeks and lakes
Peplidium sp. E (A S Weston 12768)	near fresh pools and springs
Tilliaceae	

Corchorus sericeus	watercourses
Sterculiaceae	
* *Melochia pyramidata*	rivers
Stylidiaceae	
Stylidium desertorum	seasonal wetlands
Stylidium floodii	wet depressions
Typhaceae	
Typha domingensis	freshwater swamps, creeks, rivers

Note that the suite of halophytes inhabiting playas, and grasses and annuals (especially the Asteraceae and Portulacaceae) inhabiting barlkarras has not been investigated.

There are 8 species of mangrove and 11 species of salt marsh plants that inhabit the intertidal coastal zone. The mangroves are: *Avicennia marina, Aegialitis annulata, Aegiceras corniculatum, Bruguiera exaristata, Ceriops tagal, Excoecaria agallocha, Osbornia octodonta,* and *Rhizophora stylosa* . The saltmarsh plants are: *Marsilea hirsuta, Dysphania plantaginella, Halosarcia auriculata, H. indica ssp. leiostachya, Salsola kali, Frankenia ambita, Frankenia cordata, F. setosa, Juncus kraussii, Sporobolis actinocladus, S. australasicus,* and *S. virginicus*.

8.3 Species grouped according to habitat

The Table below present the species listing in group of similar habitat, so that there can be an appreciation of the various species according to habitat occurrence.

Habitat type	**List of main wetland species in the habitat**
Inland wetlands	
Lakes, playas, sumplands, and damplands	*Ceratopteris thalictroides, Marsilia drummondii, M. hirsuta, Trianthema triquetra, Pluchea rubelliflora, P. tetranthera, Streptoglossa odora, Byblis liniflora, Wahlenbergia queenslandica, Ipomea polymorpha, Cyperus blakeanus, C. concinnus, C. pygmaeus, C. rigidellus, C. squarrosus, C. vaginatus, Eliocharus atropurpurea, E. dulchis, E. sphacelata, Fimbristylis depauperata, F. dichotoma, F. microcarya, F. oxystachya, F. rara, Fuirira ciliaris, F. incrassata, Gahnia trifida, Lipocarpha microcephala, Schoenoplectus dissacharanthus, S. laevis, S. lateriflorus, S. littoralis, S. subulatus, Schoenus falcatus, Drosera burmannii, D. indica, Goodenia lamprosperma, Vallisneria spiralis, V. annula, V. nanna, Teucrium racemosum, Utricularia australis, Rotala mexicana, Abelmoschus ficulneus, Glinus orygioides, Eremophila maculata ssp brevifolia, E. maculata ssp maculata, Eucalyptus microtheca, Melaleuca argentea, Ludwigia perennis, Sesbania formosa, Dactyloctenium radulans, Diplachne fusca, *Persicaria lapathifolia, Potamogeton javanicus, P. pectinatus, P. tricarinatus, Mimulis gracilis, Peplidium sp E (A S Weston 12768), Stylidium floodii, S. desertorum, Typha domingensis, Nympheae gigantea, Indigofera hirsuta, Calandrinia quadrivalvis,*
Rivers, creeks and wadis	*Ceratopteris thalictroides, ophioglossum lusitanicum, O. polyphyllum, Marsilea drummondii, M. hisuta, M. mutica, Pteris vittata, Amaranthus pallidiflorus, # Livistona alfredii, *Phoenix dactylifera, *Bidens bipinnata, Centipeda minima, Chrysogonum trichodesmoides, Flaveria australasica, Pulchea rubelliflora, *Sochus oleraceus, Sphaeranthus indicus, Trichodesma zeylanicum, Lepidium pholidogynum, Byblis liniflora, Parkinsonia acuelata, Atriplex cinerea ssp. rhagodioides, Dysphania glomulifera ssp. eremea, D. rhadinostachya ssp. rhadinostachya, Terminalia platyphylla, Commelina ensifolia, Ipomea polymorpha, Bulbostylis barbata, B. turbinata, Cyperus betchei spp.commiscens, C. bifax, C. blakeanus, C. bulbosus, C. concinnus, C. dactylotes, C. difformis, C. iria, C. ixiocarpus, C. pygmaeus, C. rigidellus, C. squarrosus, C. vaginatus, Eliocharus atropurpurea, E. geniculata, Fimbristylis depauperata, F. dichotoma, F. microcarya, F. rara, #F. Shay Gap, F. sieberiana, Fuirira ciliaris, F. incrassata, Gahnia trifida, Lipocarpha microcephala, Schoenoplectus dissacharanthus, S. laevis, S. lateriflorus, S. littoralis, S. subulatus, Schoenus falcatus, Drosera burmannii, D. indica, Bergia pedicellaris, Eriocaulon cinereum, Goodenia lamprosperma, Myriophyllum verrucosum, Ottelia ovalifolia, Vallisneria spiralis, V. annua, Mentha australis, Teucrium racemosum, Lobelia quadrangularis, Rotala mexicana, Abelmoschus ficulneus, Acacia ampliceps, A, citrinoviridis, A. coiacea ssp. pendens, A. farnesiana, A. holosericea, A. pyrifolia, A. spondilophylla, A. stenophulla, A. trachycarpa, Neptunia dimorphanta, Glinus lotoides, G. oppositifolius, Eucalyptus camaldulensis, E. microtheca, E. papuana (ghost gum), E. patellaris, Melaleuca bracteana, M. argentea, M. glomerata, M. lasiandra, M. linophylla, M. nervosa, Najas graminea, N.*

	*marina, N. tenuiflora, Boerhavia repleta, , Ludwigia perennis, Indigofera hirsuta, Sesbania cannabina, S. formosa, Vigna lanceolata, Zornia muelleriana, *Cenchris ciliaris, Elytrophorus spicatus, Phragmites karka, Urochloa gilesii, *Passiflora foetida var. hispida, Persicaria attenuata, Calandrinia quadrivalvis, Potamogeton crispus, P. javanicus, P. pectinatus, P. tricarinatus, Atalaya hemiglauca, Dodonea lanceolata var. lanceolata, Peplidium sp C (N T Burbidge & A Kanis 8158), Peplidium sp E (A S Weston 12768), corchorus sericeus, Melochia pyramidata, Stylidium desertorum, Typha domingensis,*
Floodplains and barlkarras	*Ophioglossum lusitanicum, O. polyphyllum, Streptoglossa tenuifloraTrichodesma zeylanicum, Dysphania glomulifera ssp eremea, D. plantaginella, commelina ensifolia, Bulbostylis barbata, Cyperus bifax, C. blakeanus, C. bulbosus, C. rigidellus, Abelmoschus ficulneus, Tinospora smilacina, A. ampliceps, A. stipuligera, Eremophila maculata ssp brevifolia, Eremophila maculata ssp maculata, Eucalyptus microtheca, E. papuana (ghost gum), E. patellaris, E. victrix, Dactyloctenium radulans, Sporobolus australasicus, S. mitchelli, *Persicaria lapathifolia, Atalya hemiglauca, Peplidium muelleri, Frankenia cordata, F. setosa*
Miscellaneous (e.g., waterfalls, seepage, granite hollows)	*Cheilanthes brownii, Ceratopteris thalictroides, Adiantum capillus-veneris, Ampelopteris prolifera, Bulbostylis burbidgeae, B. turbinata, Baumea rubiginosa, Lipocarpha microcephala*
Not differentiated	*Cheilanthes contigua, Mollugo molluginea,Bergia trimera, Eucalyptus Marandoo aff. coolibah var. rhodoclada M. Trudgen 10362, # Mimulus clementii, M. uvedaliae,*
Coastal Marine wetlands	
Salt flats	*Marsilea hirsuta, Dysphania plantaginella, Halosarcia auriculata, H. indica ssp. leiostachya, Salsola kali, Frankenia ambita, Frankenia cordata, F. setosa, Juncus kraussii, Sporobolis actinocladus, S. australasicus, S. virginicus,*
Mangals	*Avicennia marina, Aegialitis annulata, Aegiceras corniculatum, Bruguiera exaristata, Ceriops tagal, Excoecaria agallocha, Osbornia octodonta, Rhizophora stylosa*

8.4 Listing of priority vegetation species in the Pilbara

The database of the Department of Conservation and Land Management was accessed to determine what species are rare or assigned as priority flora in the Pilbara Region. There 28 such species of flora in the Region (Atkins, 1997; FloraBase, 1998). These are listed below together with their level of priority, and where they occur. Figure 11 shows the location of these sites.

	Species name	Priority Level	Location
No.	**Priority 1 species**		
1	*Barbula ehrenbergii*	1	Dales Gorge, Hamersley Ranges
2	*Eremophila coacta*	1	16.1 km Nw of Ashburton Downs on Kooline road
3	*Eremophila rigens*	1	20.2 km SW of Ashburton Downs
4	*Eremophila spongiocarpa*	1	20 km E of Cowra Outcamp of Mulga Downs Station
5	*Eucalyptus marandoo (aff. coolibah var. rhodoclada)*	1	Marandoo corridor, Mindi Springs
6	*Fimbristylis "Shay Gap"*	1	Shay Gap; inhabits sandy drainage line
7	*Goodenia nuda*	1	Weeli Wolli, Roy Hill; Mt Stuart
8	*Mimulus clementii*	1	between Ashburton and DeGrey Rivers
9	*Myriocephalus aff. nudus*	1	12 ml S of Yannarie river on N.W.C. Hwy; 4.1 km NW along Grt. Nthn. Hwy from Mt. Robinson turnoff, Hamersley Ranges
	Priority 2 species		
10	*Dicladanthera glabra*	2	Bee Gorge & Wittenoom Gorge, Hamersley Range; Robe River
11	*Euphorbia drummondii ssp. "Pilbara"*	2	Tambrey Station, Mt Edgar, Lyndon Station, Millstream
12	*Goodenia stellata*	2	Hamersley Range NW of Tom Price and Newman
13	*Olearia fluvialis*	2	Wittenoom Gorge
14	*Olearia mucronata**	2	Turner syncline E of Paraburdoo

15	*Stylidium weeliwolli*	2	Weeli Wolli Springs, Weeli Wolli Creek
	Priority 3 species		
16	*Bulbostylis burbidgeae*	3	Mt Edgar, Gorge Creek, Abydos-Woodstock
17	*Desmodium campylocaulon*	3	18 km WNW of Newman; ca Hooley Station, Mulga Downs Hmstd and Warrawagine Station
18	*Eriachne tenuiculmis*	3	Gregory Gorge, ca CRRIA Fortescue Rv Bridge, W of Hamersley Hmstd, Weelamurra Ck, Hamersley Range, Dampier Archipelago
19	*Fimbristylis sieberiana*	3	Hamersley Range, Millstream; inhabits Kalaminna Falls, muddy leve bank, edge of watercourses
20	*Fuirena incrassata*	3	Oakover River, Wandanya, Deep Creek
21	*Glycine falcata*	3	30 km W of Mulga Downs Homestead
22	*Hibiscus brachysiphonius*	3	20 km E of Millstream, 30 km W of Tom Price; Karratha; ca Yanyare Rv, Dampier
23	*Rhynchosia sp.*	3	Deepdale, Robe River; Yathala Well; ca Yarraloola Hmstd.; Bee Gorge, Hancock Gorge, Hamesley Range;ca Quarry Hill; ca
24	*Triumfetta appendiculata*	3	Fortescue River to Karratha
25	*Triumfetta maconochiena*	3	Woodstock Station, Harding River, Ruddall River, Newman, Weeli Wolli Creek
26	*Wurmbia saccata*	3	Barlee Range Nature Reserve
	Priority 4 species		
27	*Livistonia alfredii*	4	Millstream, Cave Creek; inhabits watercourses
	Rare species		
28	*Lepidium catapycnon*	R	Weeli Wolli, Wittenoom Gorge, Hamersley Range, Newman

9.0 Wetlands of importance to waterbirds and other vertebrate fauna in the Pilbara

Waterbird and other fauna data are sparse for arid zone wetlands due to their remoteness, the episodic recharge of the wetlands and general lack of survey effort. In particular, little effort has been made to assess breeding in many surveys. Despite this, many arid zone wetlands are known to be both nationally and internationally important for waterbirds (e.g. Watkins 1993, Kingsford and Halse 1998). Many wetlands require considerably more survey work over a range of seasons to assess their fauna values, particularly with respect to non-waterbird data and breeding. Only wetlands with notable values are presented in this report. Further, well-timed survey work will no doubt highlight the importance of many other wetland areas.

This compilation comprises the findings of Lane and Lynch (1996) on vertebrate fauna and a current analysis of Birds Australia and Australasian Ecological Services data bases on waterbirds (1981-1999), with some additional information from the Register of the National Estate Data Base, Garnett (1992) and Kingsford and Halse (1998). The compilation also incorporates a selection of personal communications and unpublished data. Few waterbird data exist for wetlands in northern Western Australia, and the arid zone generally, making it difficult to compare and understand the relative importance of wetlands in these areas. Where possible, comparisons are made within arid zone wetlands. In some cases, to help provide some perspective, these wetlands are also compared with wetlands evaluated for waterbird usage in southern Western Australia by Raines *et al.* (unpub.). However, only limited parameters are used, viz., species richness, variety of breeding species, numbers or variety of species listed under international migratory bird agreements and total numbers of individual waterbirds.

A wetland is considered to be of international importance if it supports more than 1% of the population of a given waterbird species in the Asian-Australasian Flyway and of national importance if it supports more than 1% of the Australian population, according to the criteria developed by Watkins (1993).

The information below is presented in the following format:

- name and location of the wetland
- location of values:
- conservation values:
- special listings:

Barlee Range Wetland System (including Kookhabinna Gorge and Yadjiyugga Claypan)

Location of Values: The Barlee Range Wetland System includes Yadjiyugga Claypan, Kookhabinna Gorge and associated floodplain and claypans in the Barlee Range Nature Reserve. The Barlee Range Nature Reserve is in the northern part of the range between Henry River and Wannery Creek and upper reaches of Wongide, Kookhabinna and Discovery Creeks (Register of the National Estate Data Base).

Yadjiyugga Claypan is a semi-permanent basin in the NW of the Barlee Range Nature Reserve, 23 04S, 115 48E (Lane and Lynch 1996). The Kookhabinna Gorge wetlands are a series of 13 or more permanent to semi-permanent pools along the narrow steep-sided gorges of the intermittent Kookhabinna creek widening into a sandy channel reach with a narrow active floodplain below Goordeman Pool. The system is 200 km WSW of Tom Price. Upstream limit 23 15S, 116,01E and down stream limit 23 04S,116 02E (Lane and Lynch 1996).

Conservation Values: The wetland habitats of the Barlee Range Wetland System provide fresh permanent and semi-permanent water sources to waterbirds and other wildlife and are an episodic focus for waterbirds. The system supports 23 species of waterbird. To help put this figure in some perspective, the Barlee Range Wetland System would rank in the top 20% of wetlands of importance in Western Australia for species richness if it were compared to wetlands evaluated in southern Western Australia. The system supports the Great Egret that is listed under two international migratory bird agreements (S. van Leeuwen unpub; Raines unpub.).

The area is a refuge for the Clamorous Reed Warbler (Lane and Lynch 1996).

The Orange Horseshoe Bat (*Rhinonicteris aurantius*) uses the Kookhabinna Gorge area. This species is listed under *the Western Australian Wildlife Conservation Act 1950* (Schedule 1) as fauna that is rare or likely to become extinct (Lane and Lynch 1996).

An isolated population of the skink *Lerista flammicauda* exists in the wetland system (Lane and Lynch 1996).

The population of the frog *Neobatrachus sutor* found at the Barlee Range is 300 km east of the northern part of the species range. The frog *Neobatrachus aquilonius* has only been recorded in one other location in the west Pilbara. The gorges are probably important to the frog *Pseudophryne douglasi* that is only found in permanently wet/damp streams in gorges. The population in the Barlee Range is therefore likely to be isolated (P. Kendrick unpub.).

The area supports a diverse range of fauna species. There are 46 species of bird (including waterbirds), 11 species of bat including the Little Red Flying Fox (*Pteropus scapulatus*), the Olive Python (*Liasis olivaceus*), five species of frog and seven species of freshwater fish (recorded from Kookhabinna, Ghanji Spring and Wongida Creeks) (Lane and Lynch 1996; Kendrick unpub.).

An undescribed species of *Cassytha* occurs in the Kookhabinna Gorge and a new species of nancy lily (Wurmbia sp.) is found only in the gorges of the Barlee Range (Lane and Lynch 1996).

The wetland system is an outstanding example of a well watered gorge environment; such systems are rather unusual in the Gascoyne bioregion (Lane and Lynch 1996)

Yadjiyugga Claypan is a wooded fresh water claypan that is probably unique to the Gascoyne bioregion (Lane and Lynch 1996).

Yadjiyugga Claypan has significance to Australian Aboriginal Peoples. It has had considerable use in the past. Numerous Aboriginal artifacts and implements were formerly present, many having been reportedly broken or removed (Lane and Lynch 1996).

Special Listings: Yadjiyugga Claypan, Kookhabinna Gorge and the downstream area described above, are entirely within the Barlee Range Nature Reserve and the Reserve is listed on the Register of the National Estate (status Registered) and in the Directory of Important Wetlands (Register of the National Estate Data Base; Lane and Lynch 1996).

Carawine Pool

Location of Values: A permanent pool on the Oakover River 140 km ESE of Marble Bar, 21 28S, 121 03E (Australian Travelers' Atlas 1983).

Conservation Values: This wetland is likely to be a refuge for waterbirds in the dry season. It supports a large variety of birds (at least 61 species) including at least 15 species of waterbird. Two of these are listed under international treaties (R.A.O.U. and A.E.S. data bases; K. Coate pers. comm.).

This wetland is a text book example of a Permian Paterson Formation showing glacial pavements and glacial striae (Register of the National Estate Data Base).

Special Listings: Carawine Pool is listed on the Register of the National Estate (status Indicative) (Register of the National Estate Data Base).

De Grey River Wetland System

Location of Values: From the confluence of the Oakover and Nullagine Rivers to the Indian Ocean near Poissonnier Point. It is about 160 km long (starting from above the tidal influence), with river bed (sand/water) typically 500 m wide and has more than 30 named river pools. The wetland system contains 4500 ha of tidal wetlands including about 500 ha of tidal mudflats. It also contains 1400 ha of mangroves, 2500 ha of coastal flats and 22 km of river and estuary within tidal reach. It is 15 km SSW of Goldsworthy and 60 km E of Port Hedland, 19 58S – 20 42S, 119 10E – 120 35E (Lynch and Lane 1996).

Conservation values: The permanent pools together constitute a significant drought refuge to wildlife, particularly fresh water fish and waterbirds (Lane and Lynch 1996). The permanent pools support at least 20 species of waterbird. To help put this figure in some perspective, the De Grey Wetland System would rank in the top 25% of wetlands of importance to Western Australia for species richness if it were compared to wetlands evaluated in southern Western Australia (Lane and Lynch 1996; Raines unpub). The mangrove and tidal flats are also very rich in bird life (K. Coate pers. comm.).

The wetland system is a good example of a major river system in the bioregion, and includes the longest permanent river pools and largest shallow estuary in northern Western Australia (Lane and Lynch 1996).

Many of the pools were valuable to the Australian Aboriginal Peoples because of their food resources (Lane and Lynch 1996). The Coolenar-Triangle Pools are also used extensively as rest stops and camping spots by tourists travelling to and from mid northern Western Australia and the Kimberley (Lane and Lynch 1996).

Special Listings: The De Grey River Wetland System is listed in the Directory of Important Wetlands (Lane and Lynch 1996).

Duck Creek Gorge

Location of Values: 7 km E of Mount Stuart in the Ashburton District, 22 28S, 116 08E (Register of the National Estate Data Base; Australian Travelers' Atlas 1983).

Conservation Values: The Duck Creek Gorge has exceptional outcrops of dolomite with nine depositional faces exposed. It is stromatolitic in places. This geological formation has great scientific and research value (Geological Society of Australia cited in the Register of the National Estate Data Base).

Special Listings: The gorge is listed on the Register of the National Estate (status Indicative) (Register of the National Estate Data Base).

Fortescue Marshes Wetland System

Location of values: Also known as Roy Hill Marshes, the wetland is an almost contiguous floodplain (lakes, marshes, pools) in the middle reaches of the Fortescue River including Powellinna, Gnalka Gnoona, Gidyea, Chaddelinna, Mungthannannie, Cook and Moorimoordinia Pools. The wetland system is 10 km N of Wittenoom, immediately W of Roy Hill Homestead, 22 05S – 22 37S, 118 06E – 119 59E (Lane and Lynch 1996; Register of the National Estate Data Base).

Conservation Values: The wetland system supports at least 22 species of waterbird. of which five species breed. In addition 5,000-10,000 waterbirds have been recorded there. To help put these facts into some perspective, this wetland system would rank in the top 20% of wetlands of importance in Western Australia for species richness if compared to wetlands evaluated in southern Western Australia. Similarly it would rank in the top 15% for variety of breeding species and in the top 5%-10% for numbers of individual waterbirds counted in any one survey (Lane and Lynch 1996; Raines unpub.). It is one of only 68 wetlands in arid Australia where 10,000 or more waterbirds have been recorded (Kingsford and Halse 1998).

It is one of the only two breeding localities for the Great Egret in northern Western Australia. The Great Egret is listed under two international migratory bird agreements (Lane and Lynch 1996). It is also one of only two inland breeding colonies of Australian Pelicans. The site is significant for breeding in both Australian Pelican and Black Swan. It is notable for numbers of Grey Teal and Eurasian Coot (Lane and Lynch 1996). The wetland system is a good example of an extensive, inland floodplain system, which is irregularly inundated. It is a unique wetland landform in Australia (Lane and Lynch 1996).

In the far east of the site there is a 'native' well (Moorimoordinia), giving the area some cultural significance (Lane and Lynch 1996).

Special Listings: The Fortescue Marshes Wetland System is listed in the Directory of Important Wetlands and most of this wetland system is listed on the Register of the National Estate (status Indicative) (Lane and Lynch 1996; Register of the National Estate Data Base).

Karijini Gorges Wetland System (Hamersley Range)

Location of Values: A series of permanent spring fed pools in the narrow gorges of Karijini National Park (previously Hamersley Range NP), Hamersley Range. These include, from south to east, Munjina, Dales, Yampire, and Kalamina Gorges, a complex of linked gorges (Joffre, Hancock, Weano, Red and Knox Gorges) and parts of Hamersley Gorge and Range Gorge. The nearest gorge (Knox) is 15 km S of Wittenoom, the furthest (Munjina) is 45 km SE of Wittenoom; 22 13S – 22 28S, 118 00E – 118 44E (Lane and Lynch 1996).

Conservation Values: The Karijini Gorges Wetland System is a refuge for disjunct flora and rare fauna and an important permanent source of water to wildlife (Lane and Lynch 1996; Register of the National Estate Data Base). The wetland supports a large range of fauna including 47 species of bird (16 species of waterbird and breeding in at least one species), at least five species of bat including Ghost Bat (*Macroderma gigas)* the Common Rock Rat (*Zyzomys argurus*), three species of frog and six species of fish (Lane and Lynch 1996; R.A.O.U. and A.E.S. data bases). An isolated population of the odonate

Nososticta liveringa (a south Kimberley species) is found in the gorges (Lane and Lynch 1996). The Karijini Gorges Wetland System is an outstanding example of gorge pools and streams (Lane and Lynch 1996). Rushbeds and permanent riffles (due to continuous flow from springs) are rare in river pools in the Pilbara bioregion (Lane and Lynch 1996). Evidence of occupation by ancestors of the Panyjima, Innawonga and Kurrama Aboriginal Peoples dates back more than 20,000 years and includes many notable paintings (Lane and Lynch 1996).

Between 30,000 – 40,000 tourists visit gorges in the Karijini National Park each year (Lane and Lynch 1996).

Special listings: The wetland system is listed on the Register of the National Estate (status Registered) and is listed in the Directory of Important Wetlands (Register of the National Estate Data Base; Lane and Lynch 1996).

Balla Balla mangroves and tidal flats

Location of Values: Mangroves and associated tidal flats east and west of the Balla Balla River from Whim Creek to Roebourne. Balla Balla river mouth 20 42S, 117 45E, (K. Coate pers. comm.; Travelers' Atlas of Western Australia 1983).

Conservation Values: Numerous ramifying tidal channels extending landward from the sub-littoral zone carry tidal water to the interior. These large areas support extensive mangrove thickets and terrains of algal mat in very good condition (Register of the National Estate Data Base; K. Coate pers. comm.). These wetland areas support a high diversity of bird life, particularly wetland and mangrove dependent species (K. Coate pers. comm.).

Special Listings: These wetland areas are included within a larger area nominated for the Register of the National Estate titled 'Mary Anne Island to Cape Keraudren Coastal Margin' (status Indicative) (Register of the National Estate Data Base).

Millstream Wetland System

Location of Values: This wetland comprises about 20 km of river bed of the Fortescue River including four permanent river pools (Deep Reach, Crossing, Livistona and Palm Pools) interconnected by permanent flowing channels and a spring-fed pool (Chinderwarriner) that flows to the river through a marshland. The system is 80 km E of Pannawonica and 90 km S of Roebourne at 21 35S, 117 05E (Lane and Lynch 1996).

Conservation Values: The Millsteam Wetland System supports 38 species of waterbird of which 8 species breed. To help put these facts into some perspective, this wetland system would rank in the top 5% of wetlands of importance in Western Australia for species richness if compared to wetlands evaluated in southern Western Australia. Similarly it would rank in the top 10% for variety of breeding species (Lane and Lynch 1996; Raines unpub.).

One of the few known isolated breeding populations of both the Black Bittern and Purple Swamphen in the Pilbara occur at Millstream (Lane and Lynch 1996).

The wetland system also supports a major colony of Black Flying Fox (*Pteropus alecto*), as well as *P. scapulatus,* 108 species of bird (including the 38 species of waterbird), a rich fish fauna (9 species) and a number of endemic species of insect including 29 species of dragonfly and damselfly (Register of the National Estate Data Base; Lane and Lynch 1996)

The Millstream Fan Palm (*Livistona alfredii*), is a relic of a humid tropical palaeoclimate in this area. It is an endemic to northern Western Australia and its main occurrence is at Millstream (Lane and Lynch 1996).

Overall this wetland is a significant area of isolated habitat for wetland flora and fauna, some species of which do not occur, or are rare, elsewhere in northern Western Australia. The wetland system supports an endemic palm and endemic insects (Lane and Lynch 1996).

The wetland system is an outstanding example of a system of permanent river pools and springs in the semi-arid tropics and the best known in northern Western Australia (Lane and Lynch 1996).

The site is especially significant to Australian Aboriginal Peoples, due to permanent water and food resources, its significance reaching people in the western and central deserts (Lane and Lynch 1996).

This system is also a very popular tourist destination (Lane and Lynch 1996).

Special Listings: The Millstream Wetland System lies in the Millstream National Park which is listed on the Register of the National Estate (status Registered) and is listed in the Directory of Important Wetlands (Register of the National Estate Data Base; Lane and Lynch 1996).

Marree Pool
Location of values: Permanent pool on the Maitland River half a kilometre upstream (south) of its intersection with the North West Coastal Highway, 25 km SW of Karratha, 20 50S, 116 40E (K. Coate pers. comm.; Australian Travelers' Atlas 1983).

Conservation Values: This permanent pool supports an abundance of bird life (K. Coate pers. comm.).

Special Listings: none.

Sherlock River Pool
Location of Values: At the intersection of the Sherlock River and the North West Coastal Highway, 50 km SE of Roebourne, 20 56S, 117 35E (K. Coate pers. comm.; Australian Travelers' Atlas 1983).

Conservation Values: A permanent river pool that supports an abundance of bird life including a variety of waterbirds (K. Coate pers. comm.).

Special Listings: none.

Weeli Wolli Springs
Location of Values: 7 km east of eastern boundary of the Karijini National Park (Australian Travelers' Atlas 1983).

Conservation Values: An oasis in an arid landscape (JR).

Special Listings:

10.0 The aquatic invertebrate fauna in the Pilbara Region, and their biogeography

10.1 Introduction

Whilst previous surveys on aquatic invertebrates to date have been concentrated in the Kimberley region, several general studies have been conducted across the Pilbara region (Massini, 1988; Massini and Walker, 1989; Kay *et al.,* 1999; Smith *et al.*, 1999). Detailed investigations of the aquatic flora and fauna at sites on the Fortescue River (Dames and Moore, 1975; 1984) and Robe River (Ecologia and Streamtec, 1992; Streamtec, 1998) have also been undertaken. However, the aquatic invertebrate fauna in northwestern Australia is still poorly known, and the biology, ecology and taxonomy of many groups within the region is still poorly understood.

For comparisons between the Pilbara aquatic invertebrate fauna and elsewhere in Western Australia, throughout this section of the report, reference is made to three Australian zoogeographic regions: the northern coastal fringe (Torresian); the interior (Eyrean); and the east and south coasts (Bassian).

10.2 Major taxa collected in the Pilbara.

Kay *et al.* (1999) conducted a broad-scale survey of 51 sites along rivers in north western Australia between August 1994 and October 1995. A total of 90 taxa were collected, most identified only to family level. The results of this survey found that family richness decreased with increasing latitude, being highest in the Kimberley (74 taxa) and lowest in the in the Gascoyne (59 taxa). The fauna was dominated by insects. About 30% of taxa occurred at most sites, while the remaining 70% had a widespread, but patchy distribution. The mayfly families Baetidae and Caenidae, odonate families Coenagrionidae and Libellulidae, trichopteran families Leptoceridae and Ecnomidae and, to a lesser extent, the hemipteran family Corixidae were collected from most sites and were the most frequently occurring groups. Two families, the Atayidae (Decapoda) and Gerridae (Hemiptera) are restricted to northern Australia (Smith *et al.*, 1999).

10.2.1 Molluscs (Snails, Limpets and Mussels)

Three families of freshwater mussels (Bivalvia) occur throughout mainland Australia. They are typically found semi-buried in shallow water habitats where there is a fine-grained substrate. Representatives from each of these families were recently collected from sites in the Pilbara (Kay *et al.*, 1999). The Corbiculidae and Sphaeridae each contain widespread species although the Corbiculidae is unknown from southwestern Australia (Williams, 1980). The Hydriidae occur across the northern, eastern and southwestern regions of mainland Australia.

Freshwater snails (Gastropoda) are also generally widespread in Australia. Five families are known from the Pilbara region. The Lymnaeidae and Planorbidae are widespread in Australia. The Ancylidae and Physidae are abundant in southeastern and southwestern Australia. *Physa acuta*, a species introduced by European settlers, is the only physid recorded from Australia and appears to be actively spreading (Davis and Christidis, 1997). Thiaridae is well represented in northern and eastern Australia.

10.2.2 Crustacea

While most species of Crustacea are marine, those occurring in inland waters are from broad selection of groups that occupy an extremely wide range of habitats. Crustaceans belonging to three major taxa, the Conchostraca, Isopoda and Decapoda (Atayidae), were recently collected during broad-scale surveys of the Pilbara (Kay *et al.*, 1999)

The Conchostraca (clam-shrimps) occur widely throughout mainland Australia, but are generally uncommon animals and their appearance is sporadic (Williams, 1980). They are able to colonise the ephemeral habitats of the north-west by possessing eggs resistant to desiccation and by developing rapidly to a sexually mature stage.

The majority of Australian isopods belong to the Phreatoicidea. Species diversity and abundance of this group is greatest in southern Australia and Tasmania. Phreatoicids have only recently been recorded from just a few sites in the Northern Territory, Kimberley and Pilbara regions (Knott and Halse, 1999). Isopods other than phreatoicids are everywhere relatively rare animals (Williams, 1980).

The Decapoda include the larger, more robust shrimps, prawns and crabs. Atayid shrimps are mostly restricted to fresh water away from the coast and although most common in eastern Australia, they have been collected from every state in Australia (Williams, 1980).

10.2.3 Ephemeroptera (Mayflies)
Across the Australian mainland larval ephemeropterans appear to require permanent, fresh water habitats. The larvae of numerous ephemeropteran species occur in the coastal streams of the east coast of Australia where they are most abundant in cool, clear-water conditions (Peters and Campbell, 1991). There are few species in South Australia and Western Australia where they are restricted to the wetter southwestern corner. However, representatives from three of the nine Australian ephemeropteran families occur in northwestern Australia (Leptophlebiidae, Baetidae and Caenidae).

10.2.4 Odonata (Dragonflies and Damselflies)
Australia has a rich odonate fauna with in excess of 280 species and subspecies. Diversity and abundance is greatest in tropical or sub-tropical regions with a considerable number of endemic species (Williams, 1980). Seven of the 17 Australian families are represented in the Pilbara.

10.2.5 Hemiptera (True bugs)
The Australian waterbug fauna contains a high level of endemic species in Old World genera mixed with a number of widespread South East Asian species (Lansbury, 1981). Both are most strongly represented in the Torresian province, and extend more diffusely into other parts of Australia (Carver *et al.*, 1991). Species from 12 of the 15 hemipteran families known to occur in association with Australian inland waters have been collected in northwestern Australia. They include semi-aquatic shore dwelling forms (Ochteridae), surface film dwelling forms (Gerridae, Hebridae, Hydrometridae, Mesoveliidae, Veliidae) and truly aquatic forms (Belostomatidae, Corixidae, Naucoridae, Nepidae, Notonectidae, Pleidae). The adults of many of these species are strong fliers which accounts for their widespread occurrence across the Australian mainland.

10.2.6 Coleptera (Beetles)

The Coleptera are an enormous group with over a quarter of a million species described so far (Williams, 1980). Aquatic coleopterans include both larval and adult forms found in a wide variety of aquatic habitats throughout Australia. Twelve beetle families in Australia are mainly or entirely aquatic. A few additional families are mostly terrestrial but have some aquatic species. Eleven of the sixteen families collected by Kay *et al.* (1999) in northwestern Australia occurred in the Pilbara region. Aquatic coleopteran families are generally widespread across mainland Australia.

10.2.7 Diptera (True Flies)

The Diptera are another large group that contains a few families in which the immature stages are either always or mainly aquatic in habit (Simuliidae, Chironomidae, Ceratopogonidae, Culcidae, Dixidae, Blephariceridae, Ephydridae, Tanyderidae and Thaumaleidae). There are also several families that have larvae which are mainly terrestrial but which are occasionally aquatic or semi-aquatic (Tipulidae, Psychodidae, Athericidae, Tabanidae, Stratiomyidae, Empididae, Dolichopodidae, Syrphidae and Muscidae). The Sciomyzidae have terrestrial and aquatic larvae (Williams, 1980). Within the Australian dipteran fauna, the origin of some groups is obscure whilst others are clearly of either northern ('Indo-Malayan') or southern ('Antarctic') origin and demonstrate a Torresian or Bassian distribution accordingly (Colless and McAlpine, 1991).

10.2.8 Trichoptera (Caddis flies)

With well over 300 species, the Australian Trichoptera are a diverse group that colonise many different types of inland waters. Of the 24 families now recognised in Australia (Neboiss, 1992) three are particularly common: the Rhyacephilidae, Hydropsychidae and Leptoceridae. Several studies, combined with extensive collections made in Tasmania, have indicated a strong trans-Antarctic relationship in the order. However the greater part of the caddisfly fauna of the north and drier parts of the continent shows close relationships with the Asiatic fauna (Neboiss and Dean, 1991).

10.2.9 Absent Taxa

Taxa of note that were absent from collections made by Kay *et al.* (1999) include the Plecoptera (Stoneflies) and the Megaloptera (Alderflies). Adult Plecoptera are poor fliers. This group is known from all the cool temperate regions of Australia. They occur in the highlands of eastern Queensland (Williams, 1980). There are no records from central, north or north-western Australia (Theischinger, 1991a) Larval Megaloptera occur principally in the upper reaches of freshwater streams on the east coast and the mountains of the south east. (Theischinger, 1991b). The group is also known from Tasmania and southwestern Australia.

10.3 Biogeography of northwestern aquatic invertebrate species.

As part of the development of a model for the Australian River Assessment Scheme (AusRuvAS) Smith *et al* (1999) sampled aquatic macroinvertebrates from habitats throughout Western Australia. Most were identified to family level. The results show that northern faunas, (Kimberley, Pilbara and Gascoyne regions) were markedly different to southern faunas. Southwestern Australia forms part of the Bassian province of temperate Australia and fauna of its streams shares a common Gondwanan origin with that of southeastern Australia and Tasmania (Bunn and Davies, 1990).

Gondwanan relics, however, are not limited to southern regions. A small proportion of the aquatic fauna present at George Gill Range in central Australia appear to be relictual (Davis *et al.*, 1993). These species are absent from large tracts of arid land that separate the Range from southern Australia but were probably more widespread when the continent was much wetter than it is today. A phreatoicidean isopod collected recently from an intermittent stream in the Pilbara is also a Gondwanan relic (Knott and Halse, 1999). These ancient isopods appear to be associated with permanent springs or groundwater habitats.

Davis *et al.* (1993) found that the majority of species occurring at the George Gill Range had either widespread or southern distributions. Relatively few species had primarily northern distributions. This central Australian Range lies at approximately the same latitude as the Fortescue and Robe Rivers in the Pilbara Region of northwestern Australia. Sites on these rivers have been sampled intensively on a seasonal basis over several years and the majority of aquatic invertebrates identified to species level.

However due to the paucity of information relating to distributional records for many aquatic invertebrate species in central and northern Australia it is difficult to comment on the biogeography of the majority of taxa collected from these two sites. The majority of aquatic snails (Gastropoda) and several midge species (Diptera: Chironomidae: *Cladopelma curtivalva, Coelopynia pruinosa, Paramerina levidensis, Procladius paludicola*) occurring on the Robe River and Millstream appear to have widespread distributions throughout Western Australia and extending into the Northern Territory.

The dragonflies and damselflies (Odonata) are one of the few groups that are relatively well known. It is clear that the affinities of the northwestern odonates, with the exception of Australia-wide species, lie to the north and northeast (Watson, 1969). Odonates collected by Kay *et al.* (1999) across northwestern Australia included species from the four main tropical groups: the protoneurids, coenagrionids, aeshnids (in part) and libellulids. No Bassian species odonate has been collected from the northwest (Watson, 1969).

The isolated nature of many wetlands in the arid northwest is a major factor that contributes to a significant level of endemism within the region. Several species of odonates occupying permanent, freshwater habitats at Millstream are regionally or locally endemic. Waterbodies located within the George Gill and MacDonnell Ranges in central Australia also appear to be sites for speciation of odonates and hemipterans (Davis *et al.*, 1993).

The three major geographical regions (Gascoyne, Kimberley, Pilbara) of northwestern Australia comprise a vast (820 000 km^2) and largely arid landscape. An analysis of data at the family level from the broad-scale survey by Kay *et al.* (1999) indicated that community composition was comparatively uniform across this large area. It was suggested that the absence of clear biogeographical patterns in the macroinvertebrate fauna may have resulted from a lack of major geographic and climatic barriers in the region. Kay *et al.* (1999) suggest that the small differences between site groups reflect a uniform community across the study area, rather than a loss of information at higher taxonomic levels. Family level studies have been used successfully to describe biogeographical patterns across large areas of northwestern America.

However, studies of the Odonate fauna of northwestern Australia by Watson (1969) indicate a distinct taxonomic disjunction across the Great Sandy Desert. This arid zone separates the wetter Pilbara and upper Gascoyne regions (*i.e.* between the De Grey and Gascoyne Rivers) from the Kimberley Region to the north. Five species or subspecies of odonate differ taxonomically from close counterparts in the Kimberley and Northern Territory. It is possible that more might be recognised as doing so if the Kimberley fauna were better known (Watson, 1969). There does not appear to be comparable disjunctions in the odonate fauna across northern Australia between the Kimberley Region and northern Queensland.

The results of this study suggest that at least for some invertebrate groups there may indeed be a loss of biogeographical information at higher taxonomic levels. Existing records may also be misleading when only part of a species total range, or only particular habitat types, are sampled. Surveys of aquatic habitats within northwestern Australia clearly indicate a distinct difference in the invertebrate faunas: of macrophyte, riffle, pool-rocks and channel habitats (Kay *et al.*, 1999); associated with different macrophyte species (Charlton, unpublished data); and even in pools of varying size (Ecologia and Streamtec, 1992).

Meaningful interpretation of distribution records of many aquatic invertebrate groups in northwestern Australia will rely on more extensive regional surveys that sample the full diversity of habitats present.

11.0 The aquatic fish fauna in the Pilbara Region, and their biogeography

11.1 Introduction

The Western Australian fish fauna comprises 55 principal species (fishes mainly restricted to inland waters throughout their life history), and 44 secondary (basically marine or estuarine forms) and introduced species (Allen, 1982). The fauna contains a southern and a northern element. The Murchison River marks the southern boundary of the northern fish fauna that is closely allied to that of New Guinea.

The arid northwestern region extending from the Murchison River northwards to the De Grey River is isolated from other major drainages by vast arid areas. The region contains an impoverished fish fauna dominated by grunters (Teraponidae) and gudgeons (Eleotridae). Ten of the 12 principle species known to occur in the region have been collected from sites in the mid reaches of the Robe and Fortescue Rivers.

11.2 Primary Species

Fork-tail catfish (*Arius australis*)
The Fork-tail Catfish is widespread in northern Australia where it may be found both in estuaries and the freshwater upper reaches of rivers. This species has been recorded from the Ashburton and Fortescue Rivers.

Freshwater herring (*Nematolosa erebi*)
The Freshwater Herring occurs in all mainland states and is known from throughout the Pilbara where the Ashburton River forms the southern limit of its distribution in Western Australia (Allen, 1982). This species is usually found in slow-flowing water or large rocky pools.

Sleeper gudgeon (*Oxyeleotris lineolatus*)
The Sleeper Gudgeon is widespread across northern Australia.

Western rainbow fish (*Melanotaenia splendida australis*)
The Western rainbow Fish is widespread in northwestern Australia (Allen, 1989). This species inhabits a wide variety of aquatic habitats. It is frequently seen in schools near the surface in open water or around plant or log debris in shallow areas.

Common eel-tail catfish (*Neosilurus hyrtlii*)
This species occurs across northern Australia and is widespread throughout the Pilbara region where the Ashburton River forms the southern limit of its distribution (Allen, 1982). This species is found in a wide variety of habitats ranging from stagnant pools to clear, flowing streams.

Barred grunter (*Amniataba percoides*)
The Barred Grunter occurs across northern Australia and is found throughout the Pilbara region where the Ashburton River forms the southern limit of its distribution (Allen, 1982).

Fortescue grunter (*Leiopotherapon aheneus*)
The Fortescue Grunter is known only from Western Australia in the Fortescue, Robe and upper Ashburton Rivers where it is confined mainly to the Fortescue River system (Allen, 1982). This species inhabits rocky pools and slow flowing sections of streams.

Spangled perch (*Leiopotherapon unicolor*)
The Spangled Perch is one of the most widespread inland fish species across northern Australia. This species occurs throughout the Pilbara region and south into the Murchison region where the Greenough River forms the southern limit of distribution in Western Australia (Allen, 1982). This species is well adapted to desert conditions. It is able to tolerate brackish water and relatively high temperatures and may also be capable of surviving in mud during drought periods.

11.3 Secondary Species

Freshwater eel (*Anguilla bicolor*)
The Freshwater Eel is known from streams in the Kimberley and also ranges widely throughout the Indo-Australian Archipelago (Allen, 1982). This freshwater species returns to the sea to spawn.

Ox-eye herring (*Megalops cyprinoides*)
This species is relatively common in some of the larger rivers of the Kimberley (Allen, 1982) and has a wide distribution throughout estuaries of the Indo-Pacific (Allen, 1989).

11.4 Biogeography of northwestern fish species

In a survey of the fish fauna in the Pilbara Region Massini (1988) found that the best developed fish assemblages occurred in relatively clear waters of permanent or semi-permanent waterbodies. The catfishes (*Neosilurus* spp.) and the Spangled Perch (*Leiopotherapon unicolor*) are amongst arid Australia's most successful fishes because they occupy and survive in such a diverse range of habitats (Glover, 1982). During the same survey the Freshwater Herring (*Nematalosa erebi*) was recorded from only one site on the Harding River. Although widespread across mainland Australia, this species appears to be susceptible to eutrophic conditions and reduced oxygen levels. Sensitivity to extremes in water quality conditions may explain the absence of this species from many sites in the region.

The fish fauna of the Pilbara region has clear affinities with northern Australia. Eight of the ten species commonly collected in surveys of the region are widespread across northern Australia with the distribution of many species extending into central Australia (Allen, 1982; Dames and Moore, 1975).

12.0 Criteria for selecting significant wetlands

This section deals with several issues: the philosophy of approach used in this study is outlined in Section 12.1, the concepts underlying assessment of geoheritage are outlined in Section 12.2, the Global setting and Global Significance of the Pilbara are described, compared and discussed in Section 12.3, general evaluation processes for inland wetlands are discussed in Section 12.4, evaluation processes specifically for inland wetlands are discussed in Section 12.5, evaluation processes specifically for coastal wetlands are discussed in Section 12.6.

12.1 Wetland evaluation: philosophy of approach, this study

Prior to discussioning wetland evaluation systems below, and as a basis to understanding the approach used in evaluating the wetlands, some discussion of the philosophy underlying the methods used in this study are provided here. Most but not all of these were directly applicable to the Study Area, but all are discussed as they provide a context of debate for the conservation of wetlands generally, and illustrate that wetlands in good condition in the Study Area are outstanding in comparison to wetlands normally afforded conservation status elsewhere.

Wetlands have many attributes, some of which may be ranked as Regionally significant and some of which may be ranked as of Statewide to International significance. Therefore, a brief description is presented herein of outstanding wetlands in the Pilbara Region.

The attributes that determine whether a wetland is of outstanding significance are:

- avifauna usage
- vegetation attributes
- geoheritage values
- well preserved example of a consanguineous suite

Avifauna usage
V & C Semeniuk Research Group commissioned Australasia Ecological Services to provide information on avifauna in this region. Australasia Ecological Services analysed the available avifauna data from RAOU (or now Birds Australia) for the area. Their analysis did not include any non-waterbird species , a waterbird being defined as a species which is dependent on wetlands for its survival and includes waterfowl, shorebirds and certain species of harrier, eagle and warbler as defined by Jaensch *et al.* (1988).

Vegetation attributes
Data on flora was obtained from CALM database on priority species and restricted communities (Section 9.0). The basis of assigning a value to wetlands based on their vegetation rests on their status (*i.e.,* Priority species, or rarity) and in their representativeness (*i.e.,* they represent a type of assemblage within the Pilbara Region).

Geoheritage values
Information on geoheritage values were obtained from the literature, and in-house R&D data of VCSRG. The issue of geoheritage resolves down to protecting those wetlands that illustrate styles of geomorphic development within the region, and those wetlands that illustrate particular stratigraphic or hydrologic pattern.

Well preserved examples of wetlands within the consanguineous suite
The wetlands of the Pilbara Region have been assigned in this report to a number of consanguineous suites (Section 8.0). In this context, it is necessary to conserve those well-preserved representative examples of wetlands from this suite in this area.

Assessment of conservation wetlands

The wetlands in the Study Area that had been evaluated as of conservation significance are listed below in terms of their suggested management category. Evaluation of any wetland is a process which requires: 1. an understanding of the particular wetland, (through field data inventory and monitoring); 2. an understanding of its context in a regional setting; and 3. an understanding of the range of wetland functions. Given the complexity of wetlands, it is an ongoing process. Added to this, the Pilbara Region Study Area contains a large number of wetlands, many of which are inaccessible. Therefore, what has been undertaken, is a preliminary analysis based on the current available knowledge of wetland attributes and values. The analysis was applied to wetlands on a suite by suite basis within the context of the consanguineous suites described above, and the following criteria in general way were used:

- representativeness of a consanguineous suite
- scarcity of wetland type
- habitat diversity
- geomorphic/landscape values
- flora values
- faunal values
- linkage of systems
- condition of wetland

Representativeness is assessed on the range of wetland types present in each suite as well as the characteristics of each suite. Scarcity relates to the size, distribution and duplication of wetland suites. Representativeness must be based on comparisons wholly within a given consanguineous suite.

Habitat diversity refers to the variability present in each suite as well as the presence/absence of restricted habitat types.

Geomorphic/landscape values, floral values, and faunal values refer to specific features present in the wetlands, or documented use of wetlands by specific fauna, occurrence of vegetation, and the importance of the wetland in maintaining populations.

Linkage of systems refers to hydrological links such as creeks flowing into or from basins, creeks on flats, and to ecological links such as a series of basins ranging from permanent open water to seasonally waterlogged vegetated damplands surrounded by upland.

Condition of wetland includes assessment of the landform and stratigraphy, hydrology such as hydroperiod, water levels, water quality, and maintenance mechanisms, and vegetation in the wetland and the buffer zone. In most of the wetlands considered here, this feature was not an issue.

12.2 Concept of Geoheritage

A fundamental tenet of conservation globally to date has been the preservation of plant and animal species, and in particular, preservation of rare and endangered species. Recently, there has been a shift to the recognition and preservation of communities or assemblages (Wyatt & Moss 1990; Blandin 1992), and hence the recognition of biodiversity and geoheritage as a basis to conservation (IUCN, 1992; Ledec, 1988; Wyatt & Moss, 1990). Thus, conservation is more than just the preservation of single rare species, or assemblages of species. It should also encompass a gamut of natural history features that should include:

1. purely biological phenomena of scientific and heritage value, ranging from preservation of rare and endangered species at one extreme, to preservation of representative assemblages of species (Soule, 1986), to preservation of "biodiversity" (McNeely *et al.*, 1990).

2. features that combine biological and geological, geomorphological, pedological and hydrological attributes, essentially linking biodiversity with "geodiversity" (Hopkins, 1994), and

3. purely physical (*i.e.*, non-biological) phenomena of scientific and heritage value, such as unusual rock or landscape formations, many of which may be termed "geoconservation", or where there is diversity, "geodiversity" (Duff, 1994; Creaser, 1994; Markovics, 1994).

Where the terrain, or a geological formation, or the physical feature in a given area is of outstanding importance, conservation of geologic or geomorphic systems is axiomatic. At the National level, examples are the geological formation known as "The Breadknife" in the Warrambungals, Uluru (Ayers Rock in Central Australia, the "Twelve Apostles" along coastal Victoria, or a classic exposure of dinosaur footprints. Not so clear to the general public, and decision-making non-scientists, is the case for "geoheritage", unless it been made more acceptable where geological diversity, or unusual geological features, or a unique geological setting results in the occurrence of unusual or rare biota.

The term "geoheritage", in the Australian setting, is used here as follows:

> *State-wide to Nationally important features of geology, including igneous, metamorphic, sedimentary, structural, geochemical, palaeontologic, geomorphic, pedologic, hydrologic attributes that offer important information or insights into the formation or evolution of the continent; or that can be used for research, teaching, or reference sites.*

12.3 Global setting and significance of the Pilbara Region: a geoheritage perspective

The framework for the conservation of coastal wetlands in the Pilbara Region from a geoheritage perspective is in a context of globally to nationally to State-wide-significant coastal landforms and inland landforms

12.3.1 Inland settings

In terms of geoheritage, the Pilbara inland region is a unique and globally significant. Its significance lies, at the megascale, in the landforms, and the array of Precambrian greenstone and granitoids in the Pilbara Craton.. This area presents features that illustrate, from a geoheritage perspective, the control of rock type to develop landforms in an arid setting, and the ocurrence of freshwater habitats within an arid climate. In an overview, the Pilbara inland region is a system of laterite capped ironstone plateaux with deeply incised gorges developed on Precambrian layered ironstone in the Hamersley Province, and adjoining terrains of volcanic rock belts and masses of granitoid and greenstone. The distinctive feature of the Pilbara region is the freshwater wetland systems occurring in an arid landscape setting.

It is useful also to compare the Pilbara region with other tropical arid uplands elsewhere. Arid area in non-tropical settings are not considered here. Other landscapes worldwide that are of similar tropical aridity to the Pilbara include Somalia, Iran, the Arabian Peninsula, Pakistan, Namibia, Sahara, Baja California, and the Peruvian-Chilean uplands. These are briefly reviewed and described for comparative purposes with the Pilbara coast.

Somalia comprises a high-relief upland, the Golis Ranges (Orme 1985). I its regional setting, Somalia with a coastal tract of alluvial plains fronting the high-relief uplands appears much like the Pilbara, but this area of plains consists of alluvial fans (bajadas), with the coast itself composed of dunes, or mangrove swamps, or emergent (raised) coral flats. Iran presents a tectonically active uplifted mountainous terrain composed of folded Phanerozoic sedimentary rocks (uplifted steep terrain composed of limestones, marls and evaporites, and hence is mostly linear and rocky), and as such it is in a completely different setting to the Pilbara. The southern part of the Arabian Peninsula has very few rivers draining into the sea, and is comprised of stretches of wadi fans, dunes, rocky shores, headlands with intervening bays, and ria shores (Bird 1985). Pakistan is comprised of a tectonically active high-relief terrain (the Makran Coastal Range, Haro Range and More Range), composed mainly of Tertiary rocks (Snead 1985), and so is unlike the Pilbara. Namibia and the Namibian Desert, and is composed mainly of Precambrian rocks, with local outcrops of younger Palaeozoic, Mesozoic and Cainzoic rocks

(Haughton 1963), but the terrain is similar in landscape aspects to the Pilbara. The Western Sahara is one of the worlds largest deserts. Thouogh rocky, it is dominated by sand seas, and hence unlike the Pilbara (Elouard *et al.*, 1969; Sarnthein & Diester-Haass 1977; Vermeer 1985). Baja California most resembles the Pilbara in the Sonoran Desert and Pacific Coastal Plain Province that borders a high-relief hinterland, the Sierra Madre Occidentale (Allison 1964).

The Peruvian-Chilean mountain chain is part of the tectonically active high-relief hinterland of the Andes mountain chain, and so is unlike the Pilbara. The Peruvian-Chilean region as the leading edge of a major plate is a collision coast (Inman & Nordstrom 1971); Snead 1980), and tectonism has been part of this system throughout the Cenozoic, with uplift of the Andes mountain chain continuing into the Quaternary.

The literature review suggests that, globally, most tropical regions, in equivalent arid settings to the Pilbara, are of different geological frameworks, and are tectonically active, and hence unlike the Pilbara. The geology and landscapes of the thus stand as globally unique. The Pilbara landscapes, wetlands and hydrologic relations thus are potentially globally significant.

12.3.2 Coastal landforms

The analysis was applied to identifying sites of geoheritage significance along the Pilbara Coast is similar to that applied to assessing significance of consanguineous suites, but the criteria are modified to the following set:

- representativeness of a coastal form globally, nationally, or from a State-wide perspective
- scarcity of coastal form
- geomorphic/landscape values
- condition of system

In addition, the criteria of the Australia Heritage Commission are applied.

In terms of geoheritage, the Pilbara Coast is a unique and globally significant. Its significance lies, at the megascale, in the origin of the range of coastal geomorphic units and the Quaternary sedimentary products within the arid Pilbara coastal zone, where the main regimes that shape the present coastal forms are wave-dominated conditions, storm surge effects, tides, and aeolian activity. This coast presents features that illustrate, from a geoheritage perspective, the control of pre-Holocene features both in developing the present coastal forms and in influencing the Holocene sedimentation patterns, and the variety of Holocene depositional styles therein.

The main influence of the inherited pre-Holocene landforms in this setting has been to control sedimentation patterns in the Holocene. As such the Pilbara Coast is a global classroom. Where exposed, the ancestral landforms are largely in erosional phase, and the Pilbara coast currently reflects the various stages of their destruction. In detail, within the Holocene, there is alongshore variation in coastal sedimentation patterns, due to phases of delta construction, delta destruction to form barrier coasts, and longshore transport with concomitant onshore aeolian transport to build sandy barrier coasts - this pattern which can be viewed as a result of the arid setting.

In an overview, the Pilbara coast thus can be seen to be an interactive system of Holocene deltas and sandy barriers, superimposed on Pleistocene landforms, viz., elic deltas, limestone barriers and the dissected terrain cut into Precambrian bedrock. This megascale picture provides a global example of the range of patterns in coastal geomorphology and sedimentation in an arid zone. The Pilbara Coast exhibits globally important patterns of sedimentation in an arid coastal setting. For instance, within the stratigraphic record, at the large scale, the coastal zone of the Pilbara appears as a synoptic series of laterally equivalent deltas and sandy barriers (later to be cemented to limestone), with the limestone ridges/barriers developed alongshore from the delta system, or developed as an eroding front to a delta, or developed within a prograding delta system at zones of hiatus. The limestone ridges, if buried and preserved, would be associated with protected lagoonal deposits. This array of synoptic facies would be superimposed on the older deposits of deltas, barriers and ridges of earlier depositional cycles, or superimposed on remnant topography cut into bedrock.

The distinctive feature of the Pilbara region is that this coastal plain assemblage of Holocene depositional forms, Pleistocene coastal landforms, and the erosional surfaces cut into pre-Holocene landforms, exist in an arid climate today, and many of the smaller scale processes and products therein are markedly influenced by this arid climate. The area should provide some distinctive features to distinguish this style of sedimentation and coastal evolution from coastal plains elsewhere set in a less arid climate.

At smaller scales, there are processes and products that are special to a tropical arid coastal setting. At this scale, the main features that separate the Pilbara Coast from those in less tropical and less arid settings include: salt flats; mangroves (and their sedimentary products); the effects of freshwater seepage; high-tidal alluvial fans and hinterland-fringing sediment aprons; the layer of red mud on the upper tidal flat (salt flat) surface; the precipitation of carbonates to form high-tidal crusts and beachrock; the effects and deposits of storm surges and storm waves; the prevailing styles of erosion of spits, cheniers, tidal creeks and limestone cliffs; the style of erosion of high-tidal salt-flat weathering of limestone; and the persistence of arid zone boulder slopes into the coastal environment.

Combination of some of these features, listed above, of arid zone tidal flats and coasts serve as tropical zone indicators in the stratigraphic column. Particularly useful are *in situ* beachrock in the mid- to high tidal interval within a beach/dune sequence, the occurrence of beachrock slabs as conglomerate and breccia in the interval above HAT in a beach/dune sequence, the occurrence of *in* situ, or even brecciated, high-tidal crusts above a mangrove sequence, and the occurrence of alluvial fans and sediment aprons along the upper tidal flat margin.

However, since some of these features are not exclusively arid zone indicators, but rather more general tropical climate indicators (e.g., the occurrence of mangroves, storm surge effects, and beachrock), it is necessary to identify what can perhaps in combination critically serve to identify specifically arid zone coastal environments; these include:

1. salt flat lithologies, particularly when overprinting mangrove deposits,
2. gypsum crystallisation in high-tidal mud,
3. pavements of limestone formed by salt flat weathering,
4. high-tidal crusts perhaps punctured by crab burrows, and brecciated and undercut by small scale tidal creek erosion,
5. well-defined and well-laminated (*i.e.,* well preserved) alluvial fans and sediment aprons along the hinterland/tidal flat contact, often with red mud interlayers,
6. boulder deposits that mantle the palaeo-topography,
7. discrete indicators of freshwater seepage zones, and
8. the general intense reddening of sedimentary sequences.

These features, in fact, are located mainly in the upper tidal and supratidal zones, where the effects of aridity or frequent storms are most evident. Mid- to low-tidal areas in arid settings are subject to frequent daily tidal and wave processes, and are bathed daily by marine waters. Thus they do not exhibit features markedly different from other marine deposits in less arid settings because the over-riding factor is on-going wave action, tidal action, oceanic water inundation, and biological perturbations of the marine environment. These sedimentological processes shape the mid- to low-tidal parts of the sedimentary sequence. Only in progressively upper tidal and supratidal settings, where the effects of marine waters are progressively decreased, will the effects of aridity be evident.

Overall, the full Pilbara Quaternary stratigraphy and geomorphology suggests that aridity was intricately involved in sedimentation, geomorphic evolution, and pedogenic and diagenetic alteration of this coastal zone, and in the control of the next phase of sedimentary accretion by an ancestral Quaternary topography. An analysis of the importance of arid zone effects on coastal processes then must take into account the full Quaternary picture [such an endeavour was beyond the scope of this report because, at this stage, the detailed information from the Pleistocene sequences is lacking]. In this regard, the full Quaternary picture for the Pilbara has the potential to provide a model of coastal plain processes and products in an arid setting.

The coastal features of the arid Pilbara distinguish this coastal tract from those in more humid climates of Western Australia further to north and south, even if the megascale sedimentary and stratigraphic patterns are similar (Woods *et al.*, 1985). For example, to the far north of the Pilbara, in the macrotidal region of the Kimberleys, there are ria/archipelago coastal systems similar to the sections of the Pilbara coast (Semeniuk 1985). However, in the Kimberleys there is higher rainfall and less pronounced evaporation and cementation, and therefore a contrast with the arid zone Pilbara in terms of small scale coastal features - there is less beachrock, no supratidal beachrock-slab conglomerate and breccia, no high tidal cementation, less groundwater hypersalinity, sediments under zones of freshwater seepage are mangrove-vegetated and extensively bioturbated, and sediments formed as aprons to the hinterland or as fans from small creeks that debouche from the uplands also are vegetated and extensively bioturbated.

To the south, along the wave-dominated, microtidal coast of the Swan Coastal Plain (Searle & Semeniuk 1985), where the climate is more humid, there also is a marked change in small scale coastal processes, even though some of the megascale coastal sedimentation patterns, such as the occurrence of sandy barriers and beach/dune shores, are similar - beachrock is uncommon to absent (Semeniuk & Searle 1987; Searle *et al.*, 1988), cyclones are rare (though winter storms are common) and there are no cyclone deposits preserved, there is much less hypersaline coastal groundwater on tidal flats and hence salt flats are largely absent (Semeniuk & Semeniuk 1990), and high-tidal aprons formed by sheet wash are extensively bioturbated. In both cases, the general features of very hypersaline, vegetation-free, high-tidal lithotopes typical of arid coasts are absent.

If the Pilbara coast provides an important model for Quaternary arid coastal sedimentation patterns at least for Australia, it is useful also to assess the usefulness of this model worldwide, and hence compare this coastal system to others in tropical, arid settings elsewhere. Arid coasts in non-tropical settings are not considered here. Other coasts worldwide that are of similar tropical aridity to the Pilbara coast include the Somalia coast, the Persian Gulf, the Red Sea and Arabian Peninsula coast, the Pakistan coast, the Namibian coast and the northwest African coast, Baja California, and the Peruvian-Chilean coastline. These are briefly reviewed and described for comparative purposes with the Pilbara coast.

The Somalia coast is a dune coast for most of its length; other coastal segments in Somalia are rocky shores cut into Tertiary rocks and alluvial plains fronting a high-relief upland, the Golis Ranges (Orme 1985). The coastal environment is wave-dominated and mesotidal to macrotidal. Superficially, in its regional setting, the coastal tract of alluvial plains fronting the high-relief uplands appears much like the Pilbara, but this area of plains consists of alluvial fans (bajadas), with the coast itself composed of dunes, or mangrove swamps, or emergent (raised) coral flats. At its seaward margin the alluvial deposits of the Quaternary interdigitate with marine deposits. Tectonism also has been an integral part of the Quaternary sedimentation, and as a result there are Quaternary marine deposits uplifted a considerable height above sea level.

The Persian Gulf separates two tectono-geological provinces, a low stable foreland on the Trucial Coast, and an uplifted mountainous terrain of the Iranian hinterland. Thus it is in a completely different setting to the Pilbara coast. The western shore of the Persian Gulf has no fluvial input; it is an evaporitic sabhka plain that grades into the Arabian desert, and is predominantly a carbonate sediment complex (Sugden 1963; Taylor & Illing 1969). The eastern coast borders an uplifted steep terrain composed of limestones, marls and evaporites, and hence is mostly linear and rocky, with narrow coastal plains associated with some small rivers that drain the uplands (Purser & Seibold 1973; Kassler 1973).

The Red Sea is a relatively young rift system, and hence its shores are composed of scarps, cliffs, uplifted terrain, narrow alluvial flats that border the sea, inundated pre-Holocene wadis, coral reefs, and local sabhkas (Guilcher 1955, 1985; Dalongeville & Sanlaville 1981). There is no major fluvial input. The southern part of the Arabian Peninsula has very few rivers draining into the sea, and is comprised of stretches of wadi fans, dunes, rocky shores, headlands with intervening bays, and ria shores (Bird 1985).

The Pakistan coast borders a tectonically active high-relief hinterland (the Makran Coastal Range, Haro Range and More Range), composed mainly of Tertiary rocks (Snead 1985), whch locally extend to the coast to form rocky shores and headlands. In this aspect, it is similar to the Pilbara coast. Between the bedrock extensions, the coast is beach ridge plains, deltas, spits, sandy barrier and associated lagoons, and tombolos joining off-shore bedrock islands. The coast is microtidal, wave-dominated, and subject to periodic cyclones. Pleistocene marine sediments are uplifted along the coast to form platforms. At the small scale, within the Holocene, in terms of local sediment patterns and stratigraphic units, this coast has many similarities to those of the Pilbara. Quaternary sedimentation along this coast, however, is intimately involved in tectonics, and the continuity of Quaternary sedimentary units, other than perhaps the Holocene, has been disrupted.

The Namibian coast is microtidal, wave-dominated, fronts the Namibian Desert, and is composed mainly of Precambrian rocks, with local outcrops of younger Palaeozoic, Mesozoic and Cainzoic rocks (Haughton 1963). A portion of the coast is blanketed by aeolian deposits (the Namibian Sand Sea, one of the most extensive coastal sand seas in the world), and hence is an aeolian coast with intermittent rocky outcrops (Tinley 1985; Bremner 1985). Locally there are accreting spits with salt pans to leeward.

The Western Sahara coast, incorporating Saraoui and Mauritania, is the coastal edge of the Sahara, one of the worlds largest deserts. Along most of Saraoui, the coast is rocky, cut into Mesozoic, Tertiary and Quaternary formations, with some Holocene dune development and associated sabhkas (Lecointre 1962; Mainguet 1985). The Mauritania coastline consists of rocky headlands with intervening bays and tidal flats; and to the south, high dunes (Elouard *et al.*, 1969; Sarnthein & Diester-Haass 1977; Vermeer 1985).

The coast of Baja California that most resembles the Pilbara is the Sonoran Desert and Pacific Coastal Plain Province that borders a high-relief hinterland, the Sierra Madre Occidentale (Allison 1964). To north is macrotidal-dominated Colorado River delta (Thompson 1968). Along the eastern coastal zone is in a tectonically active area (Hamilton 1961; Orme 1980), and there are deltaic/alluvial plains, with the development of sandy barriers and lagoons, plains of beach ridges, and dune systems. This eastern coastal system is microtidal and to some extent is wave-dominated.

The Peruvian-Chilean coast is composed of narrow coastal plains fronting a high-relief hinterland of the Andes mountain chain, but locally there are cliffed shores and indented (ria) coasts where the Andes intersect the shore, as well as a multitude of estuaries and deltas where rivers drain into the sea (Dresch 1961; Araya-Vergara 1985; Bird & Ramos 1985). At a smaller scale there are beach ridge plains, wave-dominated deltas, estuaries and mangrove swamps. A first impression would suggest that this coastal system is equivalent to the Pilbara, and, in many aspects in the contemporary system, there are in fact numerous similarities. However, there are several major differences between the Peruvian-Chilean coastal tract and that of the Pilbara. The first is the role of tectonism (Fuenzalida *et al.*, 1965). The Peruvian-Chilean coast as the leading edge of a major plate is a collision coast (Inman & Nordstrom 1971); Snead 1980), and tectonism has been part of this system throughout the Cenozoic, with uplift of the Andes mountain chain continuing into the Quaternary. This would have major influences on the disposition and inter-relationship of the various coastal facies such as deltas, beach/dune shores and sandy barriers, and the relationship of pre-Holocene coastal features to later sedimentary accretion. Secondly, the area fronts a deep ocean, unlike the wide Northwest shelf setting of the Pilbara. Thirdly, the tides along the open coast are microtidal.

The literature review suggests that most tropical coasts around the world in equivalent arid settings to the Pilbara are dominantly steep or cliffed rocky shore types, where headlands separate bays and sandy coastal stretches, or are of the aeolian type, or are low gradient sabhka type. Many in fact are active tectonic coasts. Coasts that resemble the Pilbara, in terms of setting and configuration of alluvial, deltaic and aeolian facies within a coastal plain formed down-slope from a high-relief upland, are tectonic, so that the control of the Quaternary sedimentary patterns have had less control on Holocene coastal form and stratigraphy. In the Pilbara, by contrast, the Quaternary coastal sedimentation has not been significantly uplifted, if at all, and hence there is not the complication of tectonics disrupting the pattern, and the package of Quaternary sediments are still inter-related in time and space. With subsidence and burial, sediments accumulated in the Pilbara coastal zone would form a distinct assemblage of stratigraphic units, inter-related synoptically, and across unconformities. This would suggest that the style of geomorphology, sedimentation, alteration and diagenesis, and stratigraphic evolution of the Pilbara coastal system is indeed globally significant.

12.4 The evaluation process for inland wetlands: methodology, categories & criteria

In terms of obtaining information to apply the criteria for the four evaluation schemes, there were three general methods used in this study:

- aerial photographic assessment,
- review of published information and
- field site inspection.

More specific details on methods in relationship to delineation of consanguineous suites and for implementing the criteria for evaluation are described in appropriate later sections.

The photographic analysis of a given wetland included:

1. assessment of the presence and amount of natural vegetation
2. assessment of the presence and type of a buffer zone
3. assessment of the geomorphic integrity of the wetland
4. investigation of unusual geomorphic features or setting
5. assessment of the nature of local catchment
6. assessment of hydrological linkages, and
7. assessment of possible wetland hydrological functions

The literature and database searches were undertaken to obtain information on specific functions of wetlands such as faunal usage or habitat attributes. The following databases were accessed:

- contact with CALM on rare and endangered fauna
- Birds Australia database on waterfowl use of wetlands
- in-house VCSRG R&D data

Literature and published maps were used to access information on unusual geological, landform or soil formations, pollen sites and fossil sites. Publications were also a supplementary source of information on values of specific wetlands e.g., National Directory of Important wetlands, Lane & Lynch (1996).

Where wetlands were visited on-site, inspections/assessments for the evaluation of wetlands in the Study Area included the following procedure:

1. an assessment of wetland vegetation status
2. recognition of wetland vegetation diversity (e.g., structural diversity, presence of restricted community types)
3. recognition of unusual vegetation physiognomy (potential indicators of changes to wetland hydrology)
4. recognition of dynamic biological responses as an indicator of habitat alteration (evident in floral community changes)
5. assessment of possible anthropogenic alteration to hydrology
6. assessment of degradation

The above procedures were the basis for a general evaluation of wetlands for the primary objective. There was a second objective to this study: identification of wetlands of *outstanding significance*. This translated to identification of wetlands with values recognised as being Statewide, National or even International significant. The following criteria were used to select such wetlands:

- wetlands that have outstanding values as a faunal habitat or refuge,
- wetlands that have value as a habitat for significant flora,
- wetlands that have high habitat diversity,
- wetlands that have value as a rare wetland type,
- wetlands that are an outstanding example of a particular type of wetland and wetland processes (geoheritage)
- wetlands that have value as a scientific resource
- wetlands that in association typify a geomorphic setting (geoheritage)

The wetlands in this category of outstanding environmental significance generally satisfied more than one criterion.

Information on habitat diversity and geomorphic/landscape values were obtained from field surveys conducted during this study. Traverses and field sites pertaining to this study area are shown on Figures 2-4 to illustrate the extent of the data base. In some suites the information available is depauperate and should in no way be considered a true representation of the value of the wetland suite. Criteria important to the assessment of each suite, are listed at the beginning of the description.

Three types of assessments were carried out these wetlands:

- that of the Australian Heritage Commission,
- that used in Water Resources Council (1988) & Semeniuk (1985)
- that used by Hill *et al.* (1996), and expanded by C A Semeniuk (1998).

Following description of these evaluation systems, discussion is provided of the concept of Geoheritage, and the Philosophy of Approach undertaken to assess the significance of wetlands in this Study Area.

Australian Heritage Commission Criteria
The criteria for selection of area for Register on the National Estate by the Australian Heritage Commission are listed as 4 main types (Australian Heritage Commission 1990):

1. Criterion A: Importance of an area or site in the course, or pattern, of Australia's natural or cultural history

2. Criterion B: Possession of uncommon, rare or endangered aspects of Australia's natural or cultural history

3. Criterion C: Potential of an area or site to yield information that will contribute to an understanding of Australia's natural or cultural history

4. Criterion D: Importance of an area or site in demonstrating the principle characteristics of (i) a class of Australia's natural or cultural place; or (ii) a class of Australia's natural or cultural environments

These are amplified below, according to the guidelines of the Australian Heritage Commission (AHC), with examples from this study.

Criterion A: Importance of an area or site in the course, or pattern, of Australia's natural history:

A.1 Importance in the evolution of Australian geology, fauna, flora, landscapes or climate. According to the AHC guidelines, this would include:

1. geological evolution: e.g., the evolution of the coastal deltas,
2. *Melaleuca* thickets fringing freshwater seepage zone,
3. sites significant for climate history: e.g., pollen record in some of the sediment-filled permanent pools;

A.2 Importance in maintaining existing processes or natural systems at the regional or national scale. According to the AHC guidelines, this would include coastal processes and wetland processes (examples include the maintenance of mangrove systems, and the maintenance of wetland vegetation in the inland systems);

A.3 Importance in exhibiting unusual richness or diversity of flora, fauna, landscapes or cultural features. According to the AHC guidelines, this would include:

1. biological or geological diversity. e.g., the vegetation of the springs and soaks along the Millstream system
2. landform or geomorphic diversity: coastal forms along in the Ashburton River delta and east shore of Exmouth Gulf

Criterion B: Possession of uncommon, rare or endangered aspects of Australia's natural history:

B.1 Importance for rare, endangered natural landscapes or phenomena, or as a wilderness. According to the AHC guidelines, this would include:

1. areas or sites with uncommon or rare landform or geomorphology with vegetation (e.g., the terrain of Millstream and the Marshes of the Fortescue River)

Criterion C: Potential of an area or site to yield information that will contribute to an understanding of Australia's natural history:

C.1 Importance for information contributing to a wider understanding of Australian natural history, by virtue of its use as a research site, teaching site, type locality, reference or benchmark site. According to the AHC guidelines, this would include: research areas, reference and benchmark areas, and educational areas (such as the mangrove coast, and the wetlands of the Yanrey Flats).

Criterion D: Importance of an area or site in demonstrating the principle characteristics of (i) a class of Australia's natural place; or (ii) a class of Australia's natural environments:

D.1 Importance in demonstrating the principal characteristics of the range of landscapes, environments or ecosystems, the attributes of which identify them as being characteristic of their class. According to the AHC guidelines, this would include: places demonstrating the principal characteristics of the range of landscape and ecological classes: examples of which would be the wetlands in relationship to springs in an arid zone, the wetlands in relationship to relationship to coastal evolution; some of these are of global significance, e.g., the area of Millstream and the coastal mangroves.

In this context. many of the wetlands of the Pilbara qualify for inclusion on the Register of the National Estate, as will be discussed below.

Note that Criterion E is not applied in this study.

Semeniuk (1985) & Water Resources Council (1988)
The most comprehensive evaluation of wetlands was the system of the Water Resources Council (1988), based on Semeniuk (1985). It was based on identifying some 15 criteria, and providing a weighting or score to each based on the level of significance of each of the criteria (5 = international, 4 = national, 3 = State-wide, 2 = regional, 1 = local), with a team of professional wetland scientists visiting the wetland in the field. The system was applied to wetlands of the Swan Coastal Plain, but in principle can be applied to any wetland in the State. The evaluation system, as published in the proceedings of an international workshop, originally was developed by Semeniuk (1985) for coastal wetlands and modified to account for inland wetlands, and hence can be applied to inland wetlands.

Hill *et al.* (1996) and C A Semeniuk (1998)

The evaluation system described by Hill *et al.* (1996) was based on previous systems extant in Southwestern Australia, together with a review and assessment of the International Literature. While designed for the Swan Coastal Plain, in southwestern Australia, its principles are nonetheless applicable to this present Study Area in the Pilbara Region.

According to the scheme of Hill *et al.* (1996), the evaluation of wetlands results in their categorisation into three management classes, following (Hill *et al.*, 1996); the classes are:

1. Conservation
2. Resource Enhancement
3. Multiple Use

The Conservation Category was understood to mean that the priority would be to manage the wetland as a reserve and to protect the attributes and functions which were of high value. Alteration to the wetland would be strongly discouraged and mechanisms would be put in place to protect the wetland from any man-induced deterioration.

The Resource Enhancement category was understood to mean that the priority would be to maintain the wetland, its attributes and functions, and wherever possible enhance the ecological status of the wetland by such activities as improving water quality or re-vegetating cleared areas with endemic site-appropriate species

The Multiple Use category was understood to mean that the priority would be to maintain multiple uses of the wetland including ecological functions. This would necessitate maintaining the geomorphic integrity of the wetland. It excludes destruction of the wetland through processes such as infilling, excavation, mining, or erection of urban structures.

In the context of the Pilbara Region, the Conservation Category is the most important, and will the only one dealt with here.

Although evaluation of wetlands has taken place elsewhere in other regions in Western Australia, in Australia generally, and globally, much debate and confusion surrounds the issue, and it was the intention of Hill *et al.* (1996) to present clear and comprehensive criteria for each of the various management categories with respect to natural or ecological attributes, and hence reduced the number of management categories to simplify the assessment process.

Evaluation demands a logical and systematic approach to attempt to exhaustively capture all recognised natural wetland values, therefore, criteria are needed to be designed to assess the following attributes of wetlands. C. A. Semeniuk (1998; *in* V & C Semeniuk Research Group 1998) developed criteria to assign wetlands to the conservation category, as follows:

- wetland type
- wetland processes maintaining the system
- wetland habitats
- wetland functions
- biodiversity
- scientific value

Criteria are listed below and explained for the category of *Conservation*. The list is organised in the same sequence as the list of wetland attributes above. This order does not imply priority. The evaluation criteria aim to be comprehensive.

Wetland type: A wetland may be classed as <u>Conservation</u> *if it satisfies one or more of the following criteria*

1. an anthropogenically unaltered wetland type (*i.e.*, river, creek, floodplain, lake, sumpland, dampland)
2. a scarce wetland type
3. representative wetland type (*i.e.*, representative of its consanguineous suite)

Wetland processes: A wetland may be classed as <u>Conservation</u> *if it satisfies one or more of the following criteria*

1. the wetland is subject to anthropogenically unaltered wetland processes (*i.e.*, recharge and discharge mechanisms, hydroperiod, sedimentary processes,)
2. the wetland exhibits unusual wetland processes
3. the wetland exhibits representative wetland processes (*i.e.*, representative of its consanguineous suite and geomorphic setting)

Wetland habitats: A wetland may be classed as <u>Conservation</u> *if it satisfies one or more of the following criteria*

1. the wetland is a habitat for rare & endangered fauna
2. the wetland is a habitat for rare & endangered flora
3. the wetland exhibits a high diversity of habitats

Wetland functions: A wetland may be classed as <u>Conservation</u> *if it satisfies one or more of the following criteria*

1. the wetland is necessary for maintenance of large faunal populations
2. the wetland is a refuge for resident fauna
3. the wetland is an important breeding, feeding or watering site for migratory populations (local and international)
4. the wetland is a significant regional component of the hydrological cycle (has an important hydrological storage, recharge or discharge function; or an hydrochemical function)

Biodiversity: A wetland may be classed as <u>Conservation</u> *if it satisfies one or more of the following criteria*

1. the wetland exhibits unaltered wetland vegetation and fauna
2. the wetland has a scarce vegetation association or faunal association
3. the wetland has a highly diverse wetland flora or fauna

Scientific value: A wetland may be classed as Conservation *if it satisfies one or more of the following criteria*

1. the wetland contains scientifically significant pollen records
2. the wetland is underlain by unusual wetland sediments (indicators of wetland history)
3. the wetland has unusual geomorphology (*i.e.,* it is situated in an unusual geomorphic setting or contains unusual geomorphic features within it)

12.3 The evaluation process for inland wetlands

From the aerial photographic analysis, a preliminary assessment of the nature of a given wetland was carried out. Following this, supplementary data from field inspection, databases of CALM and Birds Australia, and literature review, as outlined in the methods, were used to evaluate wetlands according to Semeniuk (1985) and Water Resources Council (1988). The various wetlands in this study in the field were noted/described in terms of:

- wetland type (dampland, sumpland, or creek, etc.),
- wetland size (leptoscale, microscale, mesoscale, macroscale,
- status of native vegetation (excellent, good, or poor condition)
- description of vegetation (main species, structure)
- status of disturbance
- key features (e.g., scientific importance)
- suggested management category (*e.g.,* Conservation) and management

12.5 The evaluation process for coastal wetlands: methodology, categories and criteria

The wetland evaluation system for coastal wetlands applied is that of Semeniuk (1985) and modified in that of Water Resources Council (1988), and that of V & C Semeniuk Research Group (1997). In the first instance, coastal wetlands from a geoheritage perspective are assigned conservation status (Section 12.5.1). In the second instance, coastal wetlands from a biologic perspective (particularly mangroves) are assigned conservation status (Section 12.5.2).

12.5.1 Conservation of mangrove coasts
The framework for the conservation of coastal wetlands for mangroves in the Pilbara Region is in a context of mangroves and coastal landforms, *i.e.*, coastal landform types form the habitats and ecosystem framework to the different types of mangrove systems. In this section the mangroves between Exmouth Gulf and the De Grey River delta and the offshore islands on the Northwest Shelf are dealt with. This region represents the most arid coast in Australia, and, from a global perspective (discussed below), presents a heterogeneous mix of coastal types in a generally depositional system. These factors are important features to address in the selection of coastal zones of significance.

This section is structured in the following way:

- Global significance of the Pilbara Coast mangroves
- Criteria for selection of mangrove areas for conservation in the Pilbara
- Scale in relation to the significance of mangroves
- The criteria for the selection of high conservation area

Global significance of the Pilbara Coast mangroves
In general, assessment of the global significance of mangroves requires determination of: 1. the species richness of various regions; and 2. variability of coastal style (habitat setting) where mangroves are located. However, in order to assess the global significance of mangrove formations located in the Pilbara Region, several inter-related aspects of their subcontinental to regional features must be considered:

1. the species pool;
2. the range of habitats;
3. the climate setting and climate gradient;
4. the maintenance processes (specifically in this case, in an arid zone);
5. inter-relationship of mangroves to geological/geomorphic setting.

Species pool:
In terms of species pool, the mangroves of northwestern Australia belong to the Eastern Group of mangroves (termed Old World Mangroves), centred on the Indian-Pacific Ocean area (Tomlinson 1986), and within this region, they specifically belong to the Indo-Malesian Group that encompasses Pakistan, India, Burma, Malaysia, Indonesia, Celebes, northern Australia and Papua-New Guinea (Chapman 1977). This Indo-Malesian group is the most species-rich region of mangroves worldwide.

In terms of endemism and restricted species, Western Australia does not support any unusual, endemic, or restricted mangrove species. In fact, all species within Western Australia are common and widespread elsewhere, either in northern Australia, or in the Indo-Pacific region proximal to northern Australia, and so in this sense, the mangroves of Western Australia are not globally significant. Furthermore, the most common of the mangrove species, *Avicennia marina* and *Rhizophora stylosa*, together form the most widespread and best developed mangrove formations along the coast.

Range of habitats:
What Western Australia does provide in terms of global significance is a richness and variability of mangrove habitats, from large to small scale. Within the same subcontinental setting there are major variations in style of coast, oceanographic setting, and climate, that interplay with the regional north/south change in the mangrove species pool. This results in variation in species richness, assemblages, vegetation structure and physiognomy, which provides excellent examples of biological response to the physico-chemical environment, and valuable information on their biogeographic patterns.

Climate setting and climate gradient:
The Pilbara mangroves are located in the most arid coast of Australia, and this coast is one of five arid coasts globally. Mangroves of the Pilbara, and of northwestern Australia generally, should be viewed as a continuation of the northern Australian system, and as part of the climatic cline extending from there into the Papuan region. There are two significant aspects to this:

- firstly, the variety of large-scale Pilbara coastal habitats contrasts with other styles of coasts further north (in Australia, and the Papuan to Malaysian archipelago region with its predominance of steep shores, high-tidal deltas and ria coasts); this allows researchers to trace changes in mangroves from humid macrotidal areas into arid and microtidal areas, and also from one coastal type (and its smaller scale habitats) to another in the same climatic setting (e.g., rias *vs* barrier islands *vs* deltas) in order to compare differing effects of habitats and climate on mangroves; and

- secondly, the Malesian-Papuan-Northern Australian mangroves form a Group that extends far into the higher latitudes. Within this Group, the Western Australian coast, being the most arid coast in Australia, uniquely carries the cline of Old World mangroves from humid and semi-arid zones to an arid zone. Thus the tropical arid Pilbara Region provides an important scientific resource for present and future researchers, and a model for mangrove biogeography and ecology that is useful globally.

Maintenance processes:
As one of five arid coasts globally, the Pilbara region uniquely carries the Old World Mangroves into arid settings. There are distinct maintenance processes that occur specifically in an arid zone (e.g., habitat development, mangrove population dynamics, freshwater effects, nutrient budgets, and responses to salinity, amongst others) that provide important scientific insight into the mangrove ecology, and it is the Pilbara region that will provide the setting for the understanding of such phenomena in the Old World Mangroves globally.

Inter-relationship of mangroves to the geological/geomorphic setting:
The variety of large-scale coastal habitats in variable geologic/geomorphic settings in the Pilbara, in contrast to other simpler styles of coasts elsewhere, gives rise to a greater range of smaller scale mangrove habitats and this can provide insight into the variability of mangrove responses.

Criteria for selection of mangrove areas of high conservation in the Pilbara

Before discussing the criteria for the selection of mangrove areas for conservation, it is important to establish their values. Mangroves usually are preserved for three reasons:

1. ecologic reasons pertaining to productivity, feeding grounds, and fish nurseries;
2. scientific reasons of heritage, research and education; and
3. preservation of biodiversity.

There are practical as well as economic reasons for mangrove preservation along a coast, e.g., mangroves can function in practical ways such as in coastal protection and in nutrient uptake.

The designation of mangrove areas for representation and conservation in the Pilbara Region should be based on a number of criteria that address their significance. The significance may be international, national, or regional. The significance of mangroves is dependent on:

- the extent or rarity of the habitat,
- the internal diversity of the habitat,
- the ecological significance of a given stand, and
- the nationally to internationally significant features of a given site.

Each of these aspects are discussed below, drawing on examples of mangrove habitats and mangrove assemblages from oceanic island, ria/archipelago, and barrier island settings.

The reader should note here that throughout this section, the term "diversity" is used in a range of contexts, viz.:

- diversity of coastal types
- diversity of habitat within coastal setting
- diversity within habitat
- diversity of processes
- diversity of floristics (*i.e.,* species variation)
- diversity of vegetation structure
- diversity of plant physiognomy

The extent or rarity of the habitat:
In the context of the extent or rarity of a habitat, it is necessary to conserve representative examples of extensive and laterally well-developed mangrove formations for global purposes where they represent a type of formation, and particularly where they are related to a specific coastal type or setting. But although extensive and laterally well developed stands of mangroves may be regionally important, particularly for fisheries, they may not be necessarily nationally/globally significant scientifically.

Where there are unusual combinations of species or scientifically important habitat and assemblage relationships, even local small patches of mangroves may assume national/global importance. In these cases, it means that local habitats may assume significance because they represent uncommon types. This applies generally to lagoon assemblages in oceanic island settings, for instance, or high-tidal alluvial fan situations in archipelago/ria coasts (as will be discussed below).

Other habitats are unusual globally, within the context of the Biogeographic Region and species pool of this part of the world, and hence become significant, e.g., limestone pavement habitats.

However, once established that small patches of mangroves are important regionally, nationally or globally, adjoining stands of mangroves (which, in isolation, normally would be less significant) also assume importance by association, because they provide a holistic context for the former. For instance, within a ria setting, a small scale high-tidal alluvial fan with a well-zoned mangrove formation may be nationally significant because of the scientific relationship it portrays between a mangrove assemblage, its internal zonation, the styles of population maintenance, edaphic features, freshwater influx, and the maintenance of the habitat. The ria embayment in general may contain habitats and mangrove assemblages common and widespread throughout this region, and in isolation would not be regionally, nationally, or globally significant, but the occurrence of an alluvial fan system within it will make the combination of the ria embayment and the alluvial fan significant.

Internal diversity of the habitat:
Internal diversity of the habitat influences the species diversity, zonation and structure of mangrove vegetation, and is thus a basis for representation and conservation. Emphasis is placed on the degree of internal heterogeneity of a habitat, in terms of hydroperiod gradients, salinity, substrate grain size and composition, and hence diversity and/or luxuriance of its mangrove vegetation assemblages. Consequently, even though many habitats may be of the same scale (e.g., narrow mangrove-vegetated tidal creeks; or small narrow mangrove-vegetated spits), equal weighting of significance cannot be given to each of them if they have different internal environmental diversity.

In the oceanic islands offshore from the Pilbara mainland, for example, zonation in mangrove involving the greatest number of species occurs in 4 main settings: spits, tidal flats, embayments, and lagoons. There is only a small species pool, and in these settings the environmental factors can only influence four aspects of mangrove populations: their composition (by regulating and eliminating species); vegetation structure; physiognomy; and maintenance of populations. The environmental heterogeneity of a given habitat results in a heterogeneous response in the mangroves in their composition, structure, physiognomy and population maintenance.

In general, therefore, environmental gradients and differences between habitats can be reflected in a variety of structural/ physiognomic categories within a limited floristic assemblage. Thus *Avicennia* may form forests in one habitat, scrub in another, and perhaps heath in a third. This aspect of differential response of mangrove composition, physiognomy, structure and maintenance to variable habitats results in structural as well as compositional diversity of mangroves. The relationships of varying response of mangrove composition and structure to habitat variability and internal gradients provides the basis to scientific significance of mangroves in a given area: areas that illustrate habitat relationship to mangrove vegetation are significant, providing important scientific sites illustrating ecologic principles.

Ecological significance of a given stand:
The significance of mangroves is also linked to the ecological role they play in terms of the fisheries and avifauna they support. In general terms, large, well-developed mangrove stands, with broad low-tidal tidal flats to seawards, tend to be ecologically significant, either locally, or in the region.

Nationally to internationally significant features of a given site:
Finally, the national to international importance of any mangrove stand should be viewed in the setting of the Pilbara mangroves as they are located globally (Semeniuk 1993). All the features described above, if they represent unusual habitats, or assemblages, or habitat/assemblage combinations, potentially assume international significance from a scientific perspective. In the context of the location of the Pilbara Region carrying the Old World mangroves biogeographic region uniquely into an arid setting with a heterogeneous mix of coastal types and habitat types, many habitats represent globally unusual or unique habitats. For example, tidal flats and tidal creeks, and mid-channel shoals are common mangrove habitats globally, but high-tidal alluvial fans, limestone pavements and are not so.

Scale in relation to the significance of mangroves
In discussing the significance of mangroves in the Pilbara area it is necessary to separate large scale processes maintaining large scale mangrove systems from those smaller scale processes maintaining local scale mangrove systems. This is needed in order to separate mangroves that are important because of their areal extent from those that are significant because they illustrate important scientific features and processes at the small scale.

At the large scale, mangroves occur as extensive productive systems that are sites of primary production for coastal food chains. At the large scale, mangroves also colonise distinctive tracts of coasts, such as delta-lands, or barrier complexes, or ria coasts, that have inter-related assemblages in each of the geomorphic settings. These extensive expanses of mangroves are abundant and widespread due to prevailing, ubiquitous processes: e.g., sediment fill of basins and inter-ridges, large scale tidal creek erosion and tidal water fluxes, all of which are the driving factors that develop and maintain the main mangrove formations in the area.

On the other hand, small scale processes may have resulted in developing habitats that are not extensive in area, and do not support large stands of mangroves. In many cases, such habitats, as mentioned above, support unusual stands or assemblages of mangroves that provide insight into mangrove ecology useful for national or global studies. The freshwater seepage from barrier island margins, for instance, or mangroves colonising high tidal alluvial fans, or those on high-tidal limestone pavements exemplify this. Some of the small scale habitats support the most species-rich assemblage in the Pilbara area. For example, in barrier limestone coastal settings, is the pocket beach habitat in a limestone bedrock habitat, that together with freshwater storage/discharge has resulted in an assemblage that contains *Aegialitis annulata*, *Avicennia marina*, *Bruguiera exaristata*, *Ceriops tagal*, *Rhizophora stylosa*, and *Osbornia octodonta*.

Thus, unusual and perhaps nationally significant mangrove assemblages may form because of local scale natural perturbations in the environment, and more common and extensive mangrove formations form because of widespread prevailing conditions. The information in this report therefore should be viewed at these two scales: the extensive scale and the local scale.

This section concentrates on the identification and selection of areas that warrant the greatest protection because they either represent globally to nationally significant mangrove stands, or because they are ecologically important to Western Australia.

The criteria for the selection of areas of high conservation

Choice of Areas of High Conservation must be based rationally on scientifically acceptable criteria. Given the discussions presented above, a number of criteria need to be established in order to select appropriate areas. The criteria need to incorporate the following, in order from most important to least important:

- representation of a coastal type and its accompanying mangroves;
- globally unique mangrove habitats and their assemblages;
- scientifically explicit mangrove/habitat relationships;
- clear and distinct examples of mangrove assemblages floristically;
- clear and distinct examples of mangrove assemblages structurally.

Biologists, ecologists and coastal managers tend to select for protection or conservation those mangrove formations that are large, luxuriant, and well developed, with a primary emphasis being on coastal productivity and function as a nursery, or alternatively, select mangrove formations that exhibit local diversity or species richness. While these matters are not dismissed here, it must be pointed out in the first instance that mangrove stands selected for protection because of their function in regional productivity and nurseries need not be internationally significant, and still can function in this manner amongst other coastal developments. Furthermore, such stands potentially could be rehabilitated sufficiently to re-support nursery functions and primary production if they were to be inadvertently damaged. In the second instance, given that the greatest diversity of mangroves (*i.e.,* species richness) occurs in the humid tropics, given that in Western Australia the most diverse mangrove formations are in the Kimberley region, and given that diversity decreases progressively from the humid Kimberley region to the arid Pilbara region, the best developed mangrove stands in terms of regional species pool diversity will be occurring outside of the Pilbara Region.

Within the Pilbara, species diversity changes from northeast to southwest from 8 species in the De Grey River Delta area, to 7 species in the Cossack area, to 6 species in the Exmouth area, a distance of 500 km, with the loss of *Excoecaria agallocha* and *Osbornia octodonta*. Since *Excoecaria agallocha* penetrates only to a very limited distance into the Pilbara region (it is already absent at Port Hedland), effectively, the Pilbara is represented by 6-7 mangrove species. This means that for much of the Pilbara there are the recurring and familiar species to constitute the mangrove stands. In this context, *Avicennia marina* and *Rhizophora stylosa* are by far the most abundant and widespread of the species, and much of the mangrove formations in the Pilbara may be composed of single species stands of *Avicennia marina*. Species richness or diversity in the Pilbara region in fact mirrors habitat diversity. That is, if the habitats in a given area are simple or depauperate, species richness in that area also tends to be low. If the habitats in a given area are varied, with sandy spits, gravely alluvial fans, tidal creek banks, shoals, and point bars, beaches and tidal flats, for instance, then the species richness in that area is higher. Selecting for species richness essentially becomes a task of selecting coastal types with diverse habitats.

Additionally, with diverse habitats as the basis for selection of mangrove stands for protection, the variability of maintenance mechanisms and variation in plant response to environmental conditions are also preserved.

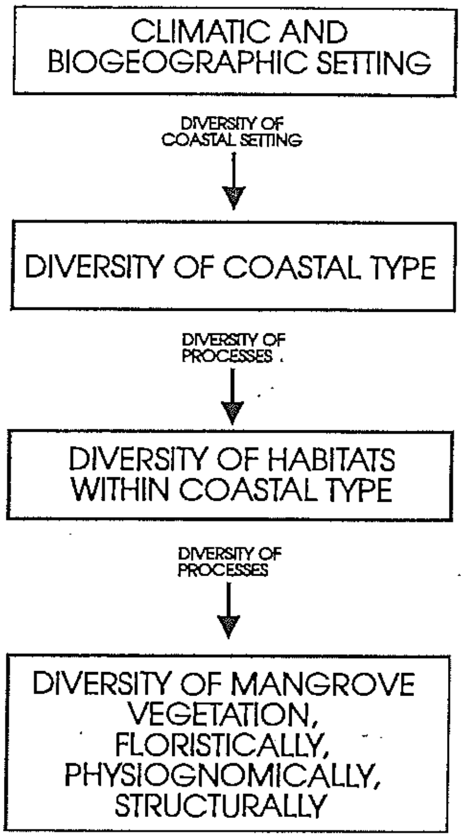
Whereas selection from a purely biological perspective, on the basis of stands of *Avicennia marina* heath alone, may result in perhaps only one representative stand of that mangrove in a given area, a more holistic perspective, using habitat type results in a wider range of *Avicennia* heaths being selected, each showing some variation in relationship to environment. For example, there may be *Avicennia* heath growing on the evaporatively concentrated hypersaline edge of a tidal flat, maintained by vegetative growth; or growing on the seaward margin of an alluvial fan, where salinity is maintained by fresh water influx, and again the population is maintained by vegetative growth; or growing on a sand spit, where salinity is maintained by daily seawater recharge, and the heath population is maintained by seedling recruitment; or growing on a sandy beach, the salinity of which is maintained by daily seawater recharge, and the heath population is maintained by a combination of vegetative growth and seedling recruitment.

The species of mangrove in the coastal formations of Western Australia are not rare or endangered forms, and thus stands of mangroves cannot be justifiably protected on this criterion. However, while all species are well represented elsewhere, and generally are widespread and abundant in the northern more tropical regions of Western Australia, for the Pilbara Region there is a need to protect the various scientifically important settings of the mangroves, and geographic limits of both species and habitats. In the first case, this means that the full variation of the relationship of mangroves to coastal setting and habitats for scientific purposes needs to be protected, largely because Western Australia presents a globally unique range of situations wherein to study/explore mangrove ecology, as described in earlier sections. In the second case, even though a given species is not rare globally, nationally, or State-wide, the geographic limit of a mangrove species and the geographic limit of a habitat type become important. For instance, the southern-most occurrence of *Excoecaria agallocha* is at the De Grey River Delta, and the southern-most occurrence of *Osbornia octodonta* is at Cossack. In both situations, these locations provide invaluable information and insight into the controls on biogeographic distribution and edaphic/climatic factors that control this distribution. Such information, given the unique and heterogeneous coast of Western Australia, may not be present elsewhere globally.

The approach in this study has been to concentrate initially on coastal type, rather than entirely on diverse, extensive, luxuriant and well-developed mangrove formations in isolation. With this approach, the various settings of mangroves are captured, and given that the mangrove species of Western Australia are not globally or nationally significant, then globally important or unique coastal tracts *with* their mangrove associations assume greater significance. Expressed another way, this means that mangroves along a given tract of coast assume greater importance if they occur along a globally unique coast, even if the mangrove species occurring there are not unusual. Also, with this approach using coastal types as the basis for selection, there is greater chance that true diversity is captured, in that heterogeneity of coastal form often means heterogeneity of habitats at the smaller scales.

Identification of the diversity of mangroves should not rest solely on species richness. True diversity of mangroves is reflected by variation in species richness, mangrove physiognomy, mangrove vegetation structure, and mangrove maintenance processes. Only by protecting diverse habitats, such as mud flats, sand flats, gravel flats, beaches, limestone pavements, beach rock pavements, alluvial fans, and so on, are the variations in species assemblages, structure, physiognomy and population maintenance potentially fully captured.

The approach using coastal types as a basis to mangrove conservation also ensures that heterogeneous mix of habitat types and hence a diverse range of mangrove types are preserved in the one coastal setting, and that the range of various habitats and maintenance processes are preserved in the one climatic and biogeographic setting. The essential components of the approach are summarised in the boxed illustration presented below. This shows within a given climatic and biogeographic setting the relationship of the various types of diversity of the mangrove settings that lead at the decreasing scale to diversity of mangrove floristics, physiognomy and structure.



In terms of habitat occurrence, the geographic limit of a given habitat also needs to be protected, especially if that habitat type results in local expression of species diversity. Ria coasts and barrier island coasts exemplify this situation. Both rias and barrier islands are coastal forms that exhibit habitat diversity which results in mangrove assemblage and mangrove species diversity.

The ria coastal forms are widespread in the subhumid to humid Kimberley coastal system, and find their expression in a contrasting climatic regime of the Pilbara in three locations: the Cape Lambert area, the Dampier Archipelago, and the Cape Preston area, with the Dampier Archipelago complex being the largest and best developed system. However, the Cape Preston area represents the most southern expression of this ria style of coast in Western Australia, and in terms of aridity and Old World Mangrove setting, this occurrence is the most southern and most arid example of a ria setting globally.

The same rationale can be applied to barrier island settings. The most northern limestone barrier system occurs in the Port Hedland to Oyster Passage. The most southern limestone barrier complex occurs in the Yardie Landing to Yammerdery Island area. Thus these two areas represent the climatic extremes for the limestone barrier islands. In the former setting, there are 7 mangrove species that inhabit the coastal type, and in the latter there are 6 species.

In more specific terms, coastal areas of high conservation significance in the Pilbara region are to be distinguished on the following criteria, two or more of which make a given selected area even more significant:

good examples of internationally significant or unique tracts of coasts with their accompanying mangrove formations (a limestone barrier complex would be an example)
at a national level, good examples of one of the six coastal types in a relatively undisturbed state, against a background that the southern coasts are located in microtidal environments, the northern ones are in macrotidal environments
regionally significant mangrove vegetation, where significance is determined by: (i) within one type of coastal form, large expanses of monospecific mangroves stands exhibiting relative physiognomic homogeneity; (ii) within one type of coastal form, large expanses of monospecific mangrove stands showing physiognomic zonation or heterogeneity; (iii) within one type of coastal form, large expanses of mangroves showing species zonation; (iv) within one type of coastal form, mangroves showing clear relationship of assemblages and zonation to habitat; (v) mangroves that are extensive, luxuriant, and important for local productivity;
mangroves that show unusual biodiversity or occurrence of uncommon species (such as those at their geographic limits); and
mangrove stands that explicitly exhibit mangrove/habitat relationships.

13.0 Significant wetlands in the Pilbara Region

The significant wetlands of the Pilbara are described in four sections below:

1. significant geoheritage site for inland wetlands in the Pilbara
2. significant general inland wetlands in the Pilbara
3. significant geoheritage site for coastal wetlands in the Pilbara
4. significant mangrove coasts in the Pilbara

The significance has been determined on one or several criteria. For inland wetlands they include avifauna, flora, aquatic fauna, geoheritage values.For coastal wetlands they include avifauna, types of mangrove stands, and geoheritage values.

13.1 Significant geoheritage sites for inland wetlands

Inland wetlands of significance in the Pilbara from a geoheritage perspective are listed below, with their level of assessment.

Inland wetland site	Significance	Rationale
Hamersley Ranges (Karajini wetlands)	International	arid zone freshwater wetlands in a dissected gorge system
Millstream complex	International	arid zone freshwater wetlands in a dissected gorge system, fed by springs and groundwater discharge
Yanrey wetlands	National	arid zone coast plain wetlands

13.2 Significant general inland wetlands

The significant wetlands in the Pilbara Region are listed in the Tables below based on:

- their vegetation
- their avifauna and other fauna
- general features of wetlands.

Specific wetlands of conservation significance based on vegetation are listed in the Table below with the numbers referring to locations on the map in Figure 11. Specific wetlands of conservation significance based on avifauna are listed in the Table below with numbers referring to locations on the map in Figure 12. Wetlands selected on geoheritage criteria are shown in Figure 13. Wetlands selected for conservation on more general holistic criteria are shown in Figure 14.

Wetlands selected on vegetation criteria

	Species name	Location	Level of significance
No. on Map	**Priority 1 species**		
1	*Barbula ehrenbergii*	Dales Gorge, Hamersley Ranges	State-wide
2	*Eremophila coacta*	16.1 km Nw of Ashburton downs on Kooline road	State-wide
3	*Eremophila rigens*	20.2 km SW of Ashburton Downs	State-wide
4	*Eremophila spongiocarpa*	20 km E of Cowra Outcamp of Mulga Downs Station	State-wide
5	*Eucalyptus marandoo (aff. coolibah var. rhodoclada)*	Marandoo corridor, Mindi Springs	State-wide
6	*Fimbristylis "Shay Gap"*	Shay Gap; inhabits sandy drainage line	State-wide
7	*Goodenia nuda*	Weeli Wolli, Roy Hill; Mt Stuart	State-wide
8	*Mimulus clementii*	between Ashburton and DeGrey Rivers	State-wide
9	*Myriocephalus aff. nudus*	12 ml S of Yannarie river on N.W.C. Hwy; 4.1 km NW along Grt. Nthn. Hwy from Mt. Robinson turnoff, Hamersley Ranges	State-wide
	Priority 2 species		
10	*Dicladanthera glabra*	Bee Gorge & Wittenoom Gorge, Hamersley Range; Robe River	State-wide
11	*Euphorbia drummondii ssp. "Pilbara"*	Tambrey Station, Mt Edgar, Lyndon Station, Millstream	State-wide
12	*Goodenia stellata*	Hamersley Range NW of Tom Price and Newman	State-wide
13	*Olearia fluvialis*	Wittenoom Gorge	State-wide
14	*Olearia mucronata**	Turner syncline E of Paraburdoo	State-wide
15	*Stylidium weeliwolli*	Weeli Wolli Springs, Weeli Wolli Creek	State-wide

	Priority 3 species		
16	*Bulbostylis burbidgeae*	Mt Edgar, Gorge Creek, Abydos-Woodstock	State-wide
17	*Desmodium campylocaulon*	18 km WNW of Newman; ca Hooley Station, Mulga Downs Hmstd and Warrawagine Station	State-wide
18	*Eriachne tenuiculmis*	Gregory Gorge, ca CRRIA Fortescue Rv Bridge, W of Hamersley Hmstd, Weelamurra Ck, Hamersley Range, Dampier Archipelago	State-wide
19	*Fimbristylis sieberiana*	Hamersley Range, Millstream; inhabits Kalaminna Falls, muddy levee bank, edge of watercourses	State-wide
20	*Fuirena incrassata*	Oakover River, Wandanya, Deep Creek	State-wide
21	*Glycine falcata*	30 km W of Mulga Downs Homestead	State-wide
22	*Hibiscus brachysiphonius*	20 km E of Millstream, 30 km W of Tom Price; Karratha; ca Yanyare Rv, Dampier	State-wide
23	*Rhynchosia sp.*	Deepdale, Robe River; Yathala Well; ca Yarraloola Hmstd.; Bee Gorge, Hancock Gorge, Hamesley Range;ca Quarry Hill; ca	State-wide
24	*Triumfetta appendiculata*	Fortescue River to Karratha	State-wide
25	*Triumfetta maconochiena*	Woodstock Station, Harding River, Ruddall River, Newman, Weeli Wolli Creek	State-wide
26	*Wurmbia saccata*	Barlee Range Nature Reserve	State-wide
	Priority 4 species		
27	*Livistonia alfredii*	Millstream, Cave Creek; inhabits watercourses	State-wide
	Rare species		
28	*Lepidium catapycnon*	Weeli Wolli, Wittenoom Gorge, Hamersley Range, Newman	State-wide

Wetlands selected on avifaunal and general faunal criteria

Wetland system	**Rationale for significance**	**Level of Significance**
Barlee Range Wetland System (including Kookhabinna Gorge and Yadjiyugga Claypan)	diverse range of fauna species (46 species of bird, 11 species of bat, the Olive Python (*Liasis olivaceus*), five species of frog and seven species of freshwater fish; an undescribed species of *Cassytha* occurs in the Kookhabinna Gorge and a new species of nancy lily (Wurmbia sp.) is found only in the gorges of the Barlee Range	National level: Yadjiyugga Claypan, Kookhabinna Gorge and the downstream area are entirely within the Barlee Range Nature Reserve and the Reserve is listed on the Register of the National Estate and in the Directory of Important Wetlands
Carawine Pool	refuge for waterbirds in the dry season (at least 61 species) including at least 15 species of waterbird, two of these are listed under international treaties)	International level: Carawine Pool is listed on the Register of the National Estate
De Grey River Wetland System	permanent pools together constitute a significant drought refuge to wildlife, particularly fresh water fish and waterbirds (at least 20 species of waterbird)	National level: De Grey River Wetland System is listed in the Directory of Important Wetlands

Only on indicative list

Fortescue Marshes Wetland System	22 species of waterbird of which five species breed; 5,000-10,000 waterbirds have been recorded; one of only 68 wetlands in arid Australia where 10,000 or more waterbirds have been recorded	National level: listed in the Directory of Important Wetlands and most of this wetland system is listed on the Register of the National Estate
Karijini Gorges Wetland System (Hamersley Range)	refuge for disjunct flora and rare fauna and an important permanent source of water to wildlife: supports a large range of fauna including 47 species of bird (16 species of waterbird and breeding in at least one species), at least five species of bat including Ghost Bat (*Macroderma gigas)* the Common Rock Rat (*Zyzomys argurus*), three species of frog and six species of fish	International level: listed on the Register of the National Estate (status Registered) and is listed in the Directory of Important Wetlands

Millstream Wetland System	supports 108 species of bird (including the 38 species of waterbird of which 8 species breed); one of the few known isolated breeding populations of the Black Bittern and Purple Swamphen; supports a major colony of Black Flying Fox (*Pteropus alecto*), as well as *P. scapulatus*; there is a rich fish fauna (9 species) and a number of endemic insects including 29 species of dragonfly and damselfly; a significant area of isolated habitat for wetland flora and fauna, some species of which do not occur, or are rare, elsewhere in NW Australia; the system supports an endemic palm	International level: the Millstream Wetland System lies in the Millstream National Park which is listed on the Register of the National Estate (status Registered) and is listed in the Directory of Important Wetlands; an outstanding example of a system of permanent river pools and springs in the semi-arid tropics and the best known in northern Western Australia
Marree Pool	permanent pool supports an abundance of bird life	Statewide level
Sherlock River Pool	permanent river pool that supports an abundance of bird life including a variety of waterbirds	Statewide level
Weeli Wolli Springs	oasis in an arid landscape	Statewide level

Wetlands selected on general (holistic) criteria

Inland wetland site	**Significance**	**Rationale and atributes important to conservation**
Hamersley Ranges (Karajini wetland)	International	arid zone freshwater wetlands in a dissected gorge system: fauna, flora, wetlands in a geologcal setting
Millstream complex	International	arid zone freshwater wetlands in a dissected gorge system, fed by springs and groundwater discharge: fauna, flora, wetlands in a geologcal setting
Yanrey wetlands	National	arid zone coast plain wetlands: setting in a delta plain
Duck Creek system	National	arid zone freshwater wetlands; Duck Creek Gorge has exceptional outcrops of dolomite and has great scientific and research value
Weeli Wolli Springs/pool	National	arid zone freshwater wetlands: fauna, flora, wetlands in a geologcal setting
Coppin Gap	State	arid zone wetland: fauna, flora, wetlands in a geologcal setting
Miaree Pool	Regional	arid zone wetland: fauna, flora, wetlands in a geologcal setting
Bullinnarwa Pool	Regional	arid zone wetland: fauna, flora, wetlands in a geologcal setting
Minnorinna Pool	Regional	arid zone wetland: fauna, flora, wetlands in a geologcal setting
Yanna Pool	Regional	arid zone wetland: fauna, flora, wetlands in a geologcal setting
Kyalina Pool	Regional	arid zone wetland: fauna, flora, wetlands in a geologcal setting
Yarramudda Pool	Regional	arid zone wetland: fauna, flora, wetlands in a geologcal setting

13.3 Significant geoheritage sites for coastal wetlands

Coastal wetlands of significance in the Pilbara from a geoheritage perspective are listed below, with their level of assessment. They are located on Figure 13.

Coastal site	Significance	Rationale
Exmouth Gulf east shore	International	gulf fringing mud flats; unique type of delta
Ashburton River Delta	National	arid zone delta, sand dominated with bars, and lagoons
Onslow-Coolgra Point coast	National	arid zone coast forms
Robe River Delta	International	facies change in a granule to gravel delta
Fortescue River Delta	International	gravel delta
Maitland Delta	National	arid zone delta, sand dominated with bars, and lagoons
Dampier Archipelago	International	arid zone ria/archipelago
Nickol Bay	State level	style of coast
Cape Lambert complex	State level	arid zone ria/archipelago
Harding River Delta	State level	style of delta in arid setting
Balla Balla coast to Ronsard Island	National	style of barrier and eroding coast in an arid setting
Yule River Delta	State level	style of delta in arid setting
Turner River Delta	State level	style of delta in arid setting
Port Hedland barrier coast	International	style of coast of oolite limestone barrier complex in an arid setting
De Grey River Delta	International	style of delta in arid setting

13.4 Significant mangrove coasts in the Pilbara

The following text is a description of and rationale for selection of significant areas of mangroves in the Pilbara. In the coastal region of the Pilbara, between Exmouth Gulf and the De Grey River delta, but not encompassing the area of the islands of the Northwest Shelf offshore from the mainland, there are 21 designated significant areas identified on the mainland in this study. These areas have been identified using the criteria outlined above. The areas occur within three natural coastal regions (Semeniuk 1993): the Pilbara Coast, incorporating the mainland coast between Giralia Bay and the De Grey River Delta; and the Carnarvon Province, incorporating the west shore of Exmouth Gulf.

From south to north, the areas are (Figure 15):

1. Bay of Rest
2. Giralia Bay to Yanrey Flats, Exmouth East Shore
3. Ashburton River Delta
4. Coolgra Point
5. Yardie Landing, Yammadery Island and the Mangrove Islands
6. Robe River Delta
7. Fortescue River Delta
8. Cape Preston area
9. Maitland River Delta
10. West Intercourse Island, Dampier Archipelago
11. Enderby Island Complex, Dampier Archipelago
12. Searipple Passage to Conzinc Bay, Dampier Archipelago
13. Nickol River Embayment
14. Dixon Island Complex
15. Cossack to Harding Delta Complex
16. Sherlock Bay Sector
17. Ronsard Island area
18. Yule River Delta
19. Turner River Delta
20. Oyster Passage Barrier
21. De Grey River Delta

Each of these areas are briefly described below, in terms of setting, habitats, and mangrove formations. Following this, there is a description of how the various criteria for selecting areas of high conservation significance have been satisfied.

Bay of Rest:
The Bay of Rest area is located in the Carnarvon Province, and is associated with a Quaternary limestone barrier on the eastern margin of the Cape Range structure. It represents, within Exmouth Gulf, a diverse system of habitats developed behind the Quaternary limestone barrier, including tidal flats, tidal creeks, spits, alluvial fans, and high tidal gravel fans. Hence there is a diverse range of mangrove species, with 6 species present (*Aegialitis annulata*, *Aegiceras corniculatum*, *Avicennia marina*, *Bruguiera exaristata*, *Ceriops tagal*, *Rhizophora stylosa*). In this context, it is the southern-most location in Western Australia where all these 6 six species of mangrove are present. The mangroves are not extensive, but nevertheless significant.

Giralia Bay to Yanrey Flats, Exmouth East Shore:
The area encompassing Giralia Bay and Yanrey Flats along the Exmouth eastern shore is located in the south-western-most part of the Pilbara Coast. It comprises large expanses of tidal flats and seaward-fringing mangroves. Technically, the east shore of Exmouth Gulf is part of the Yanrey River delta, but it also contains some local limestone barrier islands (Simpson Island, Burnside Island, and Tent Island). Though it is not diverse in terms of habitats, it represents, within Exmouth Gulf, a widespread and important mangrove system in that it exhibits insular-peninsular tidal flat topography and tidal creek networks, and a large scale continuous tidal flat mangrove formation. In regional terms, it is an important location for the fisheries of Exmouth Gulf. Throughout the main belt of mangroves there is a recurring pattern of 2 mangrove species, viz., *Avicennia marina*, and *Rhizophora stylosa*. The tidal creek networks in the system provide some diversity of habitats, such as creek banks, point bars and shoals, where a larger range of mangroves occur (*Avicennia marina*, *Rhizophora stylosa*, *Aegialitis annulata*, *Aegiceras corniculatum*). The barrier limestone islands in the system provide some diversity of habitats, such as spits, beaches and limestone cliffs, in addition to tidal flats, and here the full range of 6 species of mangrove occur (*Aegialitis annulata*, *Aegiceras corniculatum*, *Avicennia marina*, *Bruguiera exaristata*, *Ceriops tagal*, *Rhizophora stylosa*).

Ashburton River Delta:
The Ashburton River Delta is one of the three largest deltas in the Pilbara region, encompassing the area between Rocky Point and Entrance Point. As a system, the Ashburton River Delta is a sand and mud delta, and hence contains a range of habitats such as sand ridges and associated swales, barred lagoons, mud flats, tidal creeks, spits, cheniers, tributaries and abandoned tributaries. The delta is active, and important regionally in that it exhibits a coastal history of dynamic channel changes and readjustment of tidal landforms, with concomitant changes and complexity to the mangrove assemblages. The dominant mangroves in the system are *Avicennia marina* and *Rhizophora stylosa*, and these occur in most of the commonly occurring habitats. The full range of habitats in the delta at the small scale result in some diversity of vegetation, with 6 species of mangrove locally occurring in areas where there are spits, or point bars, or beaches (*Aegialitis annulata*, *Aegiceras corniculatum*, *Avicennia marina*, *Bruguiera exaristata*, *Ceriops tagal*, *Rhizophora stylosa*). The mangroves in the system vary from extensive and thick in local inter-ridge areas, to fringing tidal-creeks, cheniers, and sand-ridges.

Coolgra Point:
Coolgra Point is located to the northeast of Onslow. It combines a limestone barrier system and an adjacent beach/dune coast. The barrier protects a rich mangrove system to leeward. The beach/dune barrier is associated with a tidal creek system. Both coastal types are good representatives of coastal form and habitats in the Pilbara region. The Coolgra Point area contains a range of variable and important mangrove habitats: limestone pavements, local spits, and to leeward, mud flats and tidal creeks. The dominant mangroves in the system are *Avicennia marina* and *Rhizophora stylosa*, and these occur in most of the commonly occurring habitats. The full range of habitats at the small scale result in some diversity of vegetation, with 6 species of mangrove locally occurring in areas where there are spits, or point bars, or beaches (*Aegialitis annulata*, *Aegiceras corniculatum*, *Avicennia marina*, *Bruguiera exaristata*, *Ceriops tagal*, *Rhizophora stylosa*). The mangroves in the system are not extensive, but nevertheless important for the geomorphic and habitat setting they illustrate.

Yardie Landing, Yammadery Island and the Mangrove Islands:
The area encompassing Yardie Landing, Yammadery Island and the associated offshore Mangrove Islands (North Mangrove Island, Middle Mangrove Island, and South Mangrove Island) are important mangrove systems. They represent stages of isolation and erosion of limestone barriers and islands along the Pilbara Coast, with the concomitant development of erosional coastal landforms such as tidal creek networks, and they present mangrove assemblages in a limestone island setting that is regionally to globally distinct. The limestone barrier that trends from Yardie Landing to Yammadery Island protects an extensive and rich mangrove system to leeward that are developed on mudflats and tidal creek networks. The three islands offshore contain a range of variable and important mangrove habitats: limestone pavements, limestone cliffs, beaches, local sand spits, and mud flats. The dominant mangroves in the system are *Avicennia marina* and *Rhizophora stylosa*, and these occur in most of the commonly occurring habitats. The full range of habitats at the small scale result in some diversity of vegetation, with 6 species of mangrove locally occurring in areas where there are spits, or point bars, or beaches (*Aegialitis annulata*, *Aegiceras corniculatum*, *Avicennia marina*, *Bruguiera exaristata*, *Ceriops tagal*, *Rhizophora stylosa*).

Robe River Delta:
The Robe River Delta is a large Pilbara delta system, and encompasses the area between Weld Island to Cowrie Island. As a system, the Robe River Delta is a gravel-dominated delta, and is fronted by series of limestone and gravel barriers that are locally breached by tidal creeks. The main mangrove habitats are in the tidal creek networks, and here leeward of the barriers are developed extensive and thick mangrove formations. The Robe River Delta contains the following habitats: gravel and sand ridges and associated swales, local mud flats, tidal creeks, and tributaries and abandoned tributaries. The delta is largely inactive, but it is important regionally in that it exhibits a type of delta in the Pilbara region and its associated complexity in mangrove assemblages, and exhibits the progressive breakup of the seaward barrier by tidal creeks in a west to east direction. The dominant mangroves in the system are *Avicennia marina* and to a lesser extent, *Rhizophora stylosa*, and these occur in most of the commonly occurring habitats.

Fortescue River Delta:
The Fortescue River Delta is the second of the three largest Pilbara delta systems. The Fortescue River Delta is a gravel-dominated delta, and is fronted by series of limestone and gravel barriers that are locally breached by tidal creeks. Unlike the Robe River Delta, this system is more active, and more gravel dominated to the northwest. The main mangrove habitats in this system are in the tidal creek networks. In that portion of the Fortescue River Delta system recommended for designation as a coastal type of high conservation significance, there are three important coastal sectors: 1. Coonga Tidal Creek; 2. the Fortescue River Mouth; and 3. Edward Creek outlet.

One of the best examples of the tidal creek incisions into the barriers of the Fortescue River Delta is the Coonga Tidal Creek system. Here the tidal creek had incised into the gravel barrier, and is not sourced in a deltaic tributary. In the Coonga Tidal Creek area, the Fortescue River Delta contains the following habitats: seafront gravel flats, high-tidal sand plain, associated swales, local mud flats, and tidal creeks. Though the delta is largely inactive, and the tidal creek incising it is an erosional feature, the system is important regionally in that it exhibits a type of delta in the Pilbara region and its associated complexity in mangrove assemblages. The mangrove formation here is not large and regionally extensive, but nevertheless important. The dominant mangroves in the system are *Avicennia marina* and to a lesser extent, *Rhizophora stylosa*, and these occur in most of the commonly occurring habitats. Locally, with the edge of the sand plain and in the tidal creek deposits, there is development of *Aegialitis annulata*, *Aegiceras corniculatum*, and *Ceriops tagal*.

Where the Fortescue River empties into the sea, there have been built a series of gravel ridges, associated inter-ridge swales, tidal creek networks. Here there is an important and unusual association of gravel fans, inter-ridge swales, gravel ridges, tidal creeks, and gravel flats, each with an associated mangrove assemblage. The mangrove formations here again are not large and regionally extensive, but nevertheless important. The dominant mangroves in the system are *Avicennia marina* and to a lesser extent, *Rhizophora stylosa* and *Ceriops tagal*. These occur in most of the commonly occurring habitats. Also occurring in this system, locally are *Aegialitis annulata*, *Aegiceras corniculatum* and *Bruguiera exaristata*.

The Edward Creek outlet system resides on a tidal creek network within the northeastern part of the Fortescue River Delta, but unlike the Coonga Creek system, the Edward Creek outlet is sourced ultimately on a tributary system .of the Fortescue River where it abuts Precambrian bedrocks of the Cape Preston Complex. This tidal creek network contains the usual assemblage of mangrove species, including *Aegialitis annulata*, *Aegiceras corniculatum*, *Avicennia marina*, *Bruguiera exaristata*, *Ceriops tagal*, and *Rhizophora stylosa*. The mangrove formation here is not large and regionally extensive, but nevertheless important.

Cape Preston area:
The Cape Preston, and the adjoining Regnald Bay, presents the most southern of the occurrences of ria/ archipelago shores. As such it presents along the arid Pilbara Coast the most southern development ria-shore type of mangrove habitats that are more fully represented in the Dampier Archipelago. In this system, there are developed mud flats, tidal creeks, rocky shores, high-tidal alluvial fans, high-tidal colluvial slopes, and spits. Mangrove formations here are extensive behind the shelter afforded by the Cape structure.

Maitland River Delta:
The Maitland River Delta is a medium Pilbara delta system. Its importance lies in the fact that it borders the Dampier Archipelago system to the southwest, and as such shows a major change in facies from west (sand and mud) to east (mud-dominated) as a result of the increasing effect of the shelter afforded by the structure of the Archipelago. As a system, the bulk of the Maitland River Delta is an active sand and mud delta, and hence contains a range of habitats such as sand ridges and associated swales, barred lagoons, mud flats, tidal creeks, spits, cheniers, tributaries and abandoned tributaries. The extent of the mangrove formations varies from well developed in the east in the muddier environments where the structure of the Dampier Archipelago provides protection, to less well developed in the west where wave action allows development of sand-dominated landform structures. The dominant mangroves in the system are *Avicennia marina* and *Rhizophora stylosa*, and these occur in most of the commonly occurring habitats. The full range of habitats in the delta at the small scale result in some diversity of vegetation, with 6 species of mangrove locally occurring in areas where there are spits, or point bars, or beaches (*Aegialitis annulata*, *Aegiceras corniculatum*, *Avicennia marina*, *Bruguiera exaristata*, *Ceriops tagal*, *Rhizophora stylosa*).

West Intercourse Island, Dampier Archipelago:
The West Intercourse Island Complex, Dampier Archipelago, is an example of mangroves developed along an archipelago shore. The island presents two types of ria/archipelago settings: 1. mud-dominated tidal-land-connected environments with a full range of ria-type mangrove habitats, and with the mangroves *Aegialitis annulata*, *Aegiceras corniculatum*, *Avicennia marina*, *Bruguiera exaristata*, *Ceriops tagal* and *Rhizophora stylosa*; the mangrove formation here is thick and well developed but medium scale in terms of extent, and is one of the most important mangrove stands in the Dampier Archipelago; 2. high to mid-tidal alluvial fan setting along a rocky shore where there is an important zonation of mangroves developed concentric to the fan outline, and involving *Avicennia marina*, *Ceriops tagal* and *Rhizophora stylosa*; the mangrove formations here are not thick and extensive but scientifically very important.

Enderby Island Complex, Dampier Archipelago:
The Enderby Island Complex, Dampier Archipelago, is an example of mangroves developed along an archipelago shore. The island has three types of ria/archipelago shores: 1. mud-dominated embayments, with the full range of ria-type mangrove habitats, and with the mangroves *Aegialitis annulata*, *Aegiceras corniculatum*, *Avicennia marina*, *Bruguiera exaristata*, *Ceriops tagal* and *Rhizophora stylosa*; the mangrove formation is thick and well developed but medium scale in terms of extent; 2. sand-dominated embayments, with the full range of ria-type mangrove habitats, and with the mangroves *Aegialitis annulata*, *Avicennia marina*, *Ceriops tagal* and *Rhizophora stylosa*; the mangrove formations here are not thick and extensive; and 3. beach-ridge barrier and tidal creek system, with mainly *Avicennia marina* in local patches.

Searipple Passage to Conzinc Bay, Dampier Archipelago:
Searipple Passage to Conzinc Bay contains two types of settings of mangrove coasts within the Dampier Archipelago. Searipple Passage is a narrow tidal strait cut into bedrock and underlain by limestone; within local broad embayments there are a range of habitats and zoned mangroves, and mangrove vegetated shoals nucleated on bedrock islands (the main species being *Avicennia marina*, *Bruguiera exaristata*, *Ceriops tagal* and *Rhizophora stylosa*). The mangroves here are thick but not extensive. Secondly, Conzinc Bay represents a mud-dominated embayment setting within the Dampier Archipelago, again with the full range of ria-type mangrove habitats (with the mangroves *Aegialitis annulata*, *Aegiceras corniculatum*, *Avicennia marina*, *Bruguiera exaristata*, *Ceriops tagal* and *Rhizophora stylosa*). The Conzinc Bay setting represents a larger and more exposed embayment setting than the muddy embayment described from Enderby Island. Again, the mangroves in Conzinc Bay are thick but not extensive.

Nickol River Embayment:
The Nickol River Embayment is a large scale mangrove-vegetated embayment in the Pilbara region. The components of the embayment setting are well represented here: a mud-filled embayment, a seafront of mangroves, tidal creek networks, and a high-tidal fan system from the Nickol River. The main mangrove here is *Avicennia marina*, and it exhibits structural and physiognomic zonation. The mangroves *Ceriops tagal* and *Rhizophora stylosa* also are locally present. The mangroves here are thick but not extensive.

Dixon Island Complex:
The Dixon Island complex presents, within a large embayment coast, a sheltered island system leeward of which are extensive mangrove formations. As such it presents along the arid Pilbara Coast a local development of an archipelago/ria shore type of mangrove habitats that are more fully represented in the Dampier Archipelago. In this system, there are developed mud flats, tidal creeks, rocky shores, high-tidal alluvial fans, high-tidal colluvial slopes, and spits. Mangrove formations here are extensive behind the shelter afforded by the Dixon Island, and a full range of species are developed here: *Aegialitis annulata*, *Aegiceras corniculatum*, *Avicennia marina*, *Bruguiera exaristata*, *Ceriops tagal* and *Rhizophora stylosa*.

Cossack to Harding Delta Complex:
The Cossack to Harding Delta Complex represents a deltaic system juxtaposed against rocky structure of an archipelago/ria coast of the cape Lambert structure. The Cossack area is a ria coastal type, although it is somewhat anthropogenically modified, it is the site with the most southern occurrence of *Osbornia octodonta* in the southern hemisphere. The shelter afforded by the Cape Lambert structure had created an unusual delta for the Harding River. As a system, the Harding River Delta is a sand and mud delta, and it is bordered to its east by limestone barriers and sand ridges where the coast becomes more exposed. The range of habitats in the delta include mud flats, tidal creeks, spits, cheniers, tributaries and abandoned tributaries. The dominant mangroves in the system are *Avicennia marina* and *Rhizophora stylosa*, and these form extensive formations. The other mangroves in the system include *Aegialitis annulata*, *Aegiceras corniculatum*, *Bruguiera exaristata* and *Ceriops tagal*.

Sherlock Bay Sector:
The Sherlock Bay area, representing the eroding seafront of the Little Sherlock River delta, is a coastal sector fronted by series of limestone and sand barriers that are locally breached by tidal creeks. The main mangrove habitats are in the tidal creek networks, and here, leeward of the barriers, are developed extensive and thick mangrove formations. The Sherlock Bay coastal sector contains the following habitats: limestone and sand ridges and associated swales, mud flats, and tidal creeks. The area exhibits the progressive breakup of seaward barriers by tidal creeks. The dominant mangroves in the system are *Avicennia marina* and to a lesser extent, *Rhizophora stylosa*.

Ronsard Island area:
The Ronsard Island area, representing the eroding seafront of the Peewah River delta, is a large muddy tidal flat complex protected in part by Ronsard Island. As a system, this coastal sector is comprised of muddy tidal flats and cheniers, locally breached by tidal creeks, and contains extensive mangrove formations fronting the tidal flats and residing in the tidal creek networks. It is one of the best locations in the Pilbara for the development of cheniers through time on the muddy tidal flats. The dominant mangroves in the system are *Avicennia marina* and to a lesser extent, *Rhizophora stylosa*; *Aegialitis annulata*, *Aegiceras corniculatum*, *Bruguiera exaristata* and *Ceriops tagal* also occur locally.

Yule River Delta:
The Yule River Delta is a large Pilbara delta system, comprising a range of habitats such as sand ridges and associated swales, barred lagoons, mud flats, tidal creeks, spits, cheniers, tributaries and abandoned tributaries. The delta is largely inactive, but is important regionally in that it exhibits a long term history of dynamic coastal evolution with the development of barriers and associated protected tidal creek systems, with concomitant changes and complexity to the mangrove assemblages. Mangroves in the protected tidal creek networks are extensive, and the dominant mangroves in the system are *Avicennia marina* and *Rhizophora stylosa*, and these occur in most of the commonly occurring habitats. The full range of habitats in the delta at the small scale result in some diversity of vegetation, with 6 species of mangrove locally occurring in areas where there are spits, or point bars, or beaches (viz., *Aegialitis annulata*, *Aegiceras corniculatum*, *Avicennia marina*, *Bruguiera exaristata*, *Ceriops tagal*, *Rhizophora stylosa*).

Turner River Delta:
The Turner River Delta is a medium Pilbara delta system, comprising of mudflats, tidal creeks, sand ridges, spits, cheniers, tributaries and abandoned tributaries. The delta is largely inactive, but is important regionally in that it exhibits a long term history of coastal erosion with the development of tidal creek systems wherein are developed the mangrove formations. Mangroves in the tidal creek networks are extensive, and the dominant mangroves in the system are *Avicennia marina* and *Rhizophora stylosa*.

Oyster Passage Barrier:
The Oyster Passage Barrier is a limestone barrier coast, and with its mangrove stands, represents the most northern occurrence and best developed mangrove remaining in such a barrier setting in the Pilbara. The barrier protects mangroves to leeward. Mangrove habitats include: mudflats, tidal creeks, spits, cheniers, limestone cliffs, limestone pavements, and beaches. The barrier protects an extensive and rich mangrove system developed on mudflats and tidal creek networks. Dominant mangroves are *Avicennia marina* and *Rhizophora stylosa*, and these occur in the most commonly occurring habitats. The full range of habitats at small scale result in some vegetation diversity, with 7 species locally occurring in areas of spits, or point bars, or beaches (viz., *Aegialitis annulata*, *Aegiceras corniculatum*, *Avicennia marina*, *Bruguiera exaristata*, *Ceriops tagal*, *Osbornia octodonta*, and *Rhizophora stylosa*).

De Grey River Delta:
The De Grey River Delta is the third of the large Pilbara delta systems. The De Grey River Delta is an active sand and mud delta, and contains a range of habitats such as sand ridges and associated swales, barred lagoons, mud flats, tidal creeks, spits, cheniers, tributaries and abandoned tributaries. The dominant mangroves in the system are *Avicennia marina* and *Rhizophora stylosa*, and these occur in most of the commonly occurring habitats. The full range of habitats in the delta at the small scale result in some diversity of vegetation, with 7 species of mangrove locally occurring in areas where there are spits, or point bars, or beaches (*Aegialitis annulata*, *Aegiceras corniculatum*, *Avicennia marina*, *Bruguiera exaristata*, *Ceriops tagal*, *Rhizophora stylosa*). This delta also is important regionally in that it is the location for the most southern occurrence of the mangrove *Excoecaria agallocha*.

Correlation of the selected areas with the criteria

This section correlates the key features of the selected areas, described above, with respect to the criteria presented earlier. The selected areas are assessed in the accompanying Tables below, in terms of each of the following criteria:

- representation of a coastal type and its accompanying mangroves
- globally unique mangrove habitats and their assemblages
- scientifically explicit mangrove/habitat relationships
- clear and distinct examples of mangrove assemblages floristically
- clear and distinct examples of mangrove assemblages structurally.

Assessment of representation of coast type and mangroves

COASTAL SECTOR:	CRITERION 1: Representation of coastal type and mangroves
1. Bay of Rest	YES
2. Giralia Bay - Yanrey Flats	YES
3. Ashburton River Delta	YES
4. Coolgra Point	YES
5. Yardie Landing, Mangrove Islands	YES
6. Robe River Delta	YES
7. Fortescue River Delta	YES
8. Cape Preston area	YES
9. Maitland River Delta	YES
10. West Intercourse Island	YES
11. Enderby Island Complex	YES
12. Searipple Passage to Conzinc Bay	YES
13. Nickol River Embayment	YES
14. Dixon Island Complex	YES
15. Cossack to Harding Delta	YES
16. Sherlock Bay Sector	YES
17. Ronsard Island area	YES
18. Yule River Delta	YES
19. Turner River Delta	YES
20. Oyster Passage Barrier	YES
21. De Grey River Delta	YES

Assessment as globally unique mangrove habitats and assemblages

COASTAL SECTOR:	CRITERION 2: Globally unique mangrove habitats and assemblages
1. Bay of Rest	YES
2. Giralia Bay - Yanrey Flats	
3. Ashburton River Delta	
4. Coolgra Point	YES
5. Yardie Landing, Mangrove Islands	YES
6. Robe River Delta	YES
7. Fortescue River Delta	YES
8. Cape Preston area	YES
9. Maitland River Delta	
10. West Intercourse Island	YES
11. Enderby Island Complex	YES
12. Searipple Passage to Conzinc Bay	YES
13. Nickol River Embayment	
14. Dixon Island Complex	YES
15. Cossack to Harding Delta	
16. Sherlock Bay Sector	
17. Ronsard Island area	
18. Yule River Delta	
19. Turner River Delta	
20. Oyster Passage Barrier	YES
21. De Grey River Delta	

Assessment as scientifically explicit mangrove/habitat relationships

COASTAL SECTOR:	CRITERION 3: Scientifically explicit mangrove/ habitat relationships
1. Bay of Rest	YES
2. Giralia Bay - Yanrey Flats	YES
3. Ashburton River Delta	
4. Coolgra Point	
5. Yardie Landing, Mangrove Islands	YES
6. Robe River Delta	YES
7. Fortescue River Delta	YES
8. Cape Preston area	YES
9. Maitland River Delta	
10. West Intercourse Island	YES
11. Enderby Island Complex	YES
12. Searipple Passage to Conzinc Bay	YES
13. Nickol River Embayment	
14. Dixon Island Complex	YES
15. Cossack to Harding Delta	
16. Sherlock Bay Sector	
17. Ronsard Island area	YES
18. Yule River Delta	YES
19. Turner River Delta	YES
20. Oyster Passage Barrier	YES
21. De Grey River Delta	YES

- Clear and distinct examples of mangrove assemblages floristically

COASTAL SECTOR:	CRITERION 4: Clear, distinct examples of mangrove floristically
1. Bay of Rest	YES
2. Giralia Bay - Yanrey Flats	YES
3. Ashburton River Delta	YES
4. Coolgra Point	YES
5. Yardie Landing, Mangrove Islands	YES
6. Robe River Delta	YES
7. Fortescue River Delta	YES
8. Cape Preston area	YES
9. Maitland River Delta	YES
10. West Intercourse Island	YES
11. Enderby Island Complex	YES
12. Searipple Passage to Conzinc Bay	YES
13. Nickol River Embayment	
14. Dixon Island Complex	YES
15. Cossack to Harding Delta	YES
16. Sherlock Bay Sector	
17. Ronsard Island area	
18. Yule River Delta	
19. Turner River Delta	
20. Oyster Passage Barrier	YES
21. De Grey River Delta	YES

- Clear and distinct examples of mangrove assemblages structurally

COASTAL SECTOR:	CRITERION 5: Clear, distinct examples of mangrove structurally
1. Bay of Rest	YES
2. Giralia Bay - Yanrey Flats	YES
3. Ashburton River Delta	
4. Coolgra Point	
5. Yardie Landing, Mangrove Islands	YES
6. Robe River Delta	
7. Fortescue River Delta	YES
8. Cape Preston area	
9. Maitland River Delta	
10.West Intercourse Island	YES
11.Enderby Island Complex	YES
12.Searipple Passage to Conzinc Bay	YES
13.Nickol River Embayment	YES
14.Dixon Island Complex	YES
15.Cossack to Harding Delta	
16.Sherlock Bay Sector	
17.Ronsard Island area	
18.Yule River Delta	
19.Turner River Delta	
20.Oyster Passage Barrier	
21.De Grey River Delta	YES

The selected areas are also assessed in the Table below in terms of international, national, and regional ranking, as listed in the criteria below:

- good examples of internationally significant or unique tracts of coasts with their accompanying mangrove formations (a limestone barrier complex would be an example); ranked as "I";
- at a national level, good examples of one of the six coastal types in a relatively undisturbed state, against a background that the southern coasts are located in microtidal environments, the northern ones are in macrotidal environments; ranked as "N";
- regionally significant mangrove vegetation, *i.e.,* of State-wide significance, ranked as "R", where significance is determined by:
  (i) within one type of coastal form, large expanses of monospecific mangroves stands exhibiting relative physiognomic homogeneity;
  (ii) within one type of coastal form, large expanses of monospecific mangrove stands showing physiognomic zonation or heterogeneity;
  (iii) within one type of coastal form, large expanses of mangroves showing species zonation;
  (iv) within one type of coastal form, mangroves showing clear relationship of assemblages and zonation to habitat;
  (v) mangroves that are extensive, luxuriant, and important for local productivity;
- mangroves that show unusual biodiversity or occurrence of uncommon species (such as those at their geographic limits); ranked as "B"; and
- mangrove stands that explicitly exhibit mangrove/habitat relationships; ranked as "H".

Note that in the Table below that if a mangrove area is ranked as I (internationally significant), it obviously also qualifies as N and R (nationally and regionally significant); similarly if a mangrove area is ranked as N, it obviously also qualifies as R; the redundancy is not repeated.

Assessment of mangrove areas as to international, national, regional (*i.e.*, State-wide) ranking, and in terms of biodiversity and mangrove habitat relationships (coded I, N, R, B & H, respectively)

COASTAL SECTOR:	ASSESSMENT: I, N. R, B or H
1. Bay of Rest	I, B, H
2. Giralia Bay - Yanrey Flats	I, H
3. Ashburton River Delta	N
4. Coolgra Point	R
5. Yardie Landing; Mangrove Islands	I, B, H
6. Robe River Delta	I, H
7. Fortescue River Delta	I, B, H
8. Cape Preston area	I, B, H
9. Maitland River Delta	N
10. West Intercourse Island	I, B, H
11. Enderby Island Complex	I, B, H
12. Searipple Passage to Conzinc Bay	I, B, H
13. Nickol River Embayment	N
14. Dixon Island Complex	I, B, H
15. Cossack to Harding Delta	N, B
16. Sherlock Bay Sector	R
17. Ronsard Island area	I, H
18. Yule River Delta	N, B, H
19. Turner River Delta	N, H
20. Oyster Passage Barrier	I, B, H
21. De Grey River Delta	N, B, H

In the section describing the significant mangrove coasts, above, there has been emphasis the relationship of coastal types to mangrove formations. As outlined above, it is insufficient to simply preserve mangrove formations without the context of coastal setting - the assemblage of habitats in various coastal types with their mangroves are viewed as an ensemble. The primary basis for selection of areas of high conservation significance has been coastal type, with their selection being based on holistic grounds rather than wholly on the mangroves themselves.

However, in terms of defining these areas, even though the objective of the selection process is to identify and protect significant mangroves, the boundary to the protected area is not located directly along the edge of mangrove formations. The context or setting of the mangroves, *i.e.*, their "basin setting" (or geomorphic setting), their hydrological context, the adjoining salt flats, any contributory alluvial fans, the adjoining low tidal flats, amongst others, needs to be incorporated into the protection zone. Mangroves do not occur in isolation, and the assemblage of coastal landforms and processes that create the diversity in habitats and mangrove assemblages, and that maintain the habitats and the mangroves, need to be protected as an ensemble. Also, the tidal zones that are sustained by mangrove productivity need to be viewed as part of the mangrove system. For this reason, the boundary to the suggested protection areas of high conservation significance extends beyond the immediate areas of the mangroves and incorporates total coastal systems. The boundary has tended to be located at the "natural" boundary of any selected coastal sector.

Not all mangroves along Pilbara Coast have been captured in this selection process. Those that have not been included tended to be mangroves that are well represented and ubiquitous, or those poorly developed as a formation type but widespread along the coast. Narrow, fringing *Avicennia marina* scrub or low forests along tidal creeks, and narrow, fringing patchy *Avicennia marina* shrubs along rocky shores are example of these. However, there some important stands of mangroves that were of too small and local a nature to be captured in the coastal type or coastal sector approach. Examples of these are the mangroves showing distinct species zonation across a point bar in the southern parts of the Fortescue River delta, the mangrove stands in the small embayment to the south of Bay of Rest in southwestern Exmouth Gulf, and *Avicennia marina* low forests along the gravel pavements in the seafront of the middle and southern Fortescue River delta and on the limestone pavements in the Karratha area exemplify this. Though such areas contain significant mangrove stands, they are not of international or national importance, and not of sufficient size to be especially selected. Such stands would be captured as significant and protected within the mangrove protection.

13.5 Pilbara wetlands captured as significant in relation to consanguineous suite

The selection of significant wetlands listed and described above has been based on geoheritage, vegetational, avifaunal, other faunal, and general holistic wetland criteria. From this process a large number of wetlands have been assessed as important, ranging from internationally to regionally significant. It was also an objective of this project that a representative wetland of each of the consanguineous suites in the Pilbara Region be selected for conservation. However, the enormous area of the Pilbara Region, the numbers of wetlands, and scope of work required to document all wetlands in the region meant that many could not be examined in the field, in spite of the extensive data base gathered during fieldwork for this project and fieldwork over the past 20 years obtained as R&D by VCSRG (as described in the Methods). Where given wetlands were assessed as significant on criteria of geoheritage, vegetation, avifauna, other fauna, and general holistic wetland features, they clearly also may be used by default as the representative of the consanguineous suite within which they occur. But there is a risk that these selected wetlands mentioned above do not represent wetlands from all the consanguineous suites, and hence for some suites there are no wetlands that have been designated for conservation. Further, since there are not enough field data at this stage to select specific wetlands from within such suites, and all wetlands within such suite should be treated with caution until the key wetlands within them have been identified.

Listed below is a correlation between the main wetland consanguineous suites in the Pilbara Region, and those wetland within them already assessed as significant. Those consanguineous suites that do not have wetland within them assigned for conservation are also noted as "not designated".

Relation between designated significant wetlands and consanguineous settings

Consanguineous suite	Wetlands within suite already identified/selected for conservation
Marble Bar subregion	
Yule River Suite	Carawine Pool
Shaw Batholith Suite	not designated
Coppin Gap Suite	Coppin Gap
Gorge Range Suite	not designated
Chichester Range subregion	
Chichester Range Suite	Minnorinna Pool; Yanna Pool
Contact: Chichester Range and Fortescue River Valley	
Roy Hill Suite	not designated
Fortescue River Valley	
Ethel Creek Suite	not designated
Fortescue Marsh Suite	Fortescue Marshes Wetland System; Bullinnarwa Pool; Kyalina Pool
Millstream Suite	Millstream complex
Dogger Gorge Suite	not designated
Mardie Suite	not designated
Contact: Fortescue River Valley and Hamersley Range	
Maddina Pool Suite	not designated (or in part may be viewed by some authors as part of Fortescue Marshes)
Hamersley Range subregion	
Hamersley Gorge Suite	Hamersley Ranges (Karajini wetlands); Duck Creek system;
Turner Creek Suite	not designated
Burrup "Peninsula" subregion	
Burrup Suite	not designated
Ashburton River Valley tract	
Capricorn Range Suite	Weeli Wolli springs/pool; Barlee Range Wetland System (including Kookhabinna Gorge and Yadjiyugga Claypan)
Ashburton Downs Suite	not designated
Nanutarra subregion	
Robe River Suite	Yarramudda Pool

In this context the following consanguineous suites have not had wetlands selected from them because there is not enough information:

Consanguineous suite	Wetlands in suite not yet selected for conservation
Shaw Batholith Suite	not designated
Gorge Range Suite	not designated
Roy Hill Suite	not designated
Ethel Creek Suite	not designated
Dogger Gorge Suite	not designated
Mardie Suite	not designated
Maddina Pool Suite	not designated
Turner Creek Suite	not designated
Burrup Suite	not designated
Ashburton Downs Suite	not designated
Burbunman Flat Suite	not designated

These suites should be investigated in more detail to assign wetland within them for representative conservation.

14.0 Management recommendations for the significant Pilbara wetlands

Protection and management recomendations of wetlands identified as significant are outlined in the Table below. The protection and management are based on those attributes that are significant to the wetland, and on the mechanisms of maintenance of the wetland, as determined by its setting within a given consanguineous suite.

For many of the inland wetlands, key management procedures involve the following:

- no dewatering of the regional groundwater
- no damming of the channel way
- fencing to exclude cattle
- nutrient management to ensure low nutrient levels
- control of people access in sensitive areas
- up-catchment management of clearing and sedimentation

While these procedures are generally repeated for each of the wetlands listed as significant, more specific management requirements are noted where necessary within the Table below.

For many of the coastal wetlands, key management procedures involve the following:

- no perturbations of the tidal and freshwater interactions
- no coastal development (e.g., ports, causeways, solar ponds, emplacement of infrastructures), so that it remains holistic
- control of people access in sensitive areas
- up-catchment management of clearing and sedimentation

Again, while these procedures are generally repeated for each of the coastal wetlands listed as significant, more specific management requirements are noted where necessary within the Table below.

Wetland	Key management approach
Avifaunal and other fauna sites	
Barlee Range Wetland System (including Kookhabinna Gorge and Yadjiyugga Claypan)	no dewatering of the regional groundwater; no damming of the channel way; fencing to exclude cattle; nutrient management to ensure low nutrient levels; control of people access in sensitive areas; up-catchment management of clearing and sedimentation
Carawine Pool	no dewatering of the regional groundwater; no damming of the channel way; fencing to exclude cattle; nutrient management to ensure low nutrient levels; control of people access in sensitive areas; up-catchment management of clearing and sedimentation
De Grey River Wetland System	no dewatering of the regional groundwater; no damming of the channel way; fencing to exclude cattle; nutrient management to ensure low nutrient levels; control of people access in sensitive areas; up-catchment management of clearing and sedimentation
Fortescue Marshes Wetland System	no dewatering of the regional groundwater; no damming of the channel way; fencing to exclude cattle; nutrient management to ensure low nutrient levels; control of people access in sensitive areas; up-catchment management of clearing and sedimentation

Karijini Gorges Wetland System (Hamersley Range)	no dewatering of the regional groundwater; no damming of the channel way; fencing to exclude cattle; nutrient management to ensure low nutrient levels; control of people access in sensitive areas; up-catchment management of clearing and sedimentation
Millstream Wetland System	no dewatering of the regional groundwater; no damming of the channel way; fencing to exclude cattle; nutrient management to ensure low nutrient levels; control of people access in sensitive areas; up-catchment management of clearing and sedimentation
Marree Pool	no dewatering of regional groundwater; no damming of channel way; fencing to exclude cattle; nutrient management to ensure low levels; control people access in sensitive areas; up-catchment management of clearing and sedimentatn
Sherlock River Pool	no dewatering of the regional groundwater; no damming of the channel way; fencing to exclude cattle; nutrient management to ensure low nutrient levels; control of people access in sensitive areas; up-catchment management of clearing and sedimentation
Weeli Wolli Springs	no dewatering of the regional groundwater; no damming of the channel way; fencing to exclude cattle; nutrient management to ensure low nutrient levels; control of people access in sensitive areas; up-catchment management of clearing and sedimentation

General (holistic) wetland sites	
Hamersley Ranges (Karajini wetland)	no dewatering of the regional groundwater; no damming of the channel way; fencing to exclude cattle; nutrient management to ensure low nutrient levels; control of people access in sensitive areas; up-catchment management of clearing and sedimentation
Millstream complex	no dewatering of the regional groundwater; no damming of the channel way; fencing to exclude cattle; nutrient management to ensure low nutrient levels; control of people access in sensitive areas; up-catchment management of clearing and sedimentation
Yanrey wetlands	no damming of the channel way; fencing to exclude cattle for the specific wetlands selected as representative of this suite; up-catchment management of clearing and sedimentation
Duck Creek system	no dewatering of the regional groundwater; no damming of the channel way; fencing to exclude cattle; nutrient management to ensure low nutrient levels; control of people access in sensitive areas; up-catchment management of clearing and sedimentation
Weeli Wolli Springs/pool	no dewatering of the regional groundwater; no damming of the channel way; fencing to exclude cattle; nutrient management to ensure low nutrient levels; control of people access in sensitive areas; up-catchment management of clearing and sedimentation

Coppin Gap	no dewatering of the regional groundwater; no damming of the channel way; fencing to exclude cattle; nutrient management to ensure low nutrient levels; control of people access in sensitive areas; up-catchment management of clearing and sedimentatn
Miaree Pool	no dewatering of the regional groundwater; no damming of the channel way; fencing to exclude cattle; nutrient management to ensure low nutrient levels; control of people access in sensitive areas; up-catchment management of clearing and sedimentation
Bullinnarwa Pool	no dewatering of the regional groundwater; no damming of the channel way; fencing to exclude cattle; nutrient management to ensure low nutrient levels; control of people access in sensitive areas; up-catchment management of clearing and sedimentation
Minnorinna Pool	no dewatering of the regional groundwater; no damming of the channel way; fencing to exclude cattle; nutrient management to ensure low nutrient levels; control of people access in sensitive areas; up-catchment management of clearing and sedimentation
Yanna Pool	no dewatering of the regional groundwater; no damming of the channel way; fencing to exclude cattle; nutrient management to ensure low nutrient levels; control of people access in sensitive areas; up-catchment management of clearing and sedimentatn

Kyalina Pool	no dewatering of regional groundwater; no damming of the channel way; fencing to exclude cattle; nutrient management to ensure low nutrient levels; control of people access in sensitive areas; up-catchment management of clearing and sedimentation
Yarramudda Pool	no dewatering of regional groundwater; no damming of the channel way; fencing to exclude cattle; nutrient management to ensure low nutrient levels; control of people access in sensitive areas; up-catchment management of clearing and sedimentation

Inland geoheritage sites	
Hamersley Ranges (Karajini wetlands)	no dewatering of the regional groundwater; no damming of the channel way; fencing to exclude cattle; nutrient management to ensure low nutrient levels; control of people access in sensitive areas; up-catchment management of clearing and sedimentatn
Millstream complex	no dewatering of the regional groundwater; no damming of the channel way; fencing to exclude cattle; nutrient management to ensure low nutrient levels; control of people access in sensitive areas; up-catchment management of clearing and sedimentatn
Yanrey wetlands	no dewatering of the regional groundwater; no damming of the channel way; fencing to exclude cattle; nutrient management to ensure low nutrient levels; control of people access in sensitive areas; up-catchment management of clearing and sedimentatn

Coastal geoheritage sites	
Exmouth Gulf east shore	no perturbations of the tidal and freshwater interactions; no development of the coast (e.g., ports, causeways, solar ponds, emplacement of infrastructures), so that it remains holistic; control of people access in sensitive areas; up-catchment management of clearing and sedimentation
Ashburton River Delta	no perturbations of tidal and freshwater interactions; no development of the coast (e.g., ports, causeways, solar ponds, emplacement of infrastructures), so that it remains holistic; control of people access in sensitive areas; in particular, up-catchment management of clearing and sedimentation
Onslow-Coolgra Point coast	no perturbations of tidal and freshwater interactions; no development of the coast (e.g., ports, causeways, solar ponds, emplacement of infrastructures), so that it remains holistic; control of people access in sensitive areas; up-catchment management of clearing and sedimentation
Robe River Delta	no perturbations of tidal and freshwater interactions; no development of the coast (e.g., ports, causeways, solar ponds, emplacement of infrastructures), so that it remains holistic; control of people access in sensitive areas; up-catchment management of clearing and sedimentation

Fortescue River Delta	no perturbations of tidal and freshwater interactions; no development of the coast (e.g., ports, causeways, solar ponds, emplacement of infrastructures), so that it remains holistic; control of people access in sensitive areas; up-catchment management of clearing and sedimentation
Maitland Delta	no perturbations of tidal and freshwater interactions; no development of the coast (e.g., ports, causeways, solar ponds, emplacement of infrastructures), so that it remains holistic; control of people access in sensitive areas; up-catchment management of clearing and sedimentation
Dampier Archipelago	no perturbations of tidal and freshwater interactions; no development of the coast (e.g., ports, causeways, solar ponds, emplacement of infrastructures), so that it remains holistic; control of people access in sensitive areas; up-catchment management of clearing and sedimentation
Nickol Bay	no perturbations of tidal and freshwater interactions; no development of the coast (e.g., ports, causeways, solar ponds, emplacement of infrastructures), so that it remains holistic; control of people access in sensitive areas; up-catchment management of clearing and sedimentation

Cape Lambert complex	no perturbations of tidal and freshwater interactions; no development of the coast (e.g., ports, causeways, solar ponds, emplacement of infrastructures), so that it remains holistic; control of people access in sensitive areas
Harding River Delta	no perturbations of tidal and freshwater interactions; no development of the coast (e.g., ports, causeways, solar ponds, emplacement of infrastructures), so that it remains holistic; control of people access in sensitive areas; up-catchment management of clearing and sedimentation
Balla Balla coast to Ronsard Island	no perturbations of tidal and freshwater interactions; no development of the coast (e.g., ports, causeways, solar ponds, emplacement of infrastructures), so that it remains holistic; control of people access in sensitive areas; up-catchment management of clearing and sedimentation
Yule River Delta	no perturbations of tidal and freshwater interactions; no development of the coast (e.g., ports, causeways, solar ponds, emplacement of infrastructures), so that it remains holistic; control of people access in sensitive areas; up-catchment management of clearing and sedimentation
Turner River Delta	no perturbations of tidal and freshwater interactions; no coastal development (e.g., ports, causeways, solar ponds, emplacement of infrastructures), so that it remains holistic; control of people access in sensitive areas; up-catchment management of clearing and sedimentation

Port Hedland barrier coast	no perturbations of the tidal and freshwater interactions; no development of the coast (e.g., ports, causeways, solar ponds, emplacement of infrastructures), so that it remains in an holistic structure; control of people access in sensitive areas; up-catchment management of clearing and sedimentation
De Grey River Delta	no perturbations of tidal and freshwater interactions; no development of the coast (e.g., ports, causeways, solar ponds, emplacement of infrastructures), so that it remains holistic; control of people access in sensitive areas; up-catchment management of clearing and sedimentation

Mangrove sites	
Bay of Rest	no perturbations of the tidal and freshwater interactions; no development of the coast (e.g., ports, causeways, solar ponds, emplacement of infrastructures), so that it remains in an holistic structure; control of people access in sensitive areas; up-catchment management of clearing and sedimentation
Giralia Bay to Yanrey Flats, Exmouth East Shore	no perturbations of the tidal and freshwater interactions; no development of the coast (e.g., ports, causeways, solar ponds, emplacement of infrastructures), so that it remains in an holistic structure; control of people access in sensitive areas; up-catchment management of clearing and sedimentation
Ashburton River Delta	no perturbations of the tidal and freshwater interactions; no development of the coast (e.g., ports, causeways, solar ponds, emplacement of infrastructures), so that it remains in an holistic structure; control of people access in sensitive areas; in particular, up-catchment management of clearing and sedimentation
Coolgra Point	no perturbations of the tidal and freshwater interactions; no development of the coast (e.g., ports, causeways, emplacement of infrastructures), so that it remains in an holistic structure; control of people access in sensitive areas; up-catchment management of clearing and sedimentation

Yardie Landing, Yammadery Island and the Mangrove Islands	no perturbations of tidal and freshwater interactions; no development of the coast (e.g., ports, causeways, infrastructures), so that it remains holistic; control of people access in sensitive areas; up-catchment management of clearing and sedimentation
Robe River Delta	no perturbations of the tidal and freshwater interactions; no development of the coast (e.g., ports, causeways, solar ponds, emplacement of infrastructures), so that it remains in an holistic structure; control of people access in sensitive areas; up-catchment management of clearing and sedimentation
Fortescue River Delta	no perturbations of the tidal and freshwater interactions; no development of the coast (e.g., ports, causeways, solar ponds, emplacement of infrastructures), so that it remains in an holistic structure; control of people access in sensitive areas; up-catchment management of clearing and sedimentation
Cape Preston area	no perturbations of the tidal and freshwater interactions; no development of the coast (e.g., ports, causeways, emplacement of infrastructures), so that it remains in an holistic structure; control of people access in sensitive areas; up-catchment management of clearing and sedimentation

Maitland River Delta	no perturbations of tidal and freshwater interactions; no coast development (e.g., ports, causeways, solar ponds, emplacement of infrastructures), so that it remains holistic; control people access in sensitive areas; up-catchment management of clearing and sedimentation
West Intercourse Island, Dampier Archipelago	no perturbations of the tidal and freshwater interactions; no development of the coast (e.g., ports, causeways, emplacement of infrastructures), so that it remains in an holistic structure; control of people access in sensitive areas; up-catchment management of clearing and sedimentation
Enderby Island Complex, Dampier Archipelago	no perturbations of the tidal and freshwater interactions; no development of the coast (e.g., ports, causeways, infrastructures), so that it remains holistic; control of people access in sensitive areas; up-catchment management of clearing and sedimentation
Searipple Passage to Conzinc Bay, Dampier Archipelago	no perturbations of tidal and freshwater interactions; no coast development (e.g., ports, causeways, infrastructures), so that it remains holistic; control people access in sensitive areas; up-catchment management of clearing and sedimentation
Nickol River Embayment	no perturbations of tidal and freshwater interactions; no coastal development (e.g., ports, causeways, solar ponds, infrastructures), so that it remains holistic; control people access in sensitive areas; up-catchment management of clearing and sedimentatn

Dixon Island Complex	no perturbations of the tidal and freshwater interactions; no development of the coast (e.g., ports, causeways, solar ponds, emplacement of infrastructures), so that it remains in an holistic structure; control of people access in sensitive areas; up-catchment management of clearing and sedimentation
Cossack to Harding Delta Complex	no perturbations of the tidal and freshwater interactions; no development of the coast (e.g., ports, causeways, infrastructures), so that it remains holistic; control people access in sensitive areas; up-catchment management of clearing and sedimentatn
Sherlock Bay Sector	no perturbations of the tidal and freshwater interactions; no development of the coast (e.g., ports, causeways, solar ponds, emplacement of infrastructures), so that it remains in an holistic structure; control of people access in sensitive areas; up-catchment management of clearing and sedimentation
Ronsard Island area	no perturbations of the tidal and freshwater interactions; no development of the coast (e.g., ports, causeways, solar ponds, emplacement of infrastructures), so that it remains in an holistic structure; control of people access in sensitive areas; up-catchment management of clearing and sedimentation
Yule River Delta	no perturbations of the tidal and freshwater interactions; no development of the coast (e.g., ports, causeways, infrastructures), so that it remains in an holistic structure; control of people access in sensitive areas; up-catchment management of clearing and sedimentation

Turner River Delta	no perturbations of tidal and freshwater interactions; no development of the coast (e.g., ports, causeways, infrastructures), so that it remains in an holistic structure; control of people access in sensitive areas; up-catchment management of clearing and sedimentation
Oyster Passage Barrier	no perturbations of the tidal and freshwater interactions; no development of the coast (e.g., ports, causeways, solar ponds, emplacement of infrastructures), so that it remains in an holistic structure; control of people access in sensitive areas; up-catchment management of clearing and sedimentation
De Grey River Delta	no perturbations of the tidal and freshwater interactions; no development of the coast (e.g., ports, causeways, solar ponds, emplacement of infrastructures), so that it remains in an holistic structure; control of people access in sensitive areas; up-catchment management of clearing and sedimentation

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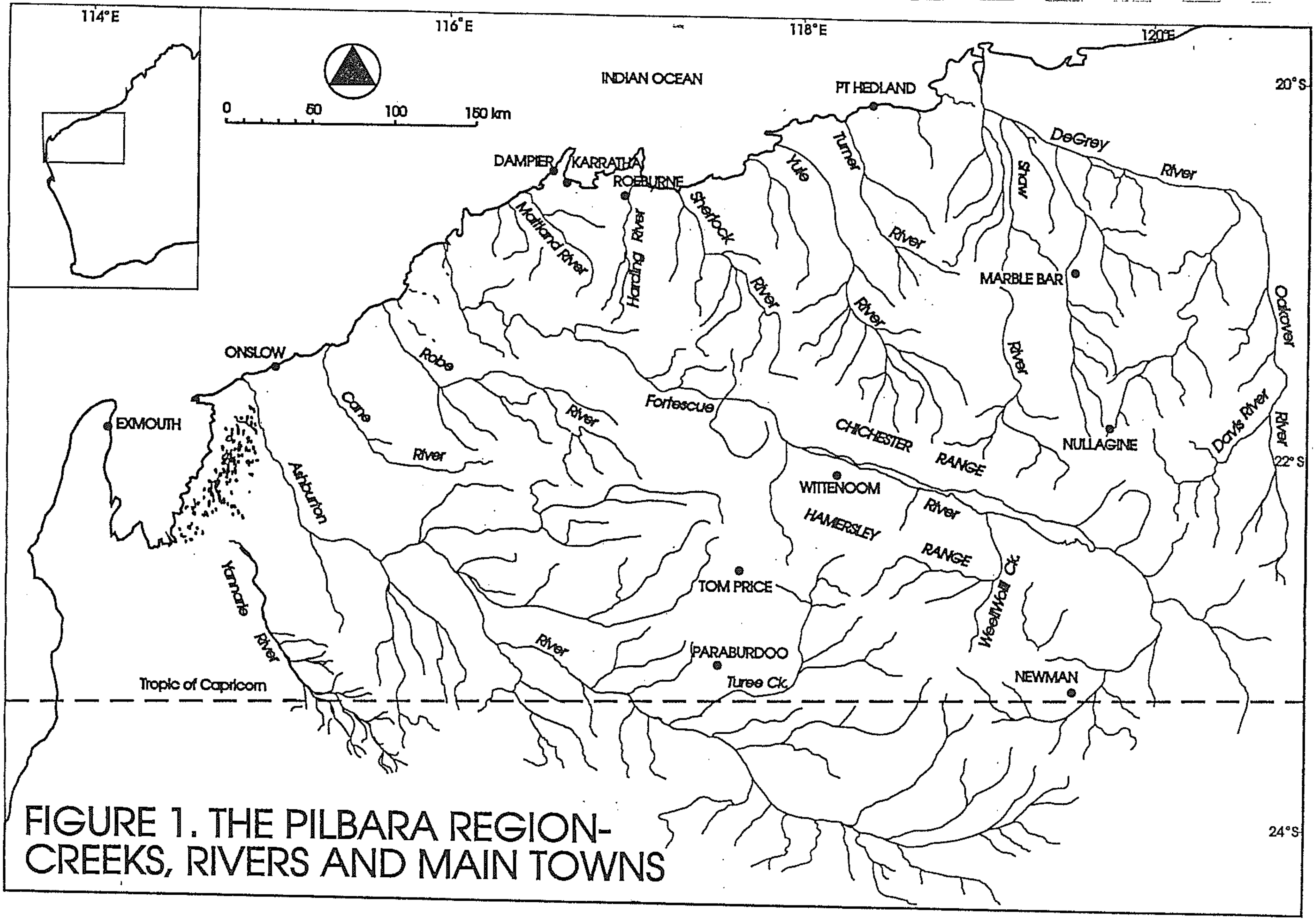

FIGURE 1. THE PILBARA REGION-
CREEKS, RIVERS AND MAIN TOWNS

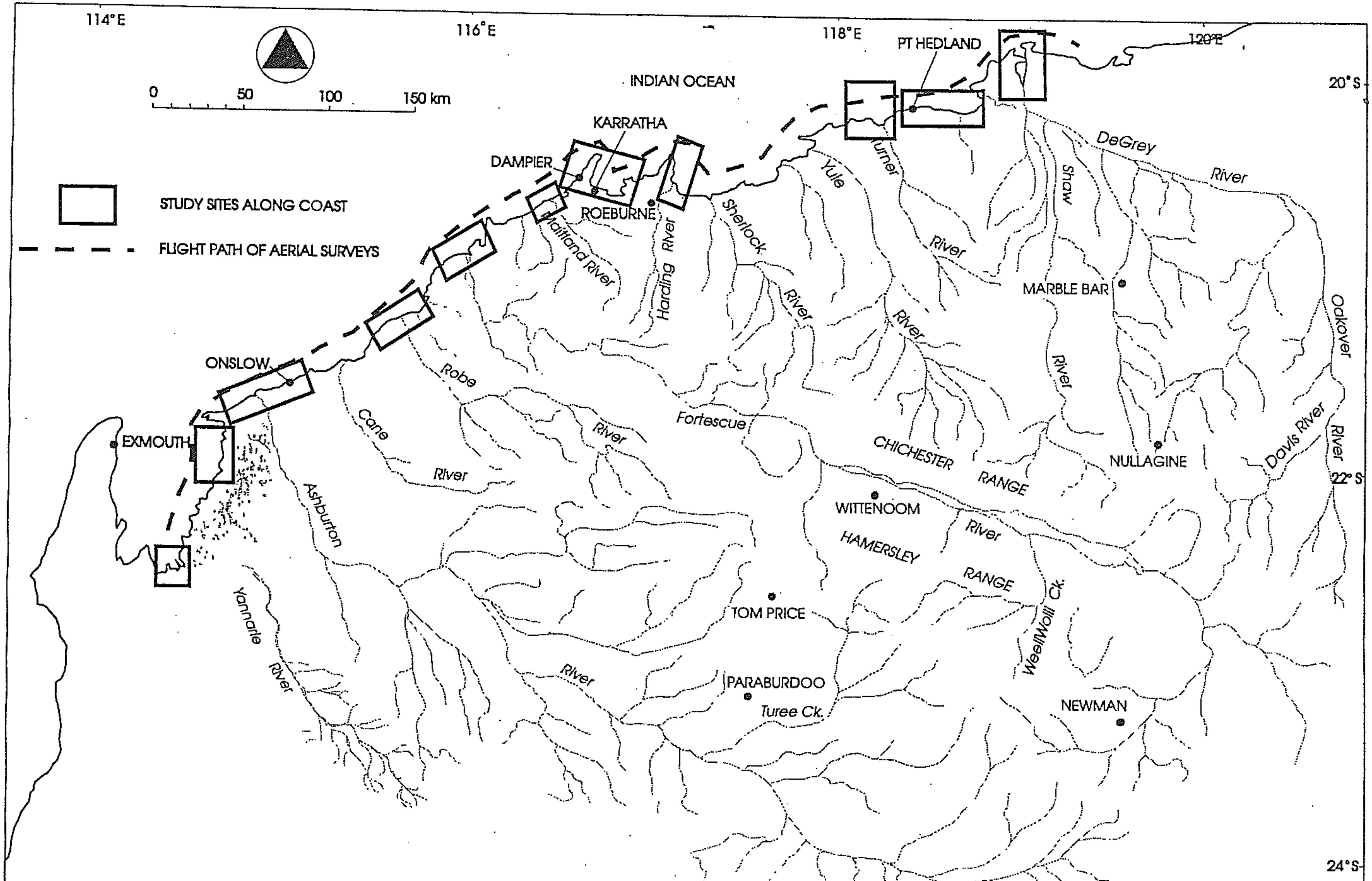

FIGURE 2. STUDY SITES ALONG COAST (VCSRG R & D)

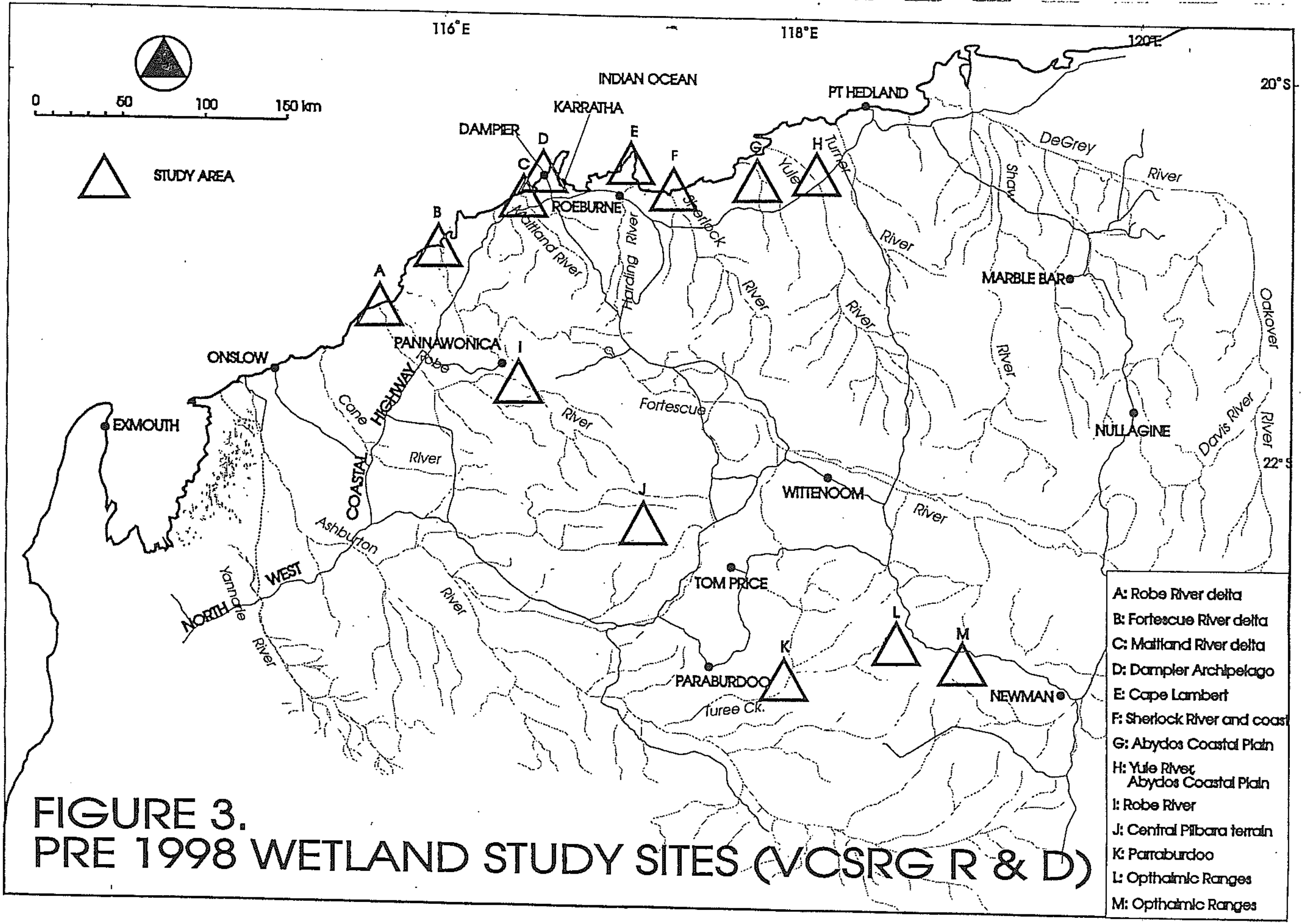

FIGURE 3.
PRE 1998 WETLAND STUDY SITES (VCSRG R & D)

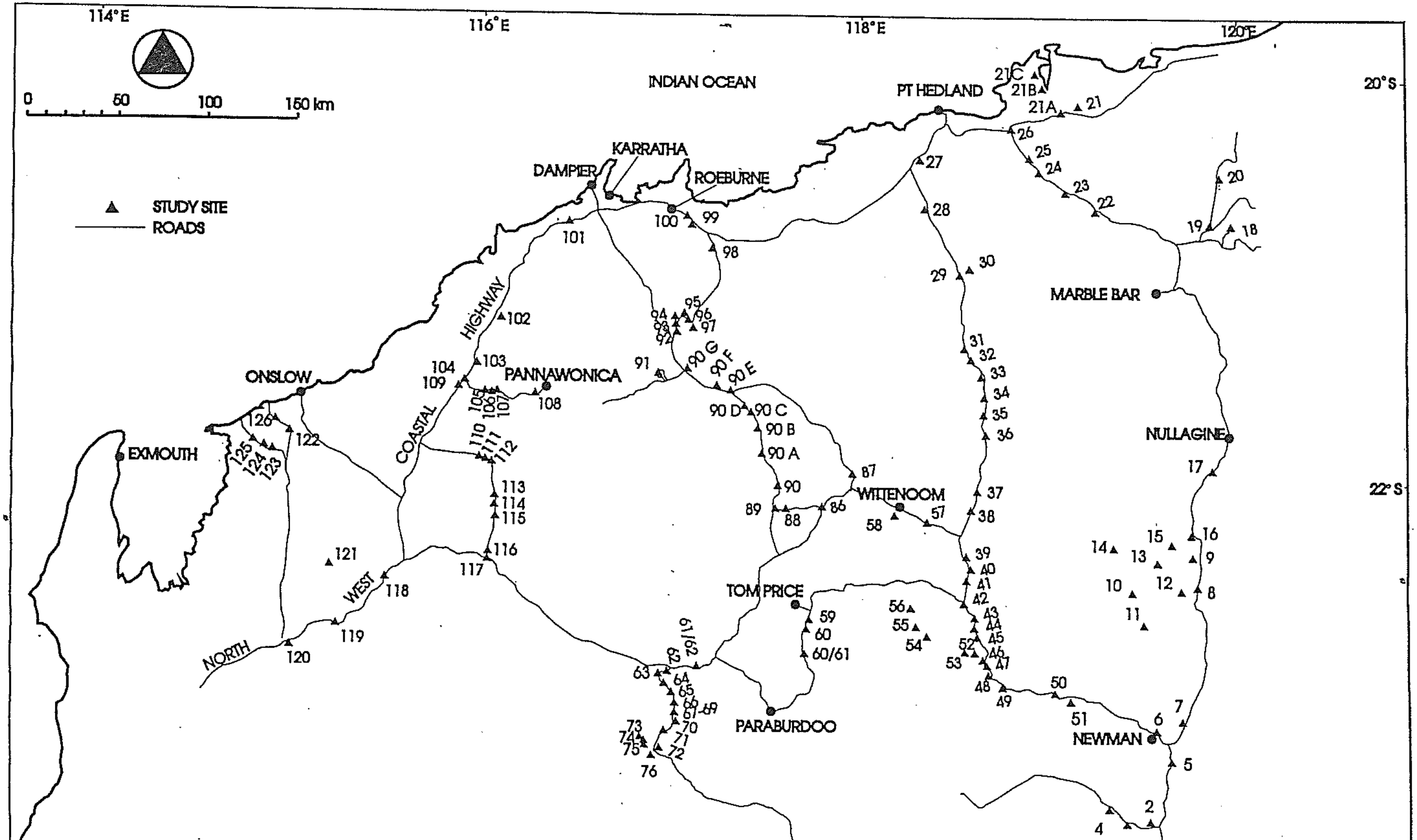

FIGURE 4.
STUDY SITES 1998, THIS STUDY

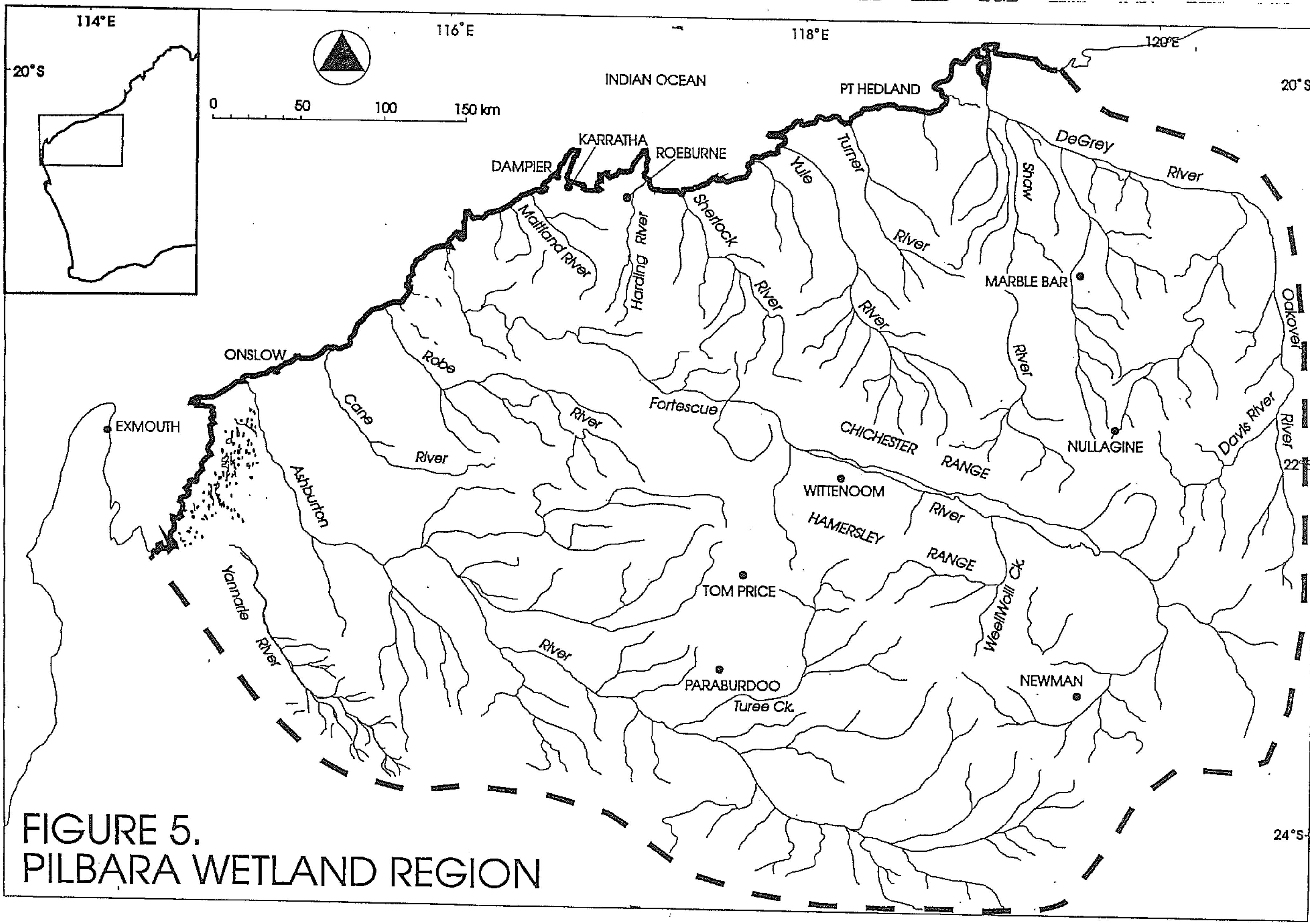

FIGURE 5.
PILBARA WETLAND REGION

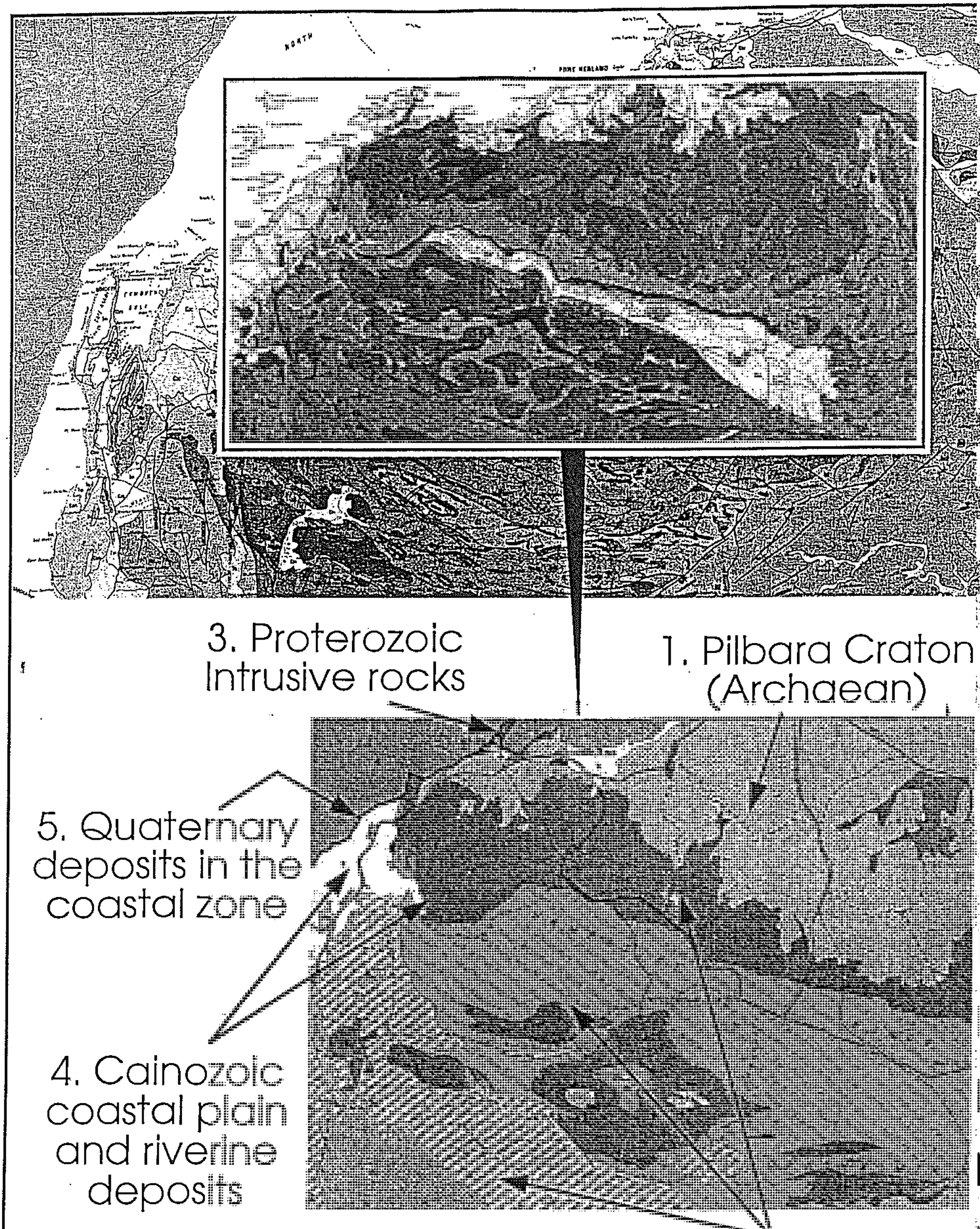

FIGURE 6. GEOLOGY OF THE PILBARA SHOWING OVERALL STRUCTURE, AND DETAILS OF THE FIVE MAIN GEOLOGICAL SEQUENCES

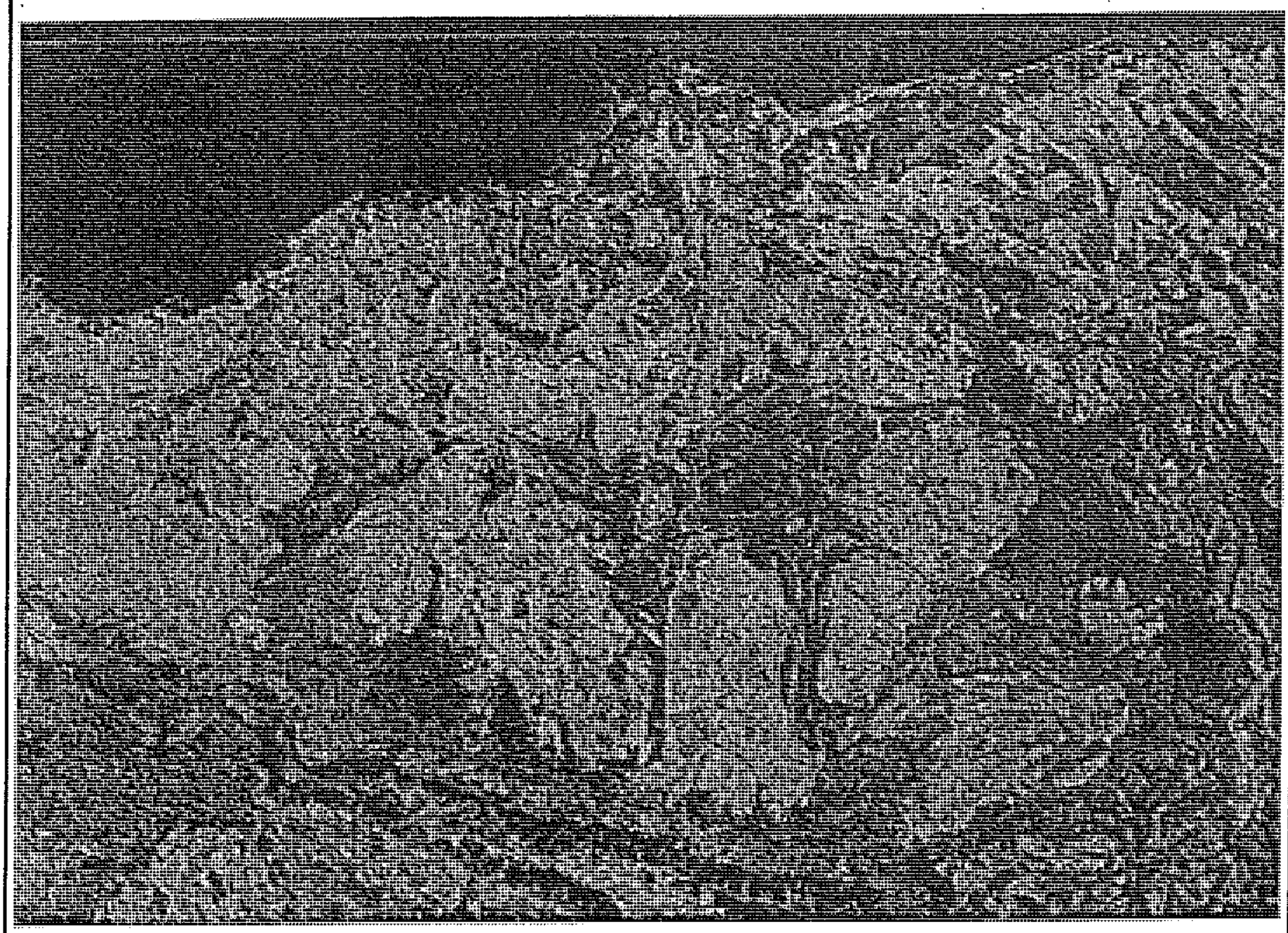

FIGURE 7. NORTHWESTERN PILBARA SHOWING PILBARA CRATON (WITH OVOID GRANITOIDS), CHICHESTER RANGES (TRENDING WNW ALONG LOWER LEFT PHOTOGRAPH), AND DE GREY, TURNER, AND YULE RIVER DELTAS (LOBES ALONG COAST)

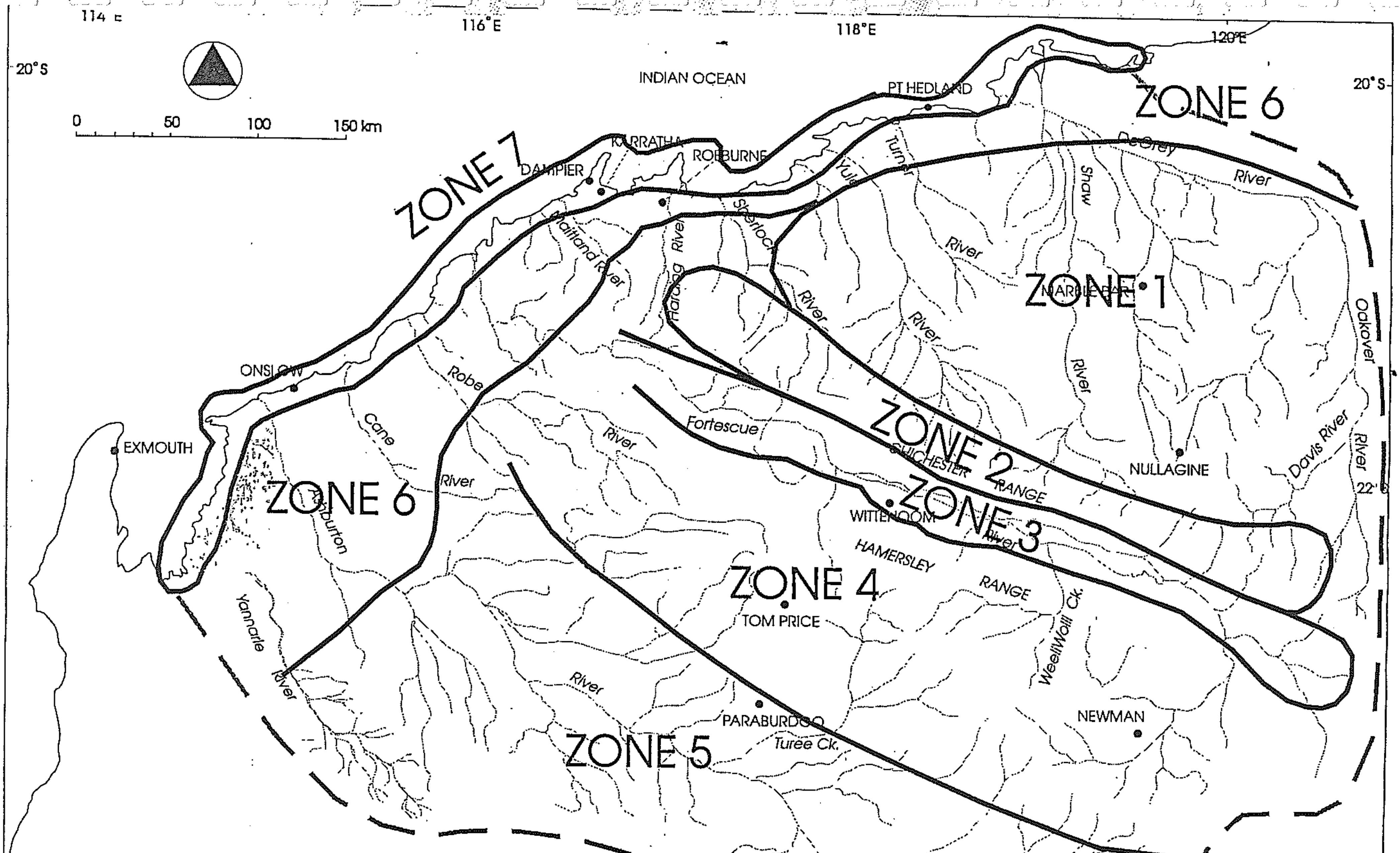

FIGURE 8.
PILBARA GROUNDWATER ZONE, THIS STUDY

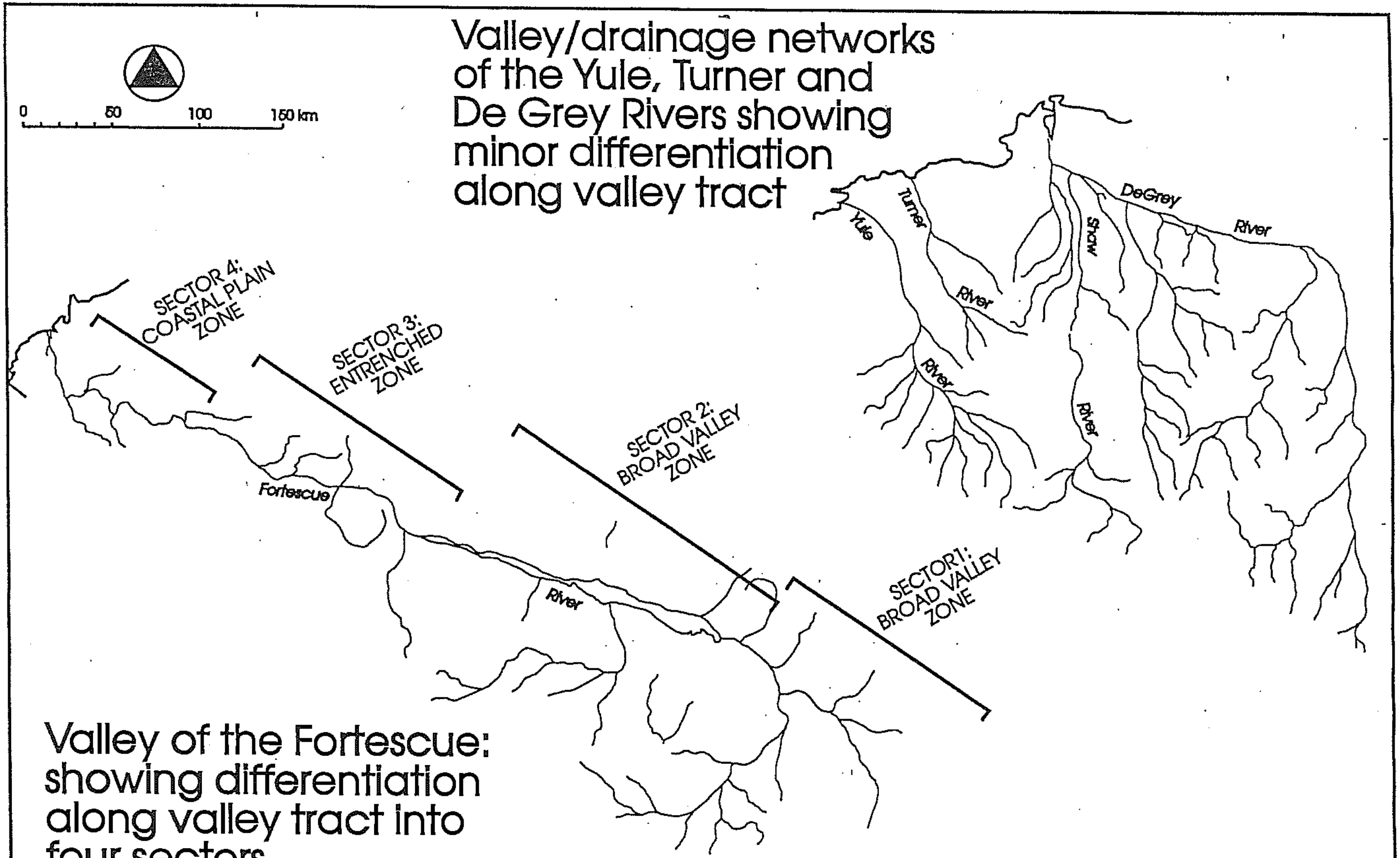

FIGURE 9. CONTRASTING FOUR RIVERS IN THE PILBARA REGION - THE FORTESCUE, DE GREY, TURNER, AND YULE

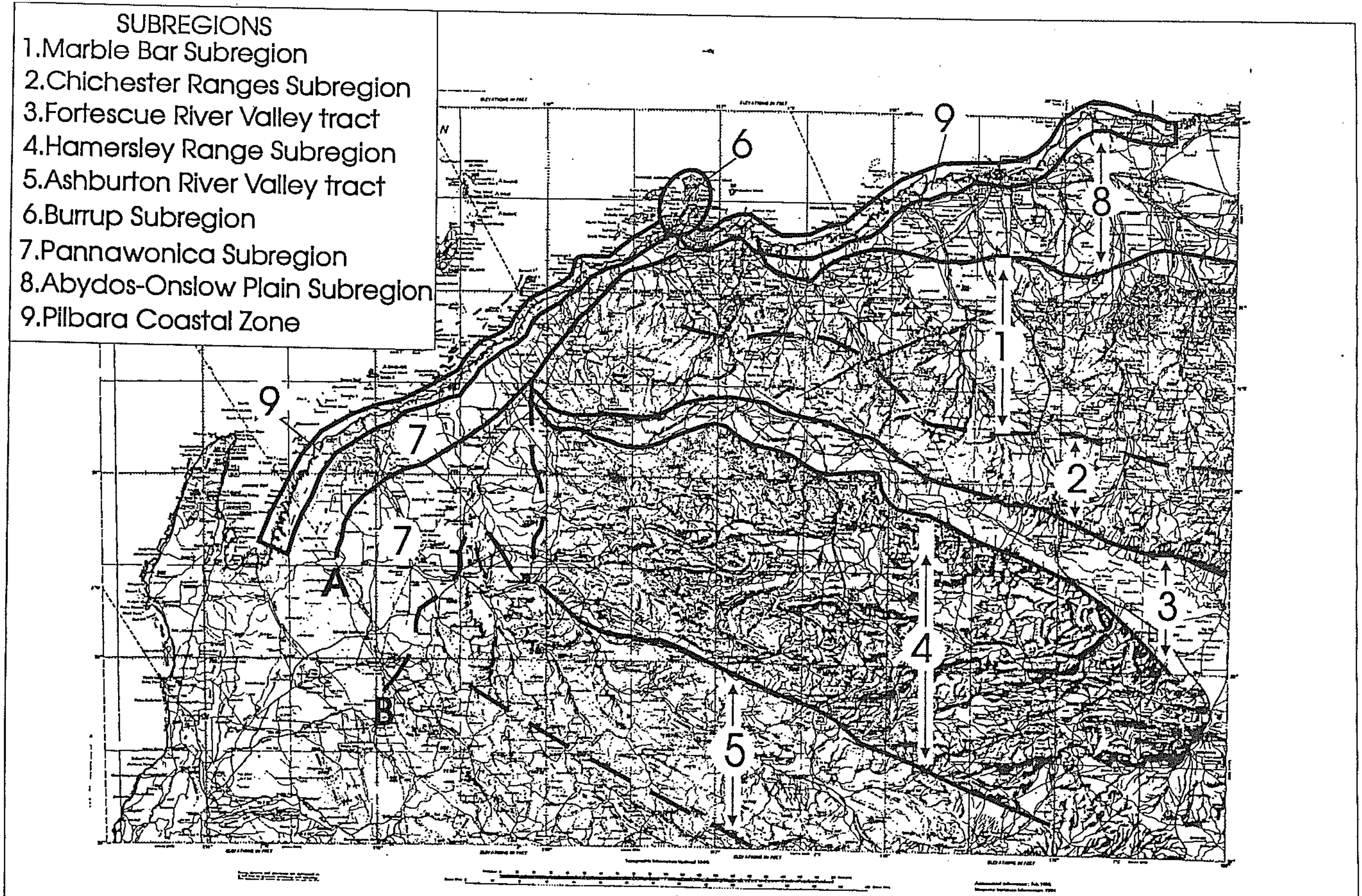

FIGURE 10. WETLAND SUBREGIONS IN THE PILBARA

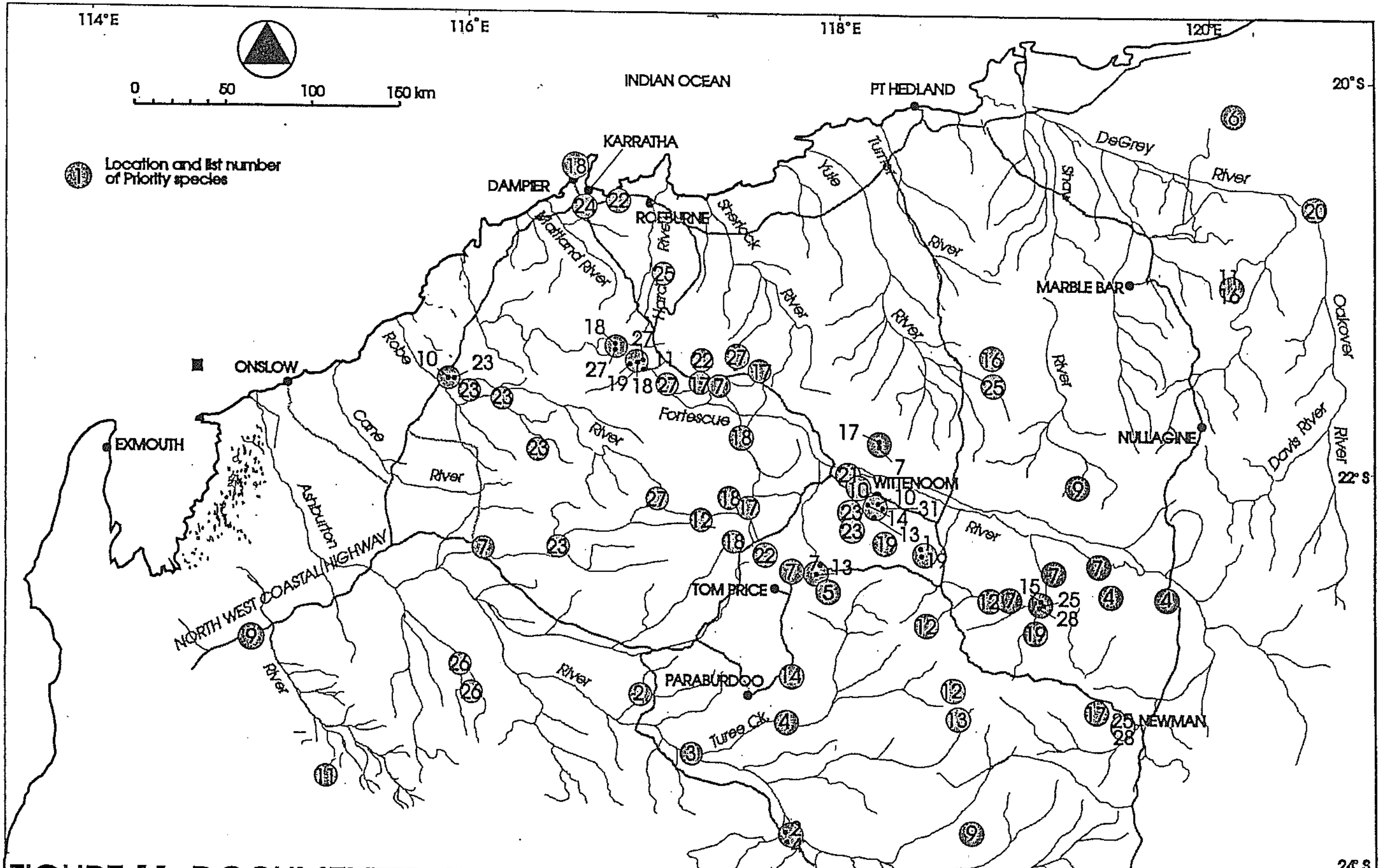

FIGURE 11. DOCUMENTED SITES OF OCCURRENCE OF PRIORITY FLORA IN THE PILBARA REGION

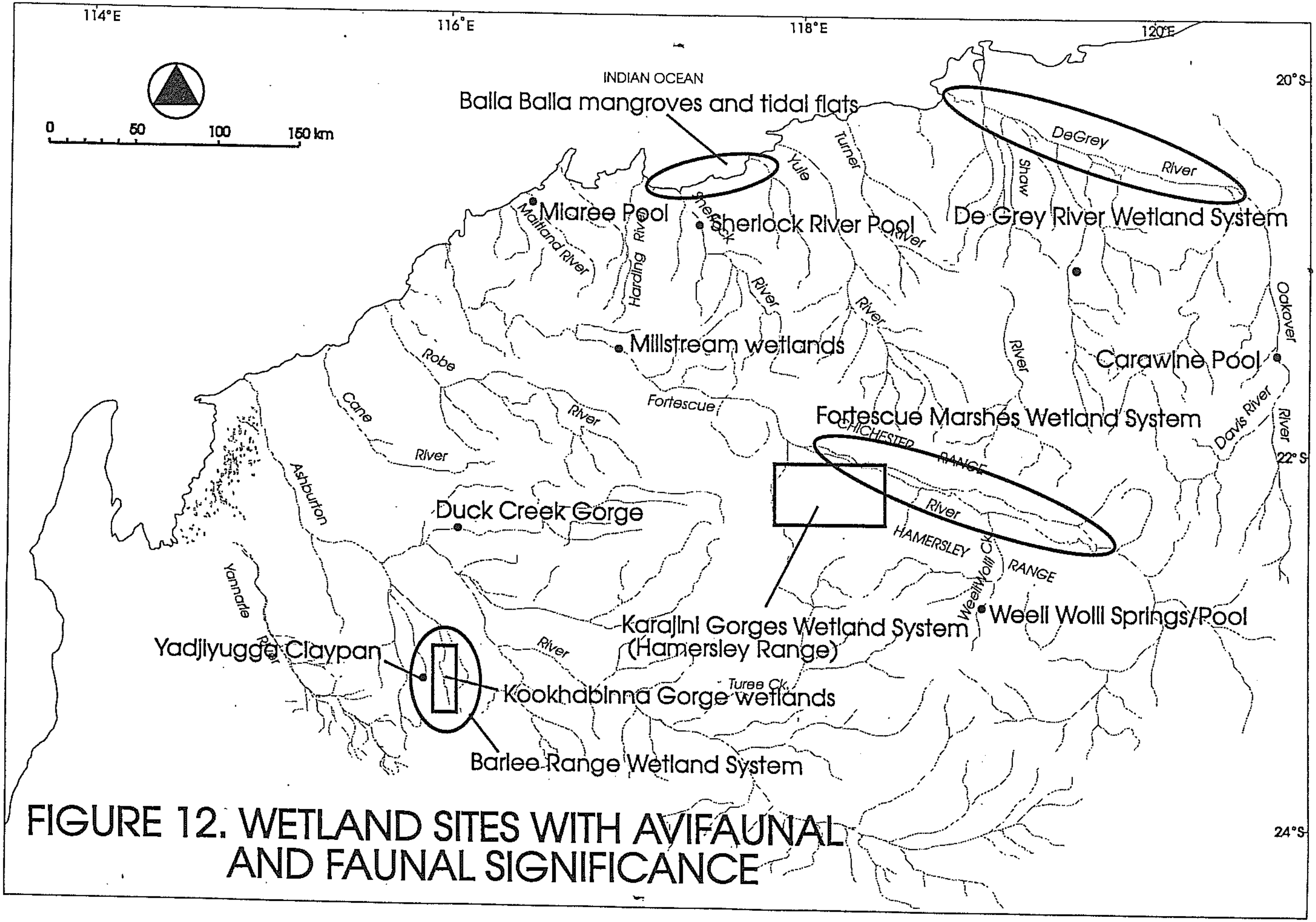

FIGURE 12. WETLAND SITES WITH AVIFAUNAL AND FAUNAL SIGNIFICANCE

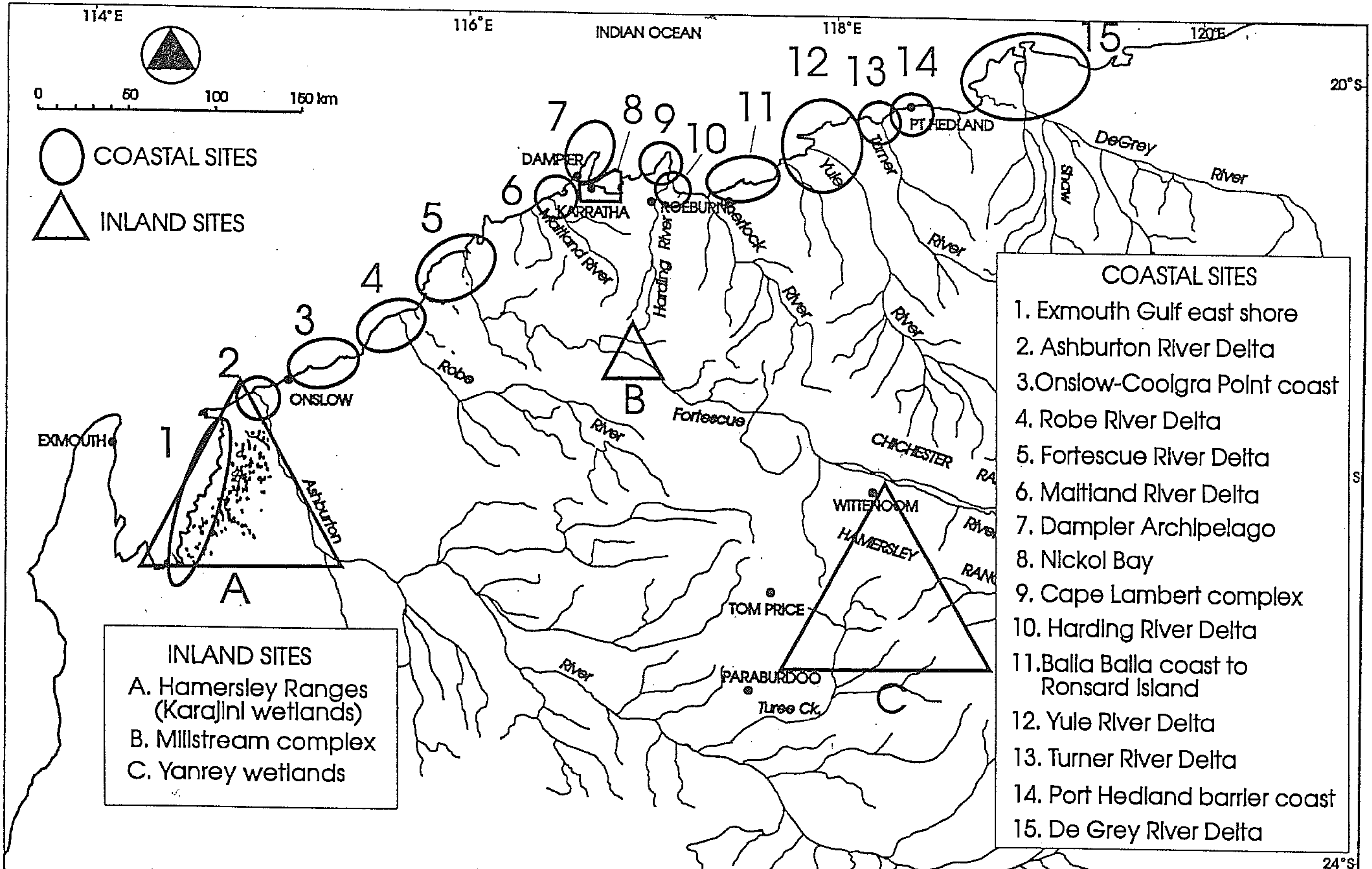

FIGURE 13. GEOHERITAGE SITES, COASTAL & INLAND PILBARA

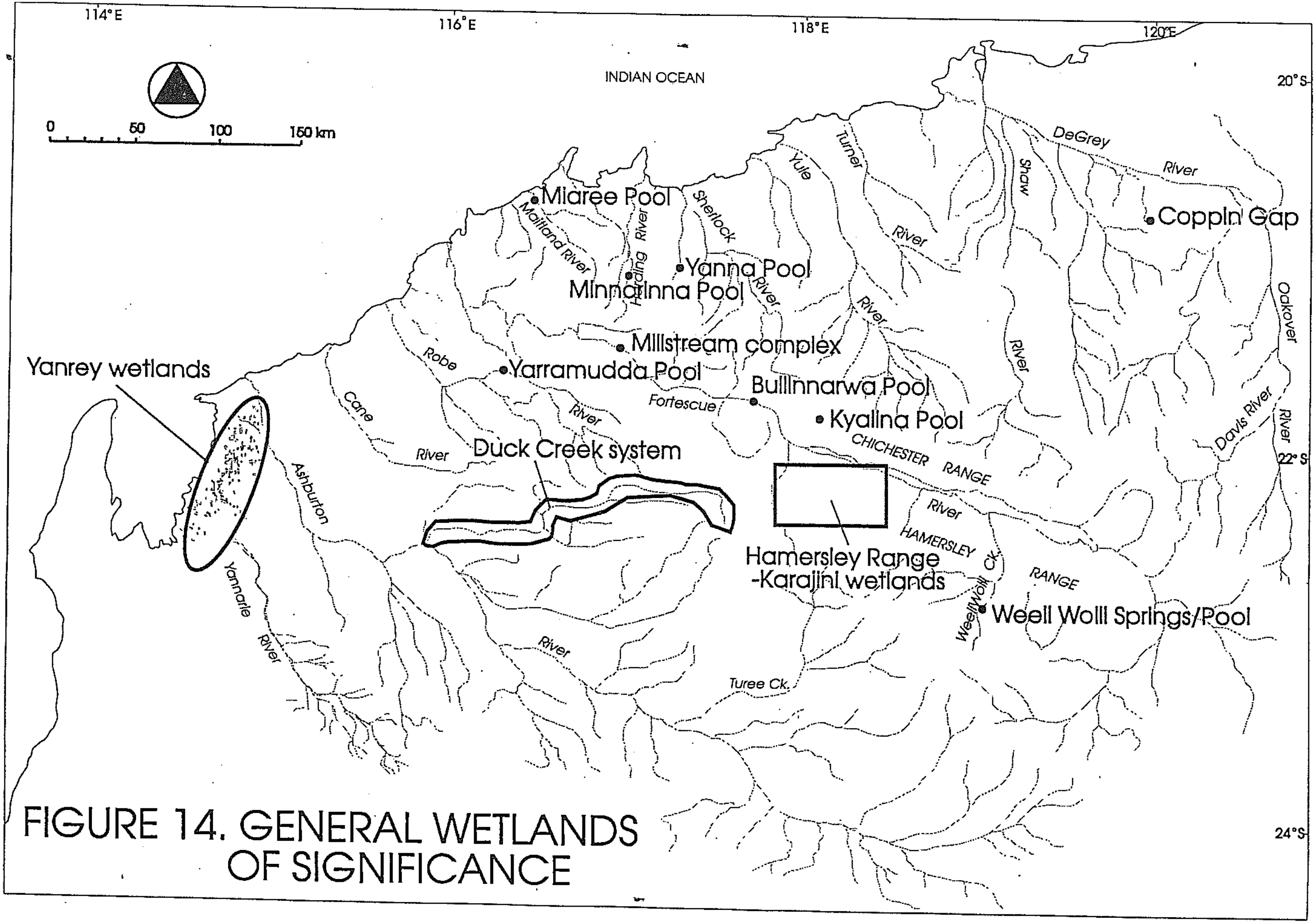

FIGURE 14. GENERAL WETLANDS OF SIGNIFICANCE

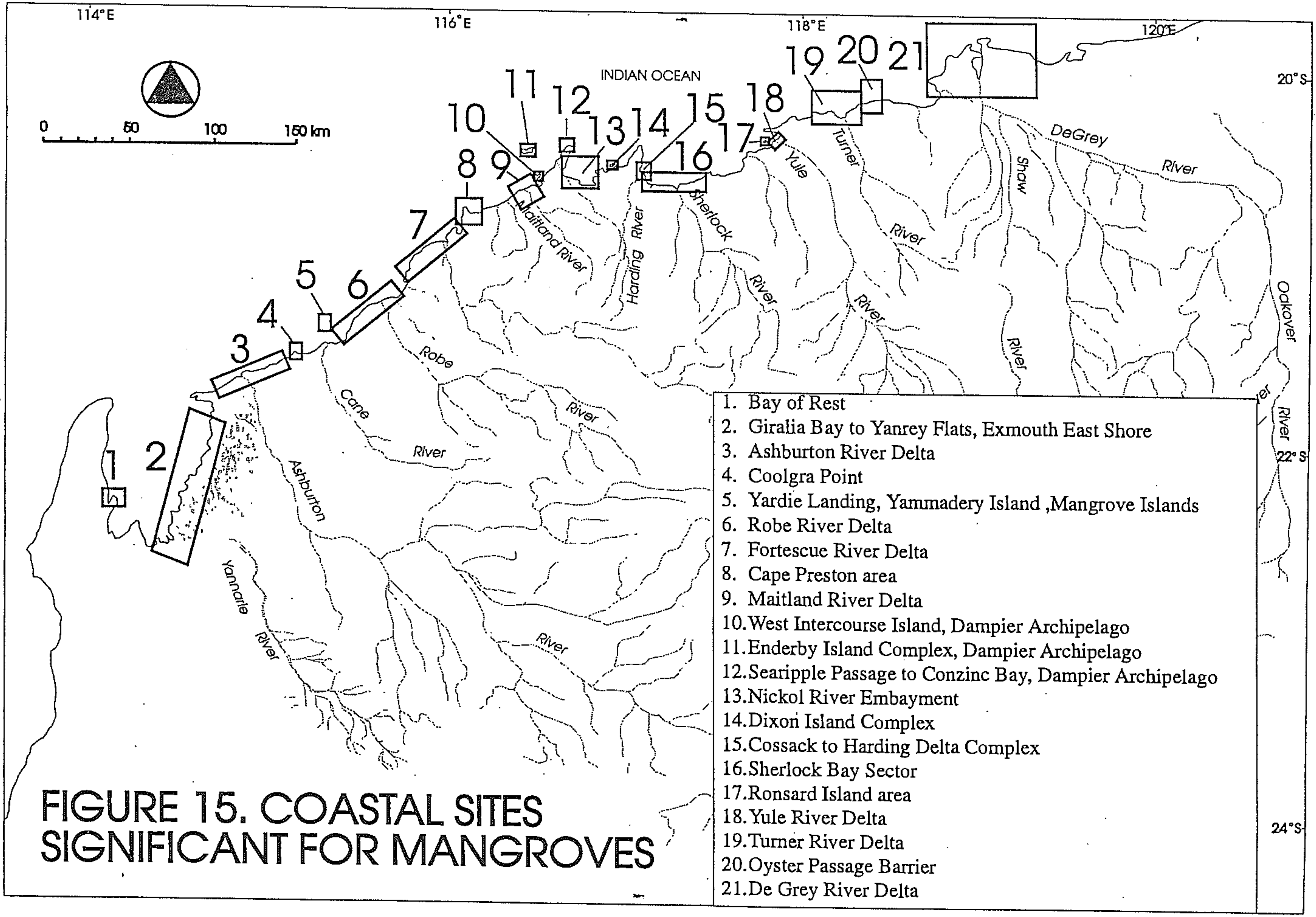

FIGURE 15. COASTAL SITES SIGNIFICANT FOR MANGROVES