Identification and evaluation of sites for the development of large-scale, land-based marine aquaculture in Western Australia

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Midwest to the Kimberley

Department of Fisheries
Government of Western Australia

Fish for the future

Identification and evaluation of sites for the development of large-scale, land-based marine aquaculture in Western Australia

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The Aquaculture Development Council

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EXECUTIVE SUMMARY

Introduction

Mariculture or land-based marine fish rearing systems has been shown to be commercially viable for many species worldwide, and especially for prawns and barramundi in Australia. Western Australia has a coastline extending 13,000 km that covers tropical, sub-tropical, warm-temperate and cool-temperate environments, providing opportunities for the commercial aquaculture of a wide variety of aquatic species. The development of the industry in Western Australia has been impeded to some extent by the difficulty of identifying and gaining right of access to suitable coastal sites. Recognising that access to sites is a major impediment to aquaculture industry in WA, the Aquaculture Development Council commissioned this study to identify and evaluate suitable large scale (greater than 2 km^2), land-based mariculture sites.

The first phase of the site identification process involved the preliminary identification of suitable sites on a broad scale, using a Geographical Information System (GIS). The second phase involved the onsite evaluation of potential sites. This report provides information generated from the first and second phases of the process. It identifies a number of sites that satisfy the preliminary and secondary selection criteria and includes a detailed description of the sites considered most suitable for large-scale, land-based mariculture.

Selection of Sites for Large-Scale, Land-Based aquaculture.

The objective of the current study was to identify three suitable sites for large-scale, land-based mariculture: oceanic tropical, oceanic temperate, and brown water tropical between South Australian and the Northern Territory borders with Western Australia. Potential sites were identified in all of the six main coastal regions: Southern, Central, Mid West, Gascoyne, Pilbara, and Kimberley.

The primary selection criteria used to identify the preliminary sites were: area, proximity to power, roads and town, distance from the low water level and the nearest river mouth.

As a result of the GIS mapping study, a total of 56 preliminary sites were identified. Some of these preliminary sites were removed from the evaluation process due to tenure, e.g. marine parks or CALM reserves. The remainder of the preliminary sites were evaluated in a second stage of the GIS mapping study, which involved the further evaluation of each site against a secondary set of selection criteria. The final list of sites considered suitable for land-based large-scale mariculture, and for which detailed descriptions are provided in this report, was reduced to 10 sites.

The second phase of this study included an on-site evaluation of these selected sites. The Midwest and Gascoyne regions including Jurien Bay, Geraldton, Port Gregory, Carnarvon and Exmouth Gulf were evaluated during January and February 2001. The Pilbara region including Dampier, Karratha, Wickham and Port Hedland were evaluated during September 2001.

Large-scale, Land-Based Mariculture Sites

The selected sites, their locations and main features are briefly described in the following table.

Table 1: Summary of features of the sites identified by the GIS mapping study and evaluated.

SITE NO.	REGION	SITE NAME	LOCATION AND MAIN FEATURES
1	MIDWEST	Lynton, Hutt Lagoon	Near Port Gregory, southern end of Hutt Lagoon. Good physical and biological features for temperate water aquaculture. Good infrastructure and services. Possibly the best site north of Geraldton. High potential.
2	GASCOYNE	Carnarvon	South of Carnarvon, near Oyster Creek. Good physical features, but prone to inundation and poor water quality. Low potential.
3		Heron Point, Exmouth Gulf	An aquaculture licence has already been granted for this site and therefore it was not subject to evaluation in this study.
4		Learmonth, Exmouth Gulf	Adjacent to Learmonth Airport. This land is prone to inundation or flooding from tropical cyclones. Low to medium potential.
5A, B		Charles Knife Road North And Charles Knife Road South, Exmouth Gulf	South of Pebble Beach to Potshot Memorial. Large area of land with good physical and biological features. Both sites have high potential.
6		Exmouth Town South to Pebble Beach, Exmouth Gulf	In this area, the majority of the land is zoned for other uses, mainly residential. The land, which has not been zoned for residential use has poor physical features. Low potential.
7		Naval Communication Centre, Exmouth Gulf	Near the Naval Communication Centre, close to Exmouth town. Excellent physical and biological features. The adjoining waters form part of the Ningaloo Marine Park. High potential.
8		Point Murat to Bundegi Nature Reserve, Exmouth Gulf	Near the North West Cape. Excellent physical and biological features. The adjoining waters form part of the Ningaloo Marine Park. Low potential.
9	NORTHERN	Port Hedland	Close to infrastructure, airport, port facilities and salt works (Cargill Salt), interest from the Pilbara Development Commission in the possibilities of land-based mariculture. Tropical – brown water. Medium potential.
10		Karratha	Close to towns (Dampier and Karratha) and international airport, deep water offshore, flat land, medium water quality due to dredging. Tropical – brown water. Medium potential.

Conclusions

The sites found to have high and high-to-medium potential for large-scale, land-based mariculture were generally characterized by favorable social, physical and biological features, particularly in respect of site elevation and water quality, and their proximity to main regional centers and infrastructure. Ultimately, there are very few sites in Western Australia suitable for the large-scale, land-based mariculture. This is due to geological and climatic conditions.

Large sections of the WA coastline are steep with over 20 m elevation above sea level that would make seawater pumping an expensive undertaking. Cyclones in the Kimberley, Pilbara and Gascoyne regions are another concern. At the time of cyclonic storms, water quality may deteriorate and it will be impossible to use seawater due to turbidity and low salinity, depending on the species to be farmed.

Of the sites described, the most promising (high potential) for further development work are:

Oceanic Temperate	Oceanic Tropical	Brown Water Tropical
Lynton, Hutt Lagoon	Naval Communication Centre, Exmouth Gulf	Charles Knife Road South, Exmouth Gulf; Charles Knife Road North, Exmouth Gulf; Port Hedland; Karratha

Recommendations

Apart from completing the remaining site inspections, the recommendations provided in this study are detailed below.

Recommendation 1
Secure the most promising sites identified in this study for large-scale land-based marine aquaculture.

Three key selection processes are fundamental to the development of a commercial aquaculture project; the choice of site, species and production system. It could be argued that Western Australia (WA) has only two parts of the key selection process to enable the development of economically viable land-based, mariculture enterprise, namely choice of site and production system, i.e. the selection of suitable fish species in terms of value and volume for WA's socio-economic situation is limited. However, it is important to take a long-term view and undertake a commitment to removing the key impediment of site availability to aquaculture development, before the opportunity is lost.

Recommendation 2
Identify critical stakeholders and form a regional steering committee.

Given the significance of the Aquaculture Development Council's proposal and its benefits to regional Western Australia, it is assumed that securing the most promising sites will be done in consultation with all relevant government stakeholders, such as the Department of Local Government and Regional Development, Land Corp, Department of Planning and Infrastructure and the Department of Industry and Resources. These departments have key resources that will assist in the Department of Fisheries in securing development (pre)approval for the land parcels, and ensure a thorough community and industry consultation process. To assist in the consultation process, it is considered that a regional committee for each site or group of sites be formed.

Recommendation 3

Identify critical issues to be resolved in respect of each of the selected most promising sites.

The perfect aquaculture site rarely exists. Good aquaculture sites are usually distinguished by being able to satisfy the essential biological and other requirements of the species and by being suited to viable, economic solutions for less favorable or unsuitable features. In this instance, all the major and minor constraints to the sites' development and their solutions will need to be considered, and possibly ameliorated to provide future proponents with a site that is investment ready

Recommendation 4

Develop and implement a staged strategy, with a limited time frame, to achieve the objective of the project, i.e. making available (investment ready) the sites for commercial aquaculture development.

The success of securing any site will require excellent project management skills. A small and highly focused team with the necessary skills and experience to develop the sites, and negotiate the issues is required. In any case, the present ADC will need to provide a steering group with a set of well-defined terms of reference, a finite timeline, and definite milestones.

Recommendation 5

To conduct the GIS mapping study without the constraint of proximity to power.

Power stations outside the Perth electricity grid utilise diesel for the production of power. In most cases the purchase cost per kilowatt-hour is usually higher than self-production of electricity. It is on this basis that there may be value in identifying any other additional sites without the limitation of being near a power grid.

Recommendation 6

To maintain the GIS mapping system, used in this study, on-line.

The GIS mapping system, based on GeoMedia software and datasets, is maintained and owned by the Department of Agriculture, Western Australia. Negotiation with the Department of Agriculture regarding access and use of the GIS mapping system on-line will be most useful for future studies.

Recommendation 7

Undertake a broad scale relative economic comparison of the high potential sites identified, utilising economic indicators such as costs of land, transport and power.

To compare the relative cost benefit of sites located close to Perth metropolitan area, which have cheaper power and transport, but higher land costs, with more northerly sites with their higher power and transport costs but lower land costs and higher growth rate due to warmer water.

Recommendation 8

Incorporate the RAMSAR wetlands, information on local geology, and information on marine bore water quality.

To broaden the information that is contained within the GIS mapping study.

Recommendation 9

To revisit this study in five years to examine the sites with medium or long term development potential.

As the selection criteria used identified only a few sites with immediate mariculture development potential, it may be valuable to re-examine medium priority sites identified in this study, with a view to identifying sites with medium to long-term development potential.

SECTION 1 INTRODUCTION

1.1 Background

The state of Western Australia is the largest in Australia with a coastline extending to 13,000 km. This extensive coastline covers tropical, sub-tropical, warm-temperate and cool-temperate environments, providing opportunities for the commercial aquaculture of a wide variety of aquatic species. Despite the length of the coastline, coastal sites have been difficult or expensive to identify and access, and as such constitute an impediment to aquaculture development. The Aquaculture Development Council identified sites for large-scale land-based commercial aquaculture development would assist in overcoming this impediment

The sites identified also needed to meet the requirements of either warm temperate and tropical fish[1] species. The requirements of such fish species fall into three broad categories:

1. Fish that require high quality, warm temperate waters with few suspended solids.
2. Fish that require high quality, tropical waters with few suspended solids.
3. Fish suitable to tropical brown water, i.e. high quality oceanic water with suspended solids.

In recent years there has been significant interest in the development of aquaculture facilities at onshore coastal locations in Western Australia for a range of aquaculture species. To acquire suitable sites, aquaculture proponents will have to undertake similar site identification, selection and application processes, resulting in substantial replication of effort and resources.

The Department of Fisheries, in an effort to reduce the time to secure a site, has established and developed two coastal aquaculture parks, which have been successful in attracting aquaculturists into the industry. The sites available at the aquaculture parks are primarily suited to hatchery operations and are not large enough to accommodate industrial-scale land-based mariculture ventures.

Phase 1

The first stage of this process involved the defining the site selection criteria by which the potential sites would be selected and assessed (Figure 1).

Phase 2

The second phase (Figure 1) required the engagement by the Department of Fisheries of a Geographical Information System (GIS) consultant to conduct a site suitability mapping exercise of coastal areas of WA between its borders with South Australia and Northern Territory, utilising set site selection criteria (Sheppard 2001).

[1] *Fish is used in a broad sense of finfish and invertebrates.*

Phase 3

The third phase of the site identification process involved the detailed onsite evaluation of the sites (Figure 1). This study is concluded by selecting three suitable sites, one oceanic tropical, one oceanic temperate, and one brown water tropical, plus making recommendations on how to progress securing tenure of the three suitable sites selected.

1.2 Objectives and Structure of this Report

The objective of this pre-feasibility study was to present a description of three sites which are technically most suitable for large scale, commercial, intensive onshore marine aquaculture in tropical and temperate WA - one oceanic tropical, one oceanic temperate, and one brown water tropical.

The process of identifying the most suitable sites was aided by GIS mapping which utilised site selection criteria, defined in consultation with the ADC technical sub-committee, with specific reference to fish species that would ultimately be targeted for aquaculture at the prospective sites.

Detailed descriptions of site features, evaluations of their potential and information about potential constraints characteristic of each individual site were compiled by on-site inspections, discussions with the existing industry members and service providers and other methods.

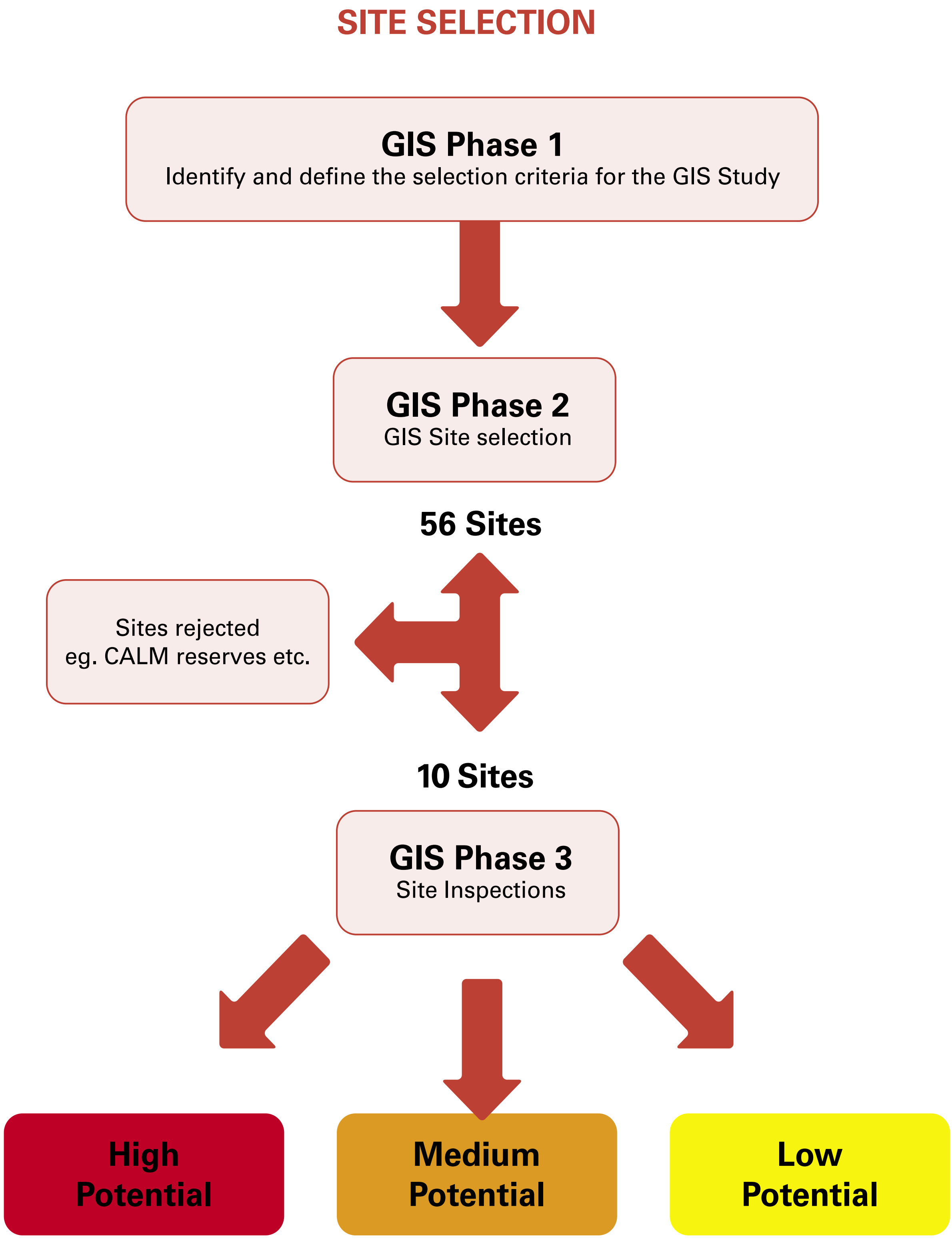
The first part of this report comprises the introduction (Section 1) and the process used to identify, select and evaluate sites. Section 2 undertakes a review of the site selection criteria used for the GIS mapping study. The site identification and selection process is then summarised and a brief summary provided of the important features for each of the preliminary sites. A synopsis is then provided of the preliminary sites and the selected sites considered the most suitable for land-based farming. Section 3 provides some relevant geomorphologic information about the regions and features common to all the selected.

The second part of this report, comprising Sections 4 and 5, provides more detailed descriptions of the six selected, suitable sites.

The third part of the report draws some relevant conclusions about the suitable sites described in the previous sections, identifies priority sites for further development and considers the approaches which could be utilised to secure the land for aquaculture.

Appendices 1 and 2 list the sites identified by the GIS mapping study and provide detailed maps for each. Appendices 3 and 4 draw in additional datasets and their sources.

Figure 1. Site selection pre-feasibility study flow chart.



SECTION 2 IDENTIFICATION AND SELECTION OF SITES

2.1 Site Selection Criteria for Land-Based Mariculture

Financial, marketing and technical feasibility studies are fundamental to the development of a commercial aquaculture project. As part of assessing the technical feasibility the choice of site, species and production system are components which require careful consideration. Many physical and biological factors need to be considered when selecting and evaluating a site for aquaculture and will vary according to the species and production system selected.

Selection of an appropriate site for an aquaculture operation is of paramount importance in determining the profitability of a farm. Commercial, land-based mariculture requires sites are characterised by certain features; generally, the optimum sites are those that best satisfy the biological requirements of the target species and the financial and management requirements of the aquaculturist (Makaira 1999). The effects that the different site features may have on a commercial aquaculture venture would need to be considered by any proponent, as a component of a detailed feasibility study.

Different site features can affect the viability of commercial aquaculture at any given site. In the selection and assessment of sites with potential for land-based aquaculture, the following relative effects were considered:

- Factors affecting yield or production capability, such as site area, can have significant effects on capital and operating costs.
- Unfavorable biological conditions. Some physical site deficiencies may be acceptable; however, good physical site conditions may not compensate for poor biological conditions.
- Intensive production systems carried out under good biological conditions can reduce the importance of physical site features and conditions.
- Water supply and discharge costs can have significant impact on capital and operating costs, with scale having an important influence; site elevation is a major determinant of pumping costs.
- Access costs can be moderate, but can become significant for extremely remote sites (Makaira 1999).

The major site selection criteria for commercial aquaculture encompass certain physical, biological, ecological, economic, social and legal factors (Huguenin and Colt, 1989; Shang, 1990; Pillay, 1993). The selection criteria used to assess the sites in this study have been defined in consultation with the ADC technical sub-committee. Sections 2.2.1 to 2.2.5 identify and summarise the selection criteria considered the most critical for successful, land-based aquaculture. These criteria are used in this study to first identify (Section 2.3) and then assess each of the selected sites.

2.1.1 Physical Features

The physical features considered important for land-based aquaculture are: site location and size; topography and hydrography; oceanography; options for sea water intake and discharge; soil and vegetation; and climate.

Location and Size

For the purpose of this study, all potential sites are onshore. Other location factors include the distance from low water and the total land area of a site. Suitable sites are those located within about 1 km of the low water mark and larger than 2 km^2 in area.

Topography
The topography of suitable sites is such that their elevations above mean sea level ("MSL") range between 0 and 17 m. Ideally, the elevation of the leveled site should be such that the maximum pumping head is 10 m or less, to allow economic pumping costs and adequate fall for gravity discharge and avoid flooding. Relatively level land is preferred, to reduce earthmoving and construction costs.

Oceanography
Tidal flows and currents should facilitate the removal and dilution of discharge water from the farm.

Sea Water Supply and Discharge
Onshore aquaculture farms require large volumes of high-quality seawater. Land sites with physical features conducive to the construction of secure, cost-effective seawater intake and discharge systems have distinct advantages.

Sea water for onshore marine aquaculture farms can be obtained from two main sources: directly from the sea by the way of a marine intake; and from beach wells that draw sea water through porous strata or sea water intrusions, when they exist.

Marine intakes supply seawater directly from the ocean and require areas with high-quality seawater and relatively deep water close to shore. A water depth of 5-10 m within about 100 m of the low water mark is acceptable.

Physical features that favor marine intakes include headlands and other rock or jetty structures that provide shelter from storms and to which pipelines may be attached.

While land-based aquaculture systems should be based on minimizing excess nutrient input and removing organic wastes prior to discharge, a discharge site that allows rapid dilution by seawater is ideal.

Soil and Vegetation
Basic information is provided about the nature of the soil and vegetation, as this is important if pond-based production systems are being considered. For intensive systems using tanks, soil properties are less important; however, features such rocky soils or outcrops are important where earth works are required to allow construction and may prove prohibitively expensive to remove to accommodate the ponds.

Typically for pond construction sub surface soils require clay content of 20 per cent, and are more suited to pond construction than sand. Rock soils and rock are unacceptable. A shallow depth of topsoil/aggregate is also helpful.

Local vegetation is important in respect of clearing and construction costs. Sites vegetated by grasses and low shrubs would clearly be preferred to those with dense vegetation. Coastal dune systems are beneficial to protect the aquaculture facilities (i.e. ponds and tanks) and should be maintained or created.

The regulations that exist in respect of clearing native vegetation and preservation of coastal sand dunes should be noted. Approval is required to clear land of native vegetation. Regulations under the *Soil and Land Conservation Act 1945* apply over the whole of the State and require that anyone wishing to clear more than 1 ha of native vegetation for a change in land use should notify the Commissioner of Soil and Land Conservation at least 90 days before the anticipated beginning of clearing. Proposals are evaluated according to a Memorandum of Understanding signed by six Government agencies and depend on advice from the Department of Agriculture, the Department of Environmental Protection, the Department of Conservation and Land Management and the Waters and Rivers Commission. The evaluation processes operate under the *Soil and*

Land Conservation Act 1945 and the *Environmental Protection Act 1986*. Clearing is usually only allowed if it can be shown that it will not cause significant land or water degradation, including adverse impacts on neighboring populations. The onus is on the landowner to provide the requisite evidence.

Climate

Climatic factors relevant to site selection that are considered important to large scale mariculture are significant meteorological events such as flooding and cyclones. Air temperature, rainfall and evaporation are less important for intensive systems as the flux of water through the production system which results on minimal impact on water quality. Access to fresh water or low salinity water is important during long dry seasons, if hypersalinity is to be avoided in pond systems.

2.1.2 Biological Features

The biological features considered important for land-based aquaculture are: water quality; parasites and predators; and pollution and history of usage.

Water Quality
Water quality is probably the single most important factor that governs the production feasibility of any site for aquaculture. Before any significant commercial commitment is made to a site, a comprehensive analysis of water quality should be undertaken during the early stages of a detailed feasibility study. Physical and chemical water-quality parameters mainly include temperature, salinity, turbidity, pH, nitrogenous compounds, heavy metals and dissolved gases.[2]

The proximity of significant rivers or water flows to potential sites is considered as part of this selection criterion since large fresh-water flows can dramatically influence the quality of seawater. Preferred sites would be more remote from major rivers, unless hypersalinity is of concern during dry seasons.

The assessments of the seawater carried out during this study were relatively subjective; the intention was to provide an indication of seawater quality at the selected sites. Any proponent should be advised to undertake a detailed support study to investigate water quality for at least twelve months.

Ground water
The availability of reliable ground water supply is of benefit to provide fresh water for use in larval fish rearing and for the provision of potable water for staff and routine hygiene procedures.

Sea Bed
The stability of the seabed, its sediment type and the presence of marine macro algae and sea grasses need to be considered in the site selection process.

The presence of macro algae and sea grasses, the extent to which they influence aquaculture, and the extent they are impacted are important site selection considerations. In areas characterised by significant deposits of drift weed or 'wrack', the quality and/or reliable quantity of sea water extracted, either from beach wells or marine intakes, can be adversely affected as a result of decomposition process.

[2] *The pH and concentration of dissolved gases, such as oxygen and carbon dioxide, in sea water extracted from beach wells may vary from natural levels, according to factors such as the depth of the wells and their distance from the coast. For the purpose of this study, it is generally assumed that beach wells located close to the shore are more likely to yield high-quality sea water with physical and chemical properties that approximate those of the adjacent ocean; however, it is emphasised that this factor needs further consideration and, if beach wells are to be used, the quality of the sea water they deliver needs to be ascertained by testing water pumped from test wells.*

Areas with significant sea grass meadows are generally considered less suitable for aquaculture; however, onshore production systems will be required under regulations to treat discharge water and therefore will have a low environmental impact.

2.1.3 Economic Factors

The economic factors considered important for land-based aquaculture are: infrastructure and services (regional and site); labour, trades and security; feed sources; equipment and raw materials; diagnostic services; processing and packaging; and transportation and markets.

Infrastructure and Services

The regional infrastructure and services relevant to the evaluation refer to the region generally. Local or site infrastructure and services refer to roads, buildings and equipment that may already exist within the boundaries of the site. Land-based marine aquaculture utilise large amounts of electrical power, to which they need cost-effective access and ideal sites would have access to three-phase electricity supplied from the *Western Power* grid. Suitable sites are within 5 km of a sealed or primary unsealed road and a power source.

We expect that feed for land-based farms would be purchased from feed mills in the eastern states. In the longer term, as the industry grows and creates the requisite demand, it is likely that Perth-based mills would be contracted to manufacture feeds. In either event, proximity of the sites to the mills is not considered a major determinant of site suitability. Similarly, all the suitable sites are well located in respect of sources of equipment, which may be purchased variously from local or domestic suppliers or imported from abroad.

Labour, Trades and Security

The availability of skilled and semi-skilled labour to build, manage and operate it is an important selection criterion for any farm.

Transportation and Markets

The proximity, availability and cost of specialised road and airfreight services are an important determinants of site suitability. Given the need to focus on relative high value of fish products produced, market proximity is considered of relatively minor importance.

2.1.4 Social and Legal Factors

The social and legal factors considered important for all aquaculture are: urban proximity, competitive resource use and land tenure, particularly Crown land and reserves.

Urban Proximity

Urban proximity is considered important if high-quality staff is to be attracted and retained. Suitable sites should be within 50 km of a significant town.

Competitive Resource Use

The competitors for use of coastal resources is seen as one of the major factors affecting aquaculture development in Western Australia. Preferred sites should not compete with any existing high value use, for example by limiting access to major recreational fishing areas.

Land Ownership and Tenure

Freehold land invariably presents fewer problems and would be preferred over unallocated Crown land. Preferred sites ideally are those comprising one or more parcels of land with common ownership.

Each of the preliminary and selected sites comprises one or more land parcels (titles). A Department of Land Administration parcel number identifies these parcels. The Department of Land Information parcel numbers for all sites, as well as their vesting and purposes, are provided in Appendix One. "Parcel numbers" for selected sites are also provided in the relevant sections in parts two and three of this report.

2.1.5 Summary of Selection Criteria

Table 2. Summary of selection criteria and preferred requirements for land based marine aquaculture sites.

Selection criteria	Preferred parameters for land-based marine aquaculture
Physical features	
Location and size	Within 1 km of the low water mark and 2-5 km^2 in area.
Topography	Maximum elevation 12 m above MSL and ideally <10 m; low-gradient land.
Bathymetry	Deep water close to shore, preferably greater than 10 m.
Oceanography	Suitable tidal flows and currents; good circulation. Tidal range < 5 m.
Sea water supply and discharge	Suitable, cost-effective options for marine intakes or beach wells.
Soil and vegetation	Few or no rocky outcrops, sparse vegetation.
Climate	No history of flooding. Low cyclone Incidence.
Biological features	
Water quality	Physical and chemical parameters to suit species; low turbidity, remote from fresh water discharge and other obvious threats to water quality.
Economic factors	
Regional infrastructure and services	Within 5 km of a sealed or primary unsealed road; within 5 km of a power source. Ideally three-phase power is available.
Site infrastructure and services	Low importance, but suitable existing infrastructure is an advantage.
Labour, trades and security	Access to labour, trades and security.
Transportation and markets	Freight services are important. Proximity to markets is not critical.
Social and legal factors	
Urban proximity	Within 50 km of a town.
Competitive resource use	No competing resource use is preferred.
Land ownership and tenure	Freehold land is preferred, unallocated Crown land is acceptable.

Table 2 provides a summary of the selection criteria used in phase 2 of this study to select and assess sites for land-based mariculture.

2.2 Review of GIS Mapping Data

Table 3 shows the site selection criteria and stages used in the GIS mapping study that enabled a preliminary site suitability of the Western Australian coastline.

Table 3. Site selection criteria used for the GIS mapping Study

Selection criterion	High Potential	Medium Potential	Low Potential
Stage One			
Distance from town with a population of 3000 people (km)	50	50-100	>100
Proximity to roads (km)	0-2	2-5	5-10
Proximity to power grid (m)	0-2	2-5	5-10
Distance from low water mark (km)	0-1	1-2	2-5
Distance from river mouth (km)	7	3-10	<3
Stage Two			
Area (km^2)	5	3-5	<3
Elevation (above MSL) (m)	0-7	7-12	12-17
Land tenure	Freehold>UCL*>vested land		
Physical protection of site	Protected by reefs, islands, shoreline shape (bays)		
Site soil type	Clay	Sand	Rock
Freshwater availability (ML)	>50	50	10
Bathymetry (m)	>10	5-10	
*UCL – Unallocated Crown Land			

Makaira (1999) conducted a similar study of land-based abalone farming sites in the southern half of Western Australia and recommended a staged approach to the GIS mapping study phase. The first stage identified sites by utilising the most important criteria. These criteria are those for which, if not satisfied, economic solutions would lead to the selection of sites that are not economically viable.

The GIS mapping study used three main terms to identify land, namely parcels, sites and areas. Parcels are the land locations numbers used by The Department of Land Information to identify all land in Western Australia. Sites comprise land parcels of common ownership. Areas comprise several adjacent sites and were identified on the draft maps as shaded zones. For the purpose of this study, the term 'site' refers to a single area that was evaluated.

All sites located within Nature Reserves, National Parks and Conservation Parks were eliminated, since it would be unrealistic to expect that commercial aquaculture would be permitted in these areas. However sites adjacent to Marine Parks were not eliminated, as aquaculture is a permitted activity in the general use zone of any Marine Park. The preliminary sites are generally considered suitable for land-based aquaculture, according to stage two of the GIS mapping study.

Section 2.3 provides a brief description about each of the potential sites, including the rationale behind their selection or rejection as sites considered suitable for more detailed evaluation. The potential sites are described separately in Sections 4 and 5 and the appendices of this report. Appendix 1 provides details of site identification numbers and ownership and Appendix 2 location and site maps for each of the preliminary sites.

GIS Mapping Study

The second phase of the project involved GIS mapping of some of the datasets collated in Stage 1 (Appendices 3,4).

The main selection criteria used to identify the preliminary sites were: proximity to power and roads; distance from the low water line; distance from a river mouth; and distance from the nearest town. Details of elevation above mean sea level and site areas are detailed on the maps generated but were not used in the GIS analysis.

Buffers were generated based on each criterion according to the rules described in Table 3. These buffers were then intersected to identify the potential sites. Initially distance from population centre buffers were intersected with distance from coastline buffers. The results of this intersection were then intersected with distance from infrastructure buffers. This result was then intersected with distance from river mouth buffers to create an interim dataset describing potentially suitable sites.

The third step in the identification process involved intersecting the result from Stage 2 with tenure data. Only sites of high to medium suitability were intersected with the tenure dataset. The area of each parcel within site of potential suitability was calculated. These can be used on close inspection of the dataset to determine areas of common tenure.

At this point, a series of ten maps were produced showing medium to highly suitable sites by tenure type (freehold, unallocated crown land and reserves). The ten maps cover all sites identified along the Western Australian coastline. These maps were passed onto the Department of Fisheries' regional Aquaculture Development Officers for comment.

Data on local soil types and freshwater availability collected by the Department of Fisheries for these sites were supplied to the Department of Agriculture for incorporation into the suitability dataset.

The final result of this project is a GIS viewer that allows the user to look at each individual criterion or all of them together and identify the sites according to the user's preferences.

2.3 The Site Identification and Selection Process

The GIS mapping study generated sufficient information to allow potential sites to be selected principally by way of a desktop study. These sites would then be individually assessed in the field.

The process used in this study to identify, select and describe sites suitable for land-based mariculture is considered to have been successful and, generally, to have significant value in respect of the future identification of sites for the aquaculture of other species.

The phases used in the identification and selection process to identify and evaluate sites for land-based mariculture may be summarised as follows.

Phase 1:

> **Stage 1:** Preliminary identification of sites ("preliminary sites"), principally by the GIS mapping study, according to specific selection criteria and current knowledge (Figure 1).[3] All the preliminary sites generally satisfy the selection criteria established for the study. Sites initially selected by the GIS Study but located within Nature Reserves, National Parks or Conservation Parks were eliminated as candidates.
>
> **Stage 2:** Interim selection of the preliminary sites for on-site inspections, according to existing knowledge of the areas in question and more specific selection criteria.

Phase 2

> **Stage 1:** Final selection of the sites considered best suited for large-scale land-based mariculture ("suitable sites"), according to information generated from the on-site assessment process.

From the GIS analysis a total of 56 individual sites of high to medium suitability were identified. Maps of these sites were provided (Appendix 2).

Sections 2.3 provides a brief overviews of the preliminary sites. A preliminary list of potential sites is provided in Appendix 1. Appendix 2 contains location and site maps.

[3] *The iterative process used to select the sites considered best suited for land-based marine aquaculture was based principally on the knowledge of the areas in question collectively possessed by the authors, and other Department of Fisheries staff including the regional Aquaculture Development Officers, research staff and members of the Aquaculture Program. During the on-site inspections, local knowledge provided useful information about the accessibility, seasonal and otherwise, of various sites.*

Figure 2: Location of the preliminary sites identified by the GIS mapping study.

Overview of the Preliminary Sites

TEMPERATE WATERS

Midwest Coastal Region

A number of small sites were identified north of Geraldton and south of Dongara. These parcels are not ideal for large-scale aquaculture venture, however, these sites may be useful for smaller mariculture projects.

2.3.1 Buller River

Situated 15 km north of Geraldton and 1 km west to northwest coastal highway, the site (Figure 4) is roughly 0.1 km^2 and lies between low hills from the east and low sand dunes in the west. The site has slight slopes from east and west to the site's center. Water inlet can be from across the sand dune where the height above sea level is 10-15 m. Discharge water can be directed to the Buller River mouth. Water quality is not considered to be high with high turbidity and seaweeds washed to the shore. The land is privately owned and currently used for agriculture.

Figure 4. Buller River site.

2.3.2 Freshwater Point

Situated half way between Dongara and Leeman on Indian Ocean Drive, the site (Figure 5) is roughly 2 km^2 and it is located east to the road. The area is flat, covered with coastal scrub, with occasional rocky outcrops. Water quality may be a problem due large deposits of drift seaweed present. The site location is relatively close to the township and Geraldton airport.

Figure 5. Freshwater Point site, east view.

TROPICAL WATERS

Gascoyne Coastal Region

2.3.3 Carnarvon

The GIS mapping study identified this site, to the south of Carnarvon (Figure 6), to have medium potential. This site is an extensive area of mud flats which is very prone to flooding, as such an enterprise would need to consider in an assessment of the engineering solution which would require additional earthworks to flood proof the production facilities. In addition, the Gascoyne River would have a great influence on the quality of the intake water. In addition the site is hypersaline location (40-50 ppt) and bordered by the Worramel seagrass bed, a protected area in World Heritage. It is on this basis that the area is considered to be of medium to low potential.

Figure 6. Carnarvon site, floods 2000.

2.3.4 Exmouth Gulf

Most of the eastern side of the Cape Range peninsular was identified to be of high potential for tropical land-based aquaculture (Figure 12). All sites have low topography, and are close to all weather roads, power and telecommunications and near to townships. A detailed description of the site is provided in Section 5. One risk to any operation is the area has a highest cyclone frequency on the WA coastline. Any infrastructure should take into account this issue.

Figure 7. Karratha Site.

Pilbara Coastal Region

2.3.5 Dampier, Karratha, Wickham and Port Hedland

The GIS mapping study identified medium priority areas near Dampier (Figure 7), Karratha and Wickham. The sites are close to the townships, highways and power supply. Based on the GIS study, Wickham (Point Sampson) was considered as high priority, with possible low topography shoreline. However, a visit revealed that the site contained extensive rocky outcrops that resulted in it being unsuitable for land-based aquaculture.

The area west of Karratha (the east side of Burrup Peninsula) has mariculture development potential and medium potential for tropical land-based aquaculture. A detailed description of the site is provided in Chapter 5.

2.3.6 Port Hedland

Port Hedland site, located 25 km east of township, is a suitable site considered to have a medium potential for tropical land-based aquaculture. A detailed description of the site is provided in Section 5. This area also has a high risk of cyclone.

Kimberley Coastal Region

2.3.7 Broome

The Broome site identified is approximately 3 km east of Broome Town Site (Figure 8). The site is bordered by Dampier Creek and Roebuck Bay. The area covers approximately 20 km^2 and is dominated by deep red or brown sandy soils. The area is relatively flat with a pumping head of 7-10 m. Broome has the advantage of power supply, roads and the distance from the township. The aquaculture park is nearby, including the multi-species hatchery. The entire region is exposed to cyclones and any infrastructure should take into account this issue. Access is via a long established unsealed road, but, may be limited for periods during the wet season due to flooding. Given this and issues associated with Aboriginal Heritage and Native Title, Environmental considerations, and large tidal movements (10 m), this site is considered to have low development potential.

Figure 8. Broome site south to the town.

2.3.8 Willie Creek

Willie Creek (Figure 9) is located 24 km north to Broome with access by sealed and established sealed roads. However, access is cut and subject to periods of flooding during the wet season. The site is not ideal due to a large area, 4-5 km^2, of mud and tidal flats that overlap the proposed Nimalarragun Wetland Reserve. The area is exposed to cyclones and has high tidal range (10 m). The area also has Aboriginal heritage significance. It is close to future urban development and tourist attractions.

Figure 9. Willie Creek site.

SECTION 3 GEOMORPHOLOGY, HYDROLOGY AND HYDROGRAPHY FEATURES

3.1 Geomorphology

3.1.1 Midwest

The coast in this region is subject to winter storm events and very infrequent cyclones which can cause small barometric tidal surges of about one to two metre changes in sea level caused by changing barometric pressures, winds and waves. The region has small tidal ranges of less than one metre and high-to-moderate wave energy. The coastline usually features long, sandy beaches with occasional limestone cliffs and headlands. Much of the coastline comprises extensive dunes, which often rise to an elevation of over 80 m within several hundred metres of the coast (Figure 11).

Figure 11. Typical coastline in the Midwest.

The area features an extensive system of offshore limestone reefs that run parallel to the coast. This is one of the largest temperate limestone reef systems in Australia. The reefs protect the sandy coastline and permit the growth of extensive beds of seaweeds and seagrasses which support the western rock lobster fishing.

Between Hutt Lagoon and Dongara, the shoreline is relatively straight and has a moderate energy and sandy beaches. Offshore, the sea water is usually very clear as a result of the Leeuwin current and limited fresh-water drainage from the adjacent land areas. Seaweeds dominate the limestone reefs. Southwards of Dongara to Perth, coastal landforms are similar and offshore limestone reefs more extensive. Onshore features generally include extensive, coastal dune fields, the oldest of which have consolidated into limestone ridges. Most of the ridges above sea level feature a mantle of Holocene sand dunes. Some small offshore islands occur in the area. In many localities, sheltered, semi-lagoonal habitats are formed behind the offshore limestone reefs. Decomposing, detached seaweeds, which often form large aggregations of "wrack" on the beach in these areas behind sheltering reefs, can have a major effect on the quality of seawater in these areas.

The region has several small to medium-size rivers, the winter discharges from which have minor effects on the relatively clear coastal waters generated by the Leeuwin current. There is a wind-driven, near shore current that flows northwards in summer during the 'trade' wind period when a daily wind speed of 20-plus knots occurs.

Climate

The Midwest region has a typical Mediterranean climate and falls within the Temperate climatic zone. This zone is characterised by moderate rainfall, and warm to hot summers and cool to mild winters.

Coastal currents near shore in the Midwest region are influenced by the wind. Generally, the wind flow is governed by the anticyclonic belt, which moves north and south with the seasons. In winter, westerly and north-westerly winds predominate, while summer patterns are governed by south-westerly coastal seabreezes renowned for their strength and regularity. In approximately 60 per cent of summer days the winds exceed 25 knots. Southern gales and storms also occur in winter, as result of deep low pressure systems moving into the region.

In regard to cyclonic activity, anticyclones occur every five to seven days in summer, bringing hot and dry conditions (Dept. of Planning and Urban Development 1994). The occasional, approximately five yearly tropical cyclones result in very strong winds, heavy rains and a high swell.

The risk of flooding is low, the major river systems discharge to the ocean in the winter of most years. River discharge can affect water quality due to the sediment and pollutant loads, and the mixing of fresh and sea water.

3.1.2 Exmouth Gulf

Exmouth Gulf is a north facing marine embayment 40 km wide by 80 km long. It is isolated from the Indian Ocean to the west by the Cape Range Peninsula, which reaches 100 to 300 m high. Numerous islands are found throughout the Exmouth Gulf zone. These are ringed by narrow beaches and fringing shallow sub-tidal to inter-tidal limestone platforms supporting coral outcrops.

Figure 12. Typical coastline, Exmouth Gulf.

The eastern hinterland is lower lying, sloping gently westward to the embayment (Le Provost, Semeniuk and Chalmer 1988). The western shore is comprised largely of a narrow coarse-grained pebble beach abutting onto a low intertidal limestone platform. The southern and eastern shores of the gulf are comprised primarily of extensive mud flats and sand flats. These areas are subject to extensive inundation during periods of higher than average sea level conditions, particularly during cyclone surge events. Limestone platforms and coral outcrops occur infrequently along the eastern shore. Maximum water depth within the gulf is 20 m.

The Holocene coastal landforms flank an extensive terrestrial dune terrain from South Wapet Creek and to the Sandalwood Peninsula. The coastline of Exmouth Gulf has three main bays, i.e. the Bay of Rest, Giralia Bay and Gales Bay. Very extensive tidal flats, extending in places up to 15 km landward of the shoreline, occurring along the eastern shore of Exmouth Gulf make access impossible particularly after cyclone events.

Cape Range is characterised by calcareous lithosols, which occur on the plateaux and steep foot slopes of Cape, Giralia and Rough Ranges. Soils are 10-40 cm deep and are usually dark reddish brown with a pH of about 8.5.

Large volumes of alluvial sediments cover much of the coastal plain and these are cut by contemporary streams attached to each Cape Range canyon. In general, the eastern part of the Cape Range has a well developed drainage net, with well-defined channels, so that flooding and surface water ponding should not pose a major problem.

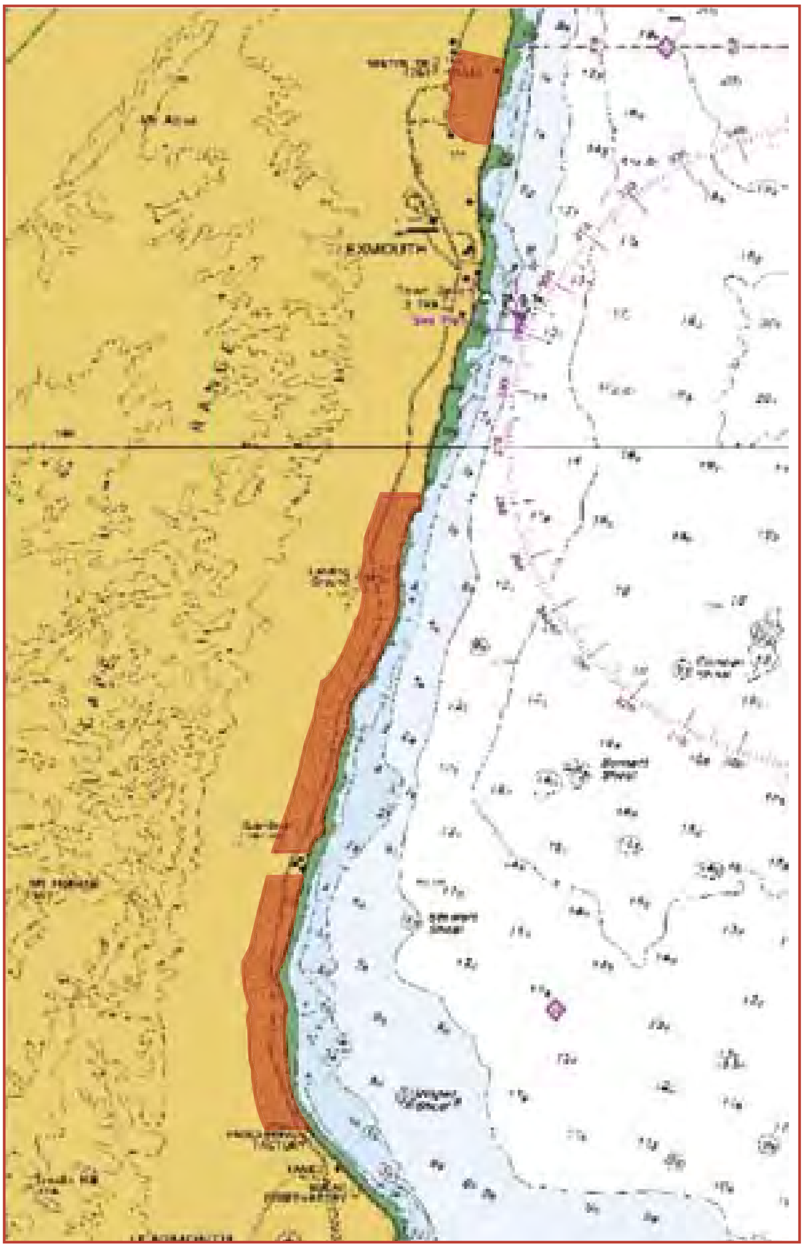
Along the western coastline of the Gulf, brownish or early sands occur on the sand plains and calcareous sands are found on the coastal dunes and beaches. Brownish or earthy sands range in depth from 60-100 cm or more over limestone. These soils have a pH of approximately 8.5. Non-cracking clays can also be found in this area. They occur up to 55 cm deep over the limestone and usually have a pH of about 8.5 (Payne et al. 1987).

Hydrology and Hydrography

A subdued ground water mound about 10 m above sea level, separated from the regional water table of the Carnarvon basin, occurs beneath the highest part of Cape Range. Recharge to the ground water system occurs after heavy rainfall by direct surface infiltration and runoff and is thought to occur rapidly (Allen 1993).

On the western shoreline of the Gulf, fresh ground water extends to more than 100 m below sea level. This indicates that a lens of fresh ground water underlies the Cape Range, overlying seawater, analogous to ground water occurrence on oceanic islands.

Figure 13: Map indicating the location of the suitable sites along the Exmouth Gulf coastline (sites are shaded in red).



At the north-eastern entrance to the Gulf, the Ashburton River discharges very large volumes of water when flooding. River flow from Cape Range creek also has a dilution effect, which could temporarily affect water quality in the Gulf (Marine Parks and Reserves Selection Working Group 1994).

A discrete intertidal to sub-tidal platform is developed along the western shore face of the Gulf. The platform is 300-800 m wide and slopes gently from high tide levels to about the five metre contour. Beyond this contour the sea floor slopes steeply and then more gently, merging with the embayment floor in depths of about 10 m at two to three km from shore. The embayment floor deepens to the northwest, reaching depths in excess of 20 m adjacent to North West Cape.

The entire Gulf is covered by either mineral tenements or petroleum permits (Fowler 1996). The majority of the coastal land within the Exmouth Gulf is crown land; either crown reserves, vacant crown land or the subject of pastoral leases. The Cape Range National Park, part of the Ningaloo Marine Park, which includes the Bundegi Reef Sanctuary Zone, island native reserves and the large recreational and coastal management reserve are vested in CALM's Executive Director and the Shire of Exmouth.

Throughout the Exmouth Gulf there is a limited supply of fresh water. The eastern and southern sections of the gulf are difficult to access and have virtually no infrastructure present. Turbidity levels in the southern and eastern Gulf are elevated. Mining operations within the Gulf present a potential pollution risk. The coastline has relatively small areas of mangroves, which are sensitive to changes within their environment. Aquaculture occurring within close proximity to mangrove communities and other environmentally sensitive areas may require monitoring.

Climate

The Exmouth climate is characterized by hot summers and low rainfall. The majority of rainfall occurs as a result of cyclonic activity from January to March. The amount of rain can be highly variable, averaging 278 mm per year. Climate conditions in the coastal Gascoyne are dominated by tropical cyclones. During 1925 and 1966 exactly one hundred cyclones were recorded in the region and the area immediately to the North (Lourensz 1981), all occurring during the summer months, in particular between January and March. Maximum temperatures are highest in January (37.9°C) and the lowest mean maxima is in July (24°C) and is higher than elsewhere in the Gascoyne region.

The areas rainfall is offset by high evaporation rates which range from 1700 – 3050 mm per year, depending on seasonal conditions. Prevailing winds are from the south and southwest and reach up to 45 km/h.

3.1.3 Pilbara

Physical features

Much of the Pilbara coastline is fringed by mangroves, especially around river mouths and tidal inlets. Behind the line of mangroves are extensive areas of saline coastal flats. There are relatively few rocky areas along the coast, Cape Preston to Cape Lambert being a notable exception. Salt marsh communities generally inhabit the landward fringe of mangroves.

Along the narrow coastal strip, mangroves gave way to spinifex grasslands and low open acacia scrubland with only occasion trees. The sandy coastal plains are inhospitable, covered by spinifex (*Triodia pungern*) interspersed with numerous low spreading shrubs. Low lying and loamy inland areas are generally covered by mulga scrub, low to medium cover of wattles, poverty bush, grass and spinifex.

Behind the low lying parts of the coast a grantic plain rises inland, a relic of previous sea level. So gentle is the rise in some places, that there is a belt 5-10 km wide which is under tidal influence. The tidal range is about three to five metres. Much of the Pilbara coast is protected from surf by offshore islands or reefs, which means there is little coastal erosion or disturbance of the sand dunes.

Extensive mangrove deltas have been created around the mouths of the large, intermittent river systems of the Pilbara, for example, the De Gray, Fortescue, Turner and Yule.

The soils of the Pilbara are generally red, as soil particles are covered by iron oxides. In the desert to the east, the soils consist of sands while in the west there are extensive rugged hills surrounded by wide tributary plains. The tributary plains have duplex soils which consist of sand or loam overlaying clay. The flood plains, ancient lakes and areas with volcanic rocks have clay soils.

Climate

The Pilbara is a located in the north-west of Western Australia. It is a semi-arid region characterized by high temperatures, low and variable rainfall, and high evaporation. Tropical cyclones bring heavy rainfall, but there are often long periods without rain. Extreme temperatures are common.

Between October and April, the temperature throughout the Pilbara reaches or exceeds 32ºC almost every day, with 40°C being recorded for extended periods over summer. The months of June, July and August are the coolest. A feature of the temperatures in the Pilbara, particularly inland, is the large diurnal ranges. There is a temperature range of 17ºC between the mean maximum and minimum for some months.

Annual rainfall in the Pilbara is between 200-350 mm. Rainfall is infrequent and intense with the main falls occurring during the cyclone season from December to May. Evaporation rates in the region are high, estimated to exceed by ten times the annual rainfall. The Pilbara is influenced by northern rainfall systems of tropical origin. These systems are responsible for heavy falls during the summer months, while the southern low-pressure systems sometimes bring limited winter rains.

The tropical cyclone season extends from November to April, and, on average, eight cyclones form each year over warm tropical oceans, generally between the Cocos Islands and Darwin. Two or three of these usually make landfall on the WA coast, which may be accompanied with destructive winds or river flooding.

Storm surge, the abnormal rise in sea level may accompany the movement of a cyclone near the coast. On occasions, storm surges have inundated the lower lying coastal Pilbara terrain, with surges of up to 5 m being recorded. The large tidal range of the Pilbara coast and its influence on storm surge flooding is an important consideration when assessing the suitability of coastal land for development. For example, the minimal level adopted for the development is 6.3 m ADH (Australian Height Datum) in Karratha which has average storm surge recurrence of about 100 years.

3.1.4 Kimberley

Physical features

The Kimberley is located at the north-west corner of the Australian continent and has a land area of approximately 421 000 km^2.

The land surface is ancient and little geological activity has taken place since the rocks were formed. The landscape, which mainly comprises plains overlain with undulating sand ridges, is also characterised by a diverse range of geographical features.

The variation of the vegetation reflects the distribution of rainfall and soil types. Dense eucalypt woodlands, mangrove forest and rainforest remnants occur in the north. Savanna woodlands occur in the central area and sparse acacia scrubland and spinifex savanna in the south. Conservation reserves comprise almost 20,000 km^2. Soil erosion is increasingly becoming a problem, especially in pastoral areas. Degraded vegetation from grazing, fire and weed invasion has left soils unprotected from the heavy seasonal rains, resulting in erosion and heavy river-sediment loads.

The longest river is the Fitzroy. Its vast catchment area often results in dramatic flooding and tremendous water flows. Many rivers such as the Drysdale and King Edward, flow from the high-rainfall parts of the northern plateau to the coastline. In the south, only semi-permanent creeks and lakes that can be mostly dry throughout the year are present. When heavy rains arrive, the creeks turn into rivers and the lakes fill with water. Wildlife is abundant during these times. During the wet season most of these areas are inaccessible.

The marine environment is partially influenced by the warm, south-equatorial current that flows from the east through the Asian and northern Australian region. There are numerous offshore islands. The coastline comprises numerous inlets, mangrove shores and bays, apart from the long, sandy stretches south of Beagle Bay. The coast is prone to large tidal variations. In King Sound, the highest tides reach 11 m. Strong tidal flows, together with summer river discharges, dramatically influence the coastal environment. These macro-tidal ranges have a significant impact on the aquaculture potential of the area.

Climate

The Kimberley region has a tropical semi-monsoonal climate with two dominant seasons separated by short transitional periods. The wet season occurs from about November to April. Monsoonal weather brings hot and humid conditions, with winds mainly from the north-west and frequent thunderstorms causing heavy rainfall. This period is unusual for the tropics in that it does not have regular cloud cover and as a consequence has air temperatures in the range of 40-45°C. The Kimberley receives about 90 per cent of its rainfall during the wet season. This time of year is often marked by tropical cyclones, which generate most of the rain, and low pressure systems. These can produce heavy rain that may flood regions such as the Fitzroy river basin. Intense cyclonic winds may cause structural and property damage.

Dry, sunny days and cooler nights typify the dry season from May to October, as the trade winds flow from central Australia. Very little rainfall occurs during the late winter to spring months.

Annual rainfall decreases southwards, from over 1400 mm near the Mitchell Plateau to below 400 mm towards the Great Sandy Desert. Rainfall is highly variable from year-to-year, depending on occurrence of tropical cyclones, which are often responsible for much of the annual total.

During the wet season begins, the river-flows across the region can build up quickly and discharge large volumes of water into the sea through the ten drainage basins. These river systems are seasonal and all, with the exception of the Ord River, are dry by the end of May. Permanent and semi-permanent pools exist in the streambeds of most of the river courses.

The region's high evaporation rates constrain the use of small dams and ponds. Consequently, most town water supplies and the water requirements of the pastoral and mining industries are provided by bores which tap into the important underground water resources.

The Kimberley region is subject to seasonal extremes of water flow and salinity. During the wet, the run-off from major and minor drainage systems influences the level of fresh surface and shallow ground-water supplies, raising the water table and filling water courses and lagoons. The seasonal fresh water flow does influence localised ocean salinities in creeks and bays for short times, coupled with an accompanying silt load during floods. The latter part of the dry season provides very little fresh water. The high evaporation rate elevates the salinities of the tidal creeks where readings of over 43 g/L have been recorded at the tidal headwaters. Tidal undulation of this nature can affect the reduced fresh-water reserves and temporarily affect localised water tables.

The highest temperatures occur in the inland parts in the south-west in November and December, before the monsoon brings increased cloudiness and humidity. With the exception of some coastal areas, average maximum temperatures exceed 35ºC during these months and are regularly over 40°C for consecutive days. Winter maximum temperatures average about 30ºC. Overnight temperatures during winter generally remain above 20ºC in the northern coastal parts but can often drop to below 5 ºC in the desert inland.

SECTION 4 SUITABLE TEMPERATE WATER SITES FOR LARGE-SCALE MARICULTURE

4.1 Port Gregory

4.1.1 Lynton

Location and Size

Lynton is located between the southern end of Hutt Lagoon and Hutt River, about 95 km north of Geraldton via Northampton, off Port Gregory Road.

A sealed road provides good, all-weather access to the site. The preliminary site selected from the GIS mapping study comprised an extensive coastal area larger than 20 km^2. The area was identified as medium priority due to the elevated frontal dunes generally characteristic of the region. However, the region does contain an area considered suitable, and hence was selected as a site for, land-based aquaculture. The area is situated at the southern end of the hypersaline Hutt Lagoon within a large, low-lying area (Figure 14). The area is about 3 km^2 and is situated to the west of Port Gregory Road, between the southern end of Hutt Lagoon and Hutt River.

Figure 14. Lynton, Hutt Lagoon (area of potential is shaded in red)

Topography and Hydrograph

In areas, the frontal dunes at Lynton are lower than is usual for the area. The width of the dunes between the coast and the low-lying areas at the southern end of the lagoon is about 500 m and their height is generally lower than 20 m. Figure 15 shows the large area of low lying land to the south of the lagoon.

The water close to shore is reasonably deep and the seabed is mainly fine sand. Towards the northern end of the site, there is an offshore reef that runs mainly parallel to the coast. The prevailing northwards-flowing current can be more pronounced during summer due to regular strong southerly winds (>20 knots). Most of the year the swell direction is southwest and up to 2.2 m high. Average wave height (winter) is 2.2 m.

Figure 15. Panoramic view of the Lynton site.

Soil and Vegetation

The soil is mainly clay and sand, according to the specific location within the site. In the north side, south to Hutt Lagoon, there are patches of limestone and rocks. Most of the area is farmland with no native vegetation.

Sea Water Supply and Discharge

A marine intake located inside the offshore reef may provide the best option for a sea water supply system, given the shelter that would be afforded. Cognis Pty Ltd, a Beta-carotene harvesting company at Hutt Lagoon, took this approach (Figure 16). The company has a pump house south to Port Gregory (Figure 17). It is suggested that any proponent negotiate with the company for the use of the same pumping site and perhaps share facilities. The alternate option of beach wells may be feasible, depending on the quality of water delivered and the flow rate that can be sustained. At this site, subject to sea-water quality and quantity conditions being satisfied, beach wells may have significant economic advantages.

Figure 16. Intake water. Port Gregory beach.

There are two main options for discharging used water: northwards to Hutt Lagoon and southwards to Hutt River.

The first option involves draining used water into the lagoon. Some synergies may be possible with Cognis Pty Ltd, since the company is pumping water to the lagoon and the increased level of nutrients in the used water may be perceived by the company as a resource. The surface of the lagoon is higher than some parts of the site, so the farm design and engineering would need to ensure the water supply and discharge system was constructed to permit gravity discharge. This option needs to be negotiated with Cognis Pty Ltd due to the impact on the algae production.

Figure 17. Cognis Pty Ltd, pumping station.

The second option for discharging water (and probably the easiest way) is to direct the flow into Hutt River and then into the sea. This would have the effect of maintaining open the bar across the river mouth but is unlikely to have any detrimental environmental, recreational or social effects, and may create a new small estuarine fish nursery.

The best option for an intake may be a pipeline laid on the bed or banks of the Hutt River (Figure 17) or an area of low lying sand dunes. The cost benefit of either approach will need to be assessed by any future proponent.

Water Quality

The water quality at the site is very good. There is no evident accumulation of large quantities of seaweed between the reef and the coast and, with the obvious exception of significant rainfall events, fresh water discharge from the Hutt River is minimal. Even at times of river flooding, due to the high-wave-energy coast and currents, we consider it unlikely that any detrimental effects would be realised by an onshore aquaculture facility.

Figure 18. Hutt River mouth, discharge option

Site Infrastructure and Services

The presence of a sealed road and three-phase power lines is an important feature of this site, giving it an economic advantage that in part compensates for its relatively remote location. A telecommunications line similarly transects the site. There is no potable water supply or sewerage at Lynton and provision would need to be made for these services in any farm design.

Competitive Resource Use

There is no apparent conflicting resource use at this site. Ruins of stone buildings near the southern part of the site are a tourist attraction; however, rather than being competitive, an aquaculture venture in the area would be more likely to augment tourism by providing an additional point of interest. There are two main users of the land in the area; Cognis Pty Ltd at Hutt Lagoon and a garnet mine at the hills east of the lagoon. None of these companies appears to have conflicting use with the suggested area.

Tenure

The area identified as having high potential for aquaculture is at the southern limit of Hutt Lagoon and about 200 m inland is private land owned by Mr R Simkin.

The Department of Land Information parcel number for the site is: VICTOL 07454; 00010, 00405, 00406, 00044.

Site Evaluation

Potential for Development

Lynton has high potential for land-based aquaculture and is considered one of the best sites in the mid-west coastal region. The site comprises several areas that may be suitable for development. Some opportunities may exist with Cognis Pty Ltd for synergies in respect of operations such as sea-water supply and discharge.

Constraints to Development

Except of the private ownership of the land, there are no known, major constraints to development. Potential minor constraints to development include:

- the high elevation of the frontal dunes;
- limited discharge options;
- the proximity to a river; and
- conflict with existing users of the resource.

If marine intakes are used, the cost of pumping large volumes of seawater may be high unless an intake channel or pipeline can be constructed or laid through the frontal dunes to limit the pumping head.

Discharge may be a problem unless the used water can be discharged through the river. In this event, the intake would be likely to be to the north and hence downstream from the discharge point, so steps would need to be taken to ensure used water is not recycled through the intake. If Hutt River or Hutt Lagoon are to be used for discharge, the environmental effects of discharging water into either would have to be ascertained.

Conflict with other resource users would probably be limited to the proposed discharge method involving Hutt River. This is not considered an important issue, since the aquatic environment in the river is already modified and not in its natural state. In fact, the water discharged from a land-based aquaculture venture may assist in rehabilitating the river environment and create a more productive fish nursery area.

SECTION 5 SUITABLE TROPICAL WATER SITES FOR LARGE-SCALE MARICULTURE

5.1 Exmouth Gulf

Exmouth Gulf is suited to land-based aquaculture. The Gulf has large quantities of relatively good quality water available with existing compatible infrastructure present. The area of interest stretches south from Bundegi Nature Reserve south to Heron Point, near the Bay of Rest (Figure 19).

Several of the selection criteria used to assess the suitable land sites in Exmouth are common to all sites, due to the homogenous nature of the coastal strip. To avoid repetition, these common criteria, which mainly include economic factors, are dealt with separately in this section.

Figure 19. Pebble Beach, south to Learmonth.

Topography
The shore is comprised largely of a narrow coarse-grained beach abutting onto a low intertidal and sub tidal limestone platform**.** The shoreline comprises of narrow beaches backed by sand dunes. Land behind the fore dunes is uniform and is typically two to five metres in elevation.

Water Quality
The water quality along the western edge of the Exmouth Gulf is very good, with the exception of periods of cyclonic storms, which can raise the turbidity and reduce salinity for periods of a week. However, the effect is species-specific.

If required, to overcome the issues of turbidity, freshwater run off and risk of pollution, the use of beach wells may be feasible, depending on the quality of water delivered and the flow rate that can be sustained. At this site, subject to seawater quality and quantity conditions being satisfied, beach wells may have significant economic advantages.

Soil and Vegetation
Brownish or early sands occur on the sand plains and calcareous sands are found on the coastal dunes and beaches. Brownish or earthy sands (Figure 20) range in depth from 60-100 cm or more over limestone. If pond systems are to be built, it is recommended testing be undertaken to assess the depth at which the rock deposits occurs. The vegetation would present no problems for clearing and comprises low to medium-density coastal heath and shrubs.

Oceanography

While a great deal is known about the offshore Leeuwin current, comparatively few studies have been undertaken on near shore currents along the coast of Western Australia. However, in broad terms and from anecdotal evidence (B. Harries, pers. comm., 2000) it is generally assumed that the near shore current along the western coast of the gulf is southerly and brings oceanic water into the gulf.

Sea temperatures are influenced greatly by the southward flowing Leeuwin current. This is warm and tropical in origin and has its maximum flow in winter and will vary between 14 to 30 °C.

Figure 20. Panoramic view, north to Exmouth.

Tides

Tides throughout the whole region are semi-diurnal with a spring tide range of approximately 1.7 metres. The data on water circulation suggest that the tidal flushing of water occurs mainly through the deeper part of the Gulf on the western side (Ayukai and Miller, 1998). (Transport WA, 2000, Ayukai and Miller, 1998).

Salinity

The low flushing and evaporation of water increase the salinity in the eastern side of the gulf (McKinnon and Ayukai, 1996). Tidal currents, along with shallow waters and wind effects, result in the waters of Exmouth Gulf being well mixed and generally unstratified (McKinnon and Ayukai, 1996). Salinity levels along the western shoreline of Exmouth Gulf vary between 36-37 ppt (pers. comm. MG Kailis Group).

Climate

Exmouth is characterised by arid and tropical climate with hot summers and low rainfall. The majority of the rainfall occurs as a result of cyclonic activity from January to April. The prevailing winds are from the south and southwest and reach speeds of up to 30 knots . There are short periods of high turbidity, associated with run-off from cyclonic rains.

The regions average annual evaporation ranges from 1700 mm to 3050 mm per year, depending on seasonal conditions. As evaporation significantly exceeds rainfall for coastal pond culture, intake waters may become elevated in their salinity levels and will require additional freshwater to remain marine, particularly in the south.

Tropical Cyclones

Tropical cyclones with winds in excess of 40-50 knots directly affect Exmouth every three to five years, with cyclones passing nearby in most years. Wind speeds are highly variable, being largely controlled by the intensity of the cyclone. Speeds of up to 145 knots have been recorded at the US Communications Station (LeProvost et al. 1988). Tornadoes and waterspouts have been recorded in the Exmouth area.

Cyclone events regularly create significant tidal surges due to the shape of the Gulf and the pathway of the cyclones, which need to be catered for in engineering design.

Native Title

Under the terms of the Commonwealth *Native Title Act 1993*, Aboriginal people may lodge objections to, amongst other activities, any aquaculture development and activity where they believe they have traditional rights and access. Currently there is a Native Title claim registered for the Exmouth Gulf area (Claim No. WA G6161/98 and WC 97/028).

Regional Infrastructure and Services

The Cape Range peninsula is well serviced with three-phase power and sealed road (Murat Rd) passing within a kilometre of all the sites. However, the capacity of the power may be limited. Murat Road links with the Northwest Coastal Highway, enabling traffic movement except for cyclone events when access is cut for short periods of time. During the fishing season this area is well serviced by transportation companies delivering chilled and frozen seafood product to Perth. In addition, all sites are close to Learmonth airport, is graded to cater for International air traffic, is the emergency backup for Perth Airport and the air force base.

The Exmouth power grid is generally reliable. Most sites are close to telecommunication landlines, which follow Murat road. Services such as potable water supplies and sewerage vary according to location, but may generally be considered lacking at most sites.

With few exceptions, the suitable sites are within a reasonable distance of and have access to light and heavy industries required for the construction and support of land-based aquaculture facilities.

Labour

Most of the suitable sites are within a short distance from Exmouth township can provide skilled, semi-skilled and unskilled work forces, sophisticated technical support and a commercial environment conducive to project development.

The Exmouth town and Learmonth to a lesser extant, have well-developed services sectors with expertise in engineering, construction. Both centres have a range of trade persons such as electricians and plumbers.

Sources of Feed, Equipment and Raw Materials

The proximity of suppliers of raw materials such as concrete will be a reasonably important criterion, particularly during the construction stages. Again, all the suitable sites are reasonably close to such suppliers.

Transportation

Freight companies are located in Perth and most of the major regional centres. Given the well-established and sophisticated road and air transportation systems in the State and assuming the relatively high value of the product (prawns, groupers and cods), transportation is not considered a critical factor. All the suitable sites may be considered to have good access to the requisite transportation services for the delivery of feeds and other materials and to ensure efficient access to domestic and export markets.

Sea Water Supply and Discharge

A marine intake located on the near shore may provide the best option for a sea water supply system. The presence of the sub-tidal limestone may pose constraint in gaining access to sea below the sandy beach, but it also provide an excellent anchoring point for the intake infrastructure.

To overcome the issues of turbidity, freshwater flooding and risk of pollution, the use of beach wells may be feasible, depending on the quality of water delivered and the flow rate that can be sustained.

All sites have few options for the discharge of water. The temporary streams that are common to the area provide a good option for discharging any water. Given the prevailing current any out-take will need to be located south of the intake to minimise the contamination of the intake water.

Any large-scale mariculture project will be referred to the Environmental Protection Authority for assessment, as such; any discharged water will need to meet the quality levels set.

Urban Proximity
The suitable sites in the Cape Range Peninsular Region are all within 40 km of the town of Exmouth. Exmouth provides housing, hospital, schools, shopping facilities and support services.

Competitive Resource Use
Land-based aquaculture should be promoted as being highly compatible with other resource uses such as tourism and recreational fishing. There are many examples of synergies between aquaculture and tourism activities, which can be mutually beneficial. Similarly, provided that they do not restrict access to favoured fishing spots, aquaculture developments can benefit recreational fishers and other resource users by providing access to previously inaccessible areas.

5.1.1 Point Murat to Bundegi Nature Reserve.

Whilst the site is technically suitable for land-based aquaculture, the area forms part of the Ningaloo Marine Park. It is on this basis that the area is not considered suitable.

5.1.2 Exmouth Town south to Pebble Beach

This area is considered to be of low development potential as the majority of the land is zoned for other uses, mainly residential. The remaining area is highly uneven with soils that contains large amounts of rocks and rocky outcrops. In addition to which, this area has a high prevalence of drainage streams which essentially divides the site into small parcels of land, not suited for large-scale marine aquaculture.

5.1.3 Learmonth (Low lying area directly East of Airport)

This site contains some low-lying land, which is prone to inundation or flooding from tropical cyclones. For this reason the area is considered as medium potential for land-based aquaculture development, as the capital works require to resolve are likely to prohibitively expensive. In addition the site is likely to be too close (approximately 1.6 km) to the aquaculture site licenced to Cape Sea Farms Pty Ltd.

5.1.4 Heron Point

This area has already been granted an aquaculture license and therefore was not subject to evaluation in this study.

5.1.5 Naval Communication Centre

Location and Size
Naval Communication Centre is a low-lying area, behind the fore dunes, located approximately 6 km north of the Exmouth town site. A sealed road provides good, all-weather access to the site. The primary dune systems found in this area are substantial and would afford sufficient protection from extreme weather conditions. The area is approximately 6 km^2 .

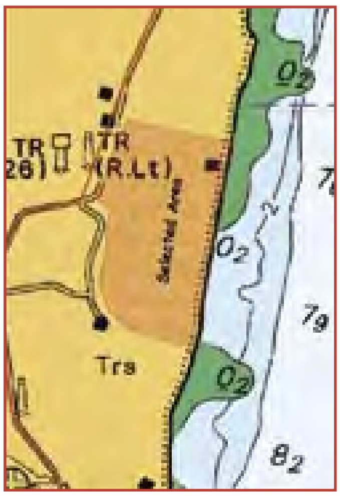


Figure 21: Site located east of the H Holt Communication Centre.

Tenure

The Commonwealth currently owns the land in freehold. An application to lease land for aquaculture can be lodged with the Commonwealth Defense Department.

The Department of Land Information parcel number for the latter site is: LYNDOL 00079, 00157.

Potential for Development

Naval Communication Centre has high potential for land-based aquaculture and is considered one of the best sites. The site has substantive fore dunes, which would afford good protection from storm surge tides. In addition, due to the hydrography of the gulf, it is likely to suffer relatively less effect from turbidity generated from cyclonic storms, as it is proximate to oceanic flushing. The site is close to the Exmouth town site and excellent access to services and infrastructure, inclusive of existing saline bores.

Constraints to Development

The major constraints to development are:

1. The site proximity to the Ningaloo Marine Park.
2. Land is currently owned by the Commonwealth. Proponents wishing to excise or lease the land may experience lengthy delays.
3. High occurrence of tropical cyclones.

Potential minor constraints to development include:

- Limited discharge options.
- Conflict with existing users of the resource, such as recreational fishers that use the beach frontage extensively.
- Unknown saline bore salinities.

Conflict with other resource users and conservationists would probably be considerable and a period of community consultation would be recommended as part of the feasibility study.

5.1.6 Charles Knife Road North and South.

Location and Size

Charles Knife Road North and South comprises of an extensive area of flat land, approximately 5 km^2 each, behind the fore dunes, located approximately 9 and 14 km south of the Exmouth Town site. A sealed road provides good, most weather access to the site. The primary dune systems found in this area are lower than to the north of the Exmouth town site, providing less protection from extreme weather conditions.

Tenure

The land is currently vested as Exmouth Station pastoral lease by Mr G F Lefroy.

The Department of Land Information parcel number for the latter site is: LYNDOL 00164.

Potential for Development

Due to the risk of sediment loads in the water, both Charles Knife Road North and Charles Knife Road South sites are have high potential for brown water tropical aquaculture. Both sites are comprised of several areas that may be suitable for development, and are afforded protection from surge tides by the fore dunes. Each site has excellent access to sealed roads, power and telecommunications, and transport. Both sites are well located to a range of services and light industries provided in Exmouth, inclusive of Kailis processing facilities, which may be available in the off-season. The local drainage streams offer good discharge options.

Constraints to Development

The major constraints to development are:

1. Proponents wishing to excise the land may experience lengthy delays.
2. Uncertainty with respect to the Native Title.
3. High occurrence of tropical cyclones.

Potential minor constraints to development include:

- Limited discharge options.
- Duration of post-cyclonic turbidity.
- Conflict with existing users of the beach frontage.
- Unknown bore salinities.

It would be recommended that as part of the feasibility study the proponent undertaken a period of community consultation to address any community concerns and issues with any proposed development.

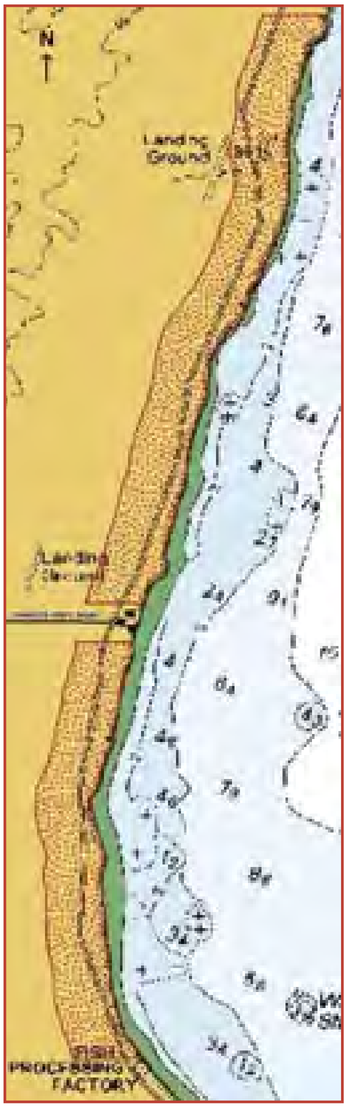


Figure 22: Sites located to the North and South of Charles Knife Road, Exmouth.

5.2 Pilbara

5.2.1 Karratha

Topography

The area identified is an extensive area of flat land. This area is located between the town and the airport and is approximately 9 km^2 in size. The area is relatively close to the shore and the pumping distance is 3 km with a maximum head of 10-12 m. The capital and operational costs to access a suitable water supply may be prohibitively expensive, however, this cost may be offset by the benefit the site has due to its size, proximity to transport links and availability of non-porous soils. Although, all the area is prone to cyclones, this area is above the one in a hundred year surge level of 6.3 m. The surrounding lower lying areas are prone to flooding and large walls have been built by the salt mining companies to prevent surge tide flooding of the sites.

Water Quality

The water quality along the Dampier peninsula and the Pilbara coast considered to be 'brown water' or turbid. The suspension of particulate matter into the water column is the result of a number of events: the dredging operations to maintain shipping channels, the significant rainfall during the wet season, and the high tidal range.

Soil and Vegetation

The main vegetation in the flats are spinifex grass and coastal scrub to the shore line, which are typified by mangroves. The subsurface soils contain suitable clay content for pond construction.

Figure 23. Karratha site

Oceanography

Bathymetry proximate to the site increases to between 10-15 m depth, approximately 100 m from the shore. However, due to cyclonic and tidal activity the bathymetry often alters and constant dredging is necessary to maintain shipping channels. The seabed consists of sand, shells and rocks. Swell height is up to 1.7 m and direction is south, southwest with average wave height of 1.8 m. Water quality (according to locals) is low with considerable turbidity due to the Port Authority's dredging activities around the area.

Infrastructure and services

This area is well serviced due to the gas, oil and mining industry. Power supply is available in most areas close to the townships.

Seawater supply

A marine intake located on the near shore may provide the best option for a sea water supply system, approximately 3 km away. Currently, two pipelines are planned by AquaCarotene Pty Ltd (beta-carotene producer) with an estimate cost of $0.5-1million.

To overcome the issues of turbidity and risk of pollution, the use of beach wells may be feasible, depending on the quality of water delivered and the flow rate that can be sustained.

Figure 24. Northerly view of the site towards Karratha airport

Any large-scale mariculture project will need to be referred to the Environmental Protection Authority for assessment. As such, any discharged water will need to meet the quality levels set.

Competitive Resources Use

This area is regarded as suitable for large-scale land-based aquaculture (for fish or prawns) due to its geology and sub-surface soil types, topography and close proximity to transport (airport, railway, port) and services. However, the majority of the area is allocated to mining leases because of its extensive gravel deposits.

Therefore, any aquaculture development would require the consent of Dampier Salt Pty Ltd and would also be subject to Native Title.

Tenure

The Department of Land Information parcel number for the latter site is: DEWITL 00096 and Vacant Crown Land.

Potential for Development

The Karratha –West site has medium potential for land-based aquaculture. The elevation of the site would afford good protection from storm surge tides. The site is close to Karratha and excellent access to services and infrastructure.

Constraints to Development

The major constraints to development are:

1. The majority of the site has mining leases over it. Proponents wishing to excise or lease the land may experience lengthy delays.
2. High occurrence of tropical cyclones.
3. Discharge of bitterns from salt washing by the salt mining companies that may have a risk on water quality.

Potential minor constraints to development include:

- Limited discharge options.
- Distance from water supply source.
- Conflict with existing users of the resource.

Conflict with other resource users would probably be considerable and a period of community consultation would be recommended as part of the feasibility study.

5.2.2 Port Hedland

Topography

The part of the area identified by the GIS mapping study is east of Port Hedland. It is bordered by two rivers, Beebingarra Creek and Petermarer Creek from west and east, respectively, and the brine channel and railway from north and south, respectively. It is large, flat area of around 30 km^2, with maximum head height is estimated to be 10-12 m. The area is prone to flooding, especially near the rivers. It is possible that the roads are not accessible during the wet season.

Figure 25. Port Hedland

Water Quality
The seabed consists of sand and mud that may result in poor water quality.

Any onshore aquaculture venture will need to take into account potential pollution problems due to the harbour and the salt mining discharge, as well as the ore handling facilities.

Soil and Vegetation
The main vegetation in the flats are spinifex grass and coastal scrub to the shore line, which are typified by mangroves. The subsurface soils contain suitable clay content for pond construction.

Figure 26. Port Hedland site, view north

Oceanography
Swell height is up to 1.7 m with changing direction from southwest in the summer to southeast in the winter with an average wave height of 1.6 m. Water quality, according to locals, is considered to be low to medium, dependent on the time of the year.

Infrastructure and services
In terms of facilities, the area is similar to Karratha (although the population is smaller). An airport, a railway and a port is nearby. This area is well serviced due to the iron ore and salt shipping. Power is available in most areas close to the townships.

Seawater supply
The shore is relatively close, however, incoming water will need to be pumped from at least 5 km due to land formation (mainly, mangroves and mud/salt flats). Cargill Salt Pty Ltd salt production ponds are nearby. It is suggested that the proponents negotiate with the company regarding a joint venture using the existing pumping facilities. Saline groundwater may provide a more cost effective method. The Water and Rivers Commission (Ground Water Atlas 2001) consider it likely that all the alluvial aquifers contain saline groundwater at the coastline, as such high yielding bores (100 L/s) may have potential for the site.

Figure 27. Port Hedland, Cargil Salt Pty Ltd brine channel

Any large-scale mariculture project may need to be referred to the Environmental Protection Authority for assessment. As such, any discharged water will need to meet the quality levels set.

Competitive Resources Use
This area regarded as low to medium for large-scale land-based aquaculture of hyper salinity tolerant species (finfish or prawn) due to its geology and sub-surface soil types, topography and close proximity to transport (airport, railway and port) and services. However, the majority of the area is allocated to mining leases. Therefore, any aquaculture development would require the consent of Cargill Salt Ltd and would also be subject to Native Title.

Tenure

The Department of Land Information parcel number for the latter site is: FORREL 00202, 000225 and Vacant Crown Land.

Potential for Development

Port Hedland – East site has low to medium potential for land-based aquaculture. The elevation of the site would afford low to medium protection from storm surge tides but this would be offset by pumping cost and potential conflict with Dampier Salt. The site is close to Port Hedland and excellent access to services and infrastructure.

Constraints to Development

The major constraints to development are:

1. The majority of the site has mining leases over it. Proponents wishing to excise or lease the land may experience lengthy delays.
2. High occurrence of tropical cyclones.
3. Hyper salinity.
4. No reasonable access to saltwater unless Dampier Salt Pty Ltd assists.

Potential minor constraints to development include:

- Limited discharge options.
- Conflict with existing users of the resource.

Conflict with other resource users would probably be considerable and a period of community consultation would be recommended as part of the feasibility study.

SECTION 6 RECOMMENDATIONS

The time taken required to gain relevant approvals for any large scale aquaculture project continues to be a major constraint to commercial aquaculture development in Western Australia. The availability of suitable sites, fully licensed, would present an attractive offer for future investment into this sector.

The following recommendations refer to the securing of the most promising sites for large-scale, land-based marine aquaculture. At the completion of the report the most promising sites are:

Oceanic Temperate	Oceanic Tropical	Brown Water Tropical
Lynton, Hutt Lagoon.	Naval Communication Centre, Exmouth Gulf	Charles Knife Road South – Exmouth Gulf Charles Knife Road North – Exmouth Gulf Karratha Port Hedland

The following table is summarized the sites. Ranking is on scale of 5, where the best performance is 5.

Site	Topography	Water Quality	Soil	Infrastructure	Oceanography	Seawater	Competitive use	Tenure
Lynton, Hutt Lagoon	5	5	4	3.5	4	4	4	4
Harold Holt Naval Communication Centre, Exmouth Gulf	3.5	4-5	3.5	3.5	4	4	2.5	3.5
Charles Knife Road South – Exmouth Gulf	3.5	2-3	4	3.5	3	3-4	4.5	4
Charles Knife Road North – Exmouth Gulf	3.5	2.5-3.5	4	3.5	3	3-4	4.5	4
Karratha	3	3-3.5	3.5	4.5	3	3	2.5	3
Port Hedland	3	3	2.5	4.5	3	2.5	2	3

Recommendation 1

Secure the most promising sites identified in this study for large-scale, land-based marine aquaculture.

Three key selection processes are fundamental to the development of a commercial aquaculture project; the choice of site, species and production system. It could be argued that Western Australia has only two parts of the key selection process to enable the development of economically viable land-based, mariculture enterprise, namely choice of site and production system, i.e. the selection of suitable fish species in terms of value and volume for WA's socio-economic situation is limited. However, it is important to take a long-term view and undertake a commitment to removing the key impediment of site availability to aquaculture development, before the opportunity is lost.

Recommendation 2

Identify critical stakeholders and form a regional steering committee.

Given the significance of the Aquaculture Development Council's proposal and its benefits to regional Western Australia, it is assumed that securing the most promising sites will be done in consultation with all relevant government stakeholders, such as the Department of Local Government and Regional Development, Land Corp, Department of Planning and Infrastructure and the Department of Minerals and Energy. These departments have key resources that will assist in the Department of Fisheries in securing development (pre)approval for the land parcels, and ensure a thorough community and industry consultation process. To assist in the consultation process, it is considered that regional committee for each site or group of sites beformed.

Recommendation 3

Identify critical issues to be resolved in respect of each of the selected most promising sites.

The perfect aquaculture site rarely exists. Good aquaculture sites are usually distinguished by being able to satisfy the essential biological and other requirements of the species and by being suited to viable, economic solutions for less favorable or unsuitable features. In this instance, all the major and minor constraints to the sites' development and their solutions will need to be considered, and possibly ameliorated, to provide future proponents with a site that is investment-ready.

Recommendation 4

Develop and implement a staged strategy, with a limited time frame, to achieve the objective of the project, i.e. making available (investment-ready) the sites for commercial aquaculture development.

The success in securing any site will require excellent project management skills. A small and highly focused team with the necessary skills and experience to develop the sites, and negotiate the issues, is required. In any case the present ADC will need to provide a steering group with a set of well-defined terms of reference, a finite timeline, and definite milestones.

Recommendation 5

To conduct the GIS mapping study without the constraint of proximity to power.

Power stations outside the Perth grid utilise diesel for the production of power. In most cases the purchase cost per kilowatt-hour is usually higher than self-production of electricity. It is on this basis that there may be value in identifying any other additional sites without the limitation of being near a power grid.

Recommendation 6

To maintain the GIS mapping system, used in this study, on line.

The GIS mapping system, based on GeoMedia software and datasets, is maintained and owned by the Department of Agriculture, Western Australia. Negotiation with the Department of Agriculture regarding access and use of the GIS mapping system on-line will be most useful for future studies.

Recommendation 7

Undertake a broad scale relative economic comparison of the high potential sites identified, utilising economic indicators such as costs of land, transport and power.

To compare the relative cost benefit of sites located close to Perth Metropolitan area, which have cheaper power and transport, but higher land costs, with more northerly sites with their higher power and transport costs but lower land costs and higher growth rate due to warmer water.

Recommendation 8

Incorporate the RAMSAR wetlands, information on local geology, and information on marine bore water quality.

To broaden the information that is contained within the GIS mapping study.

Recommendation 9

To revisit this study in five years to examine the sites with medium or long term development potential.

As the selection criteria used identified only a few sites with immediate mariculture development potential, it may be valuable to re-examined medium priority sites identified in this study, with a view to identifying sites with medium to long-term development potential.

SECTION 7 REFERENCES

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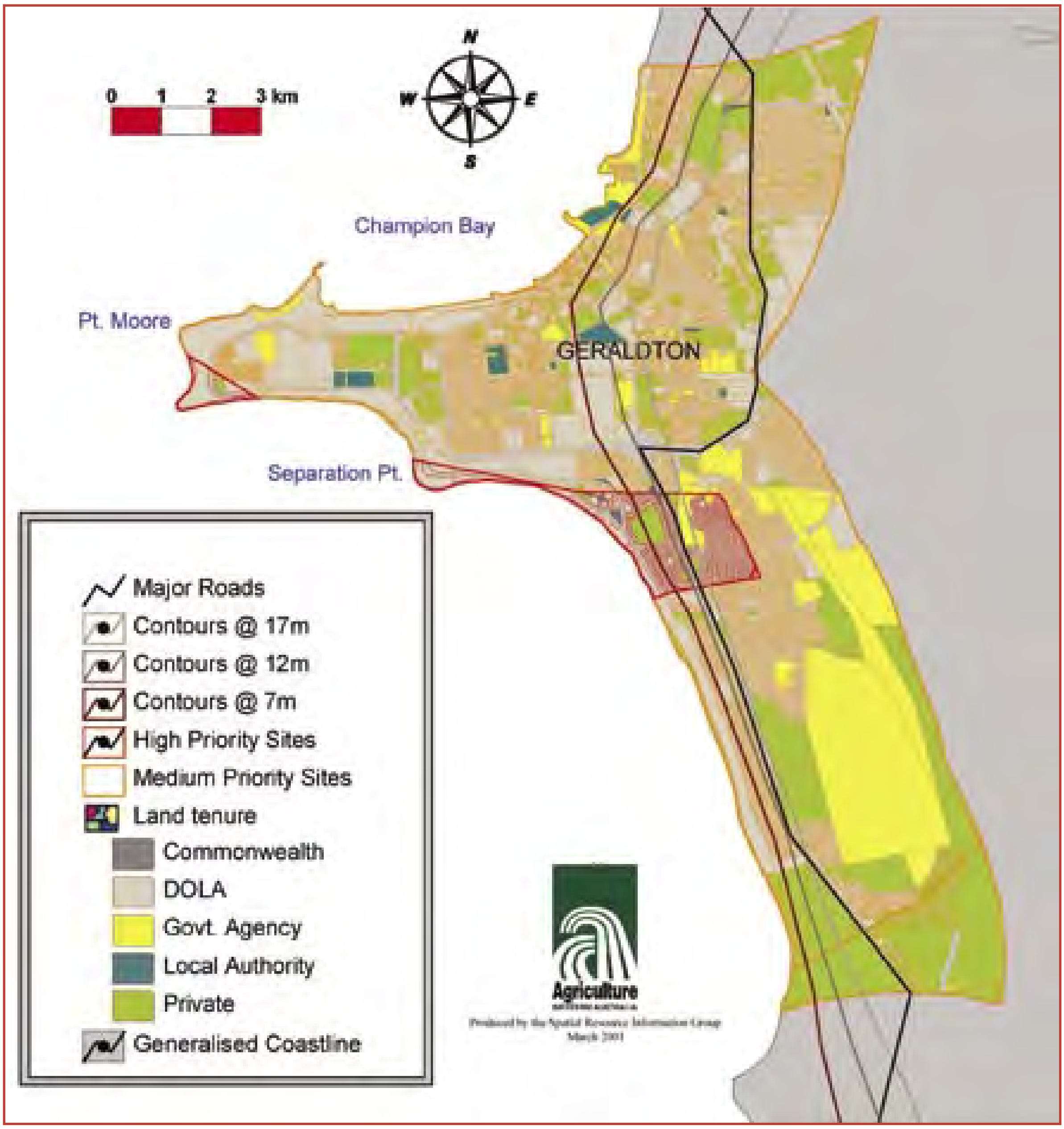
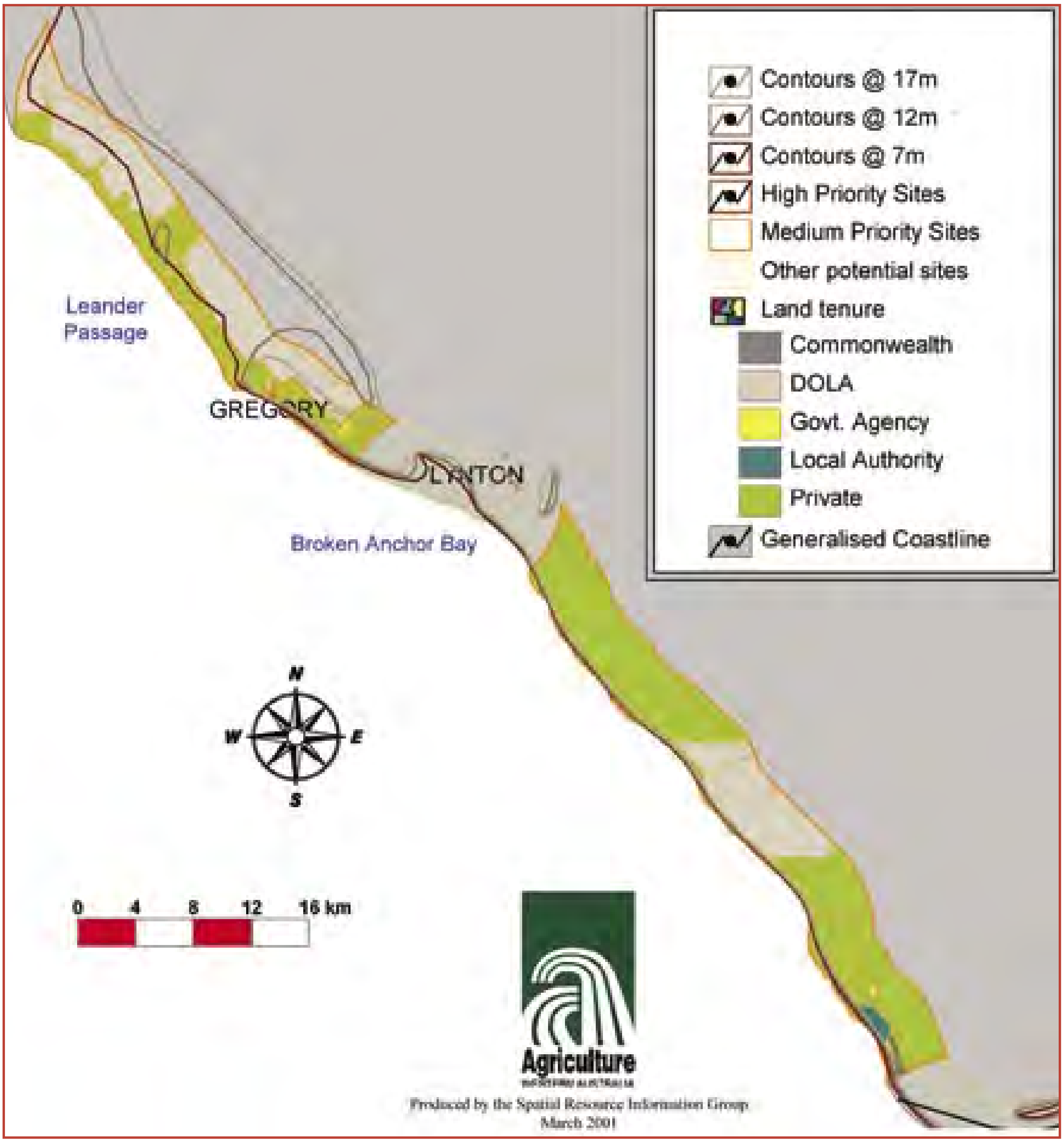
APPENDIX 1: LIST OF PRELIMINARY SITES FOR LARGE-SCALE, LAND-BASED MARICULTURE

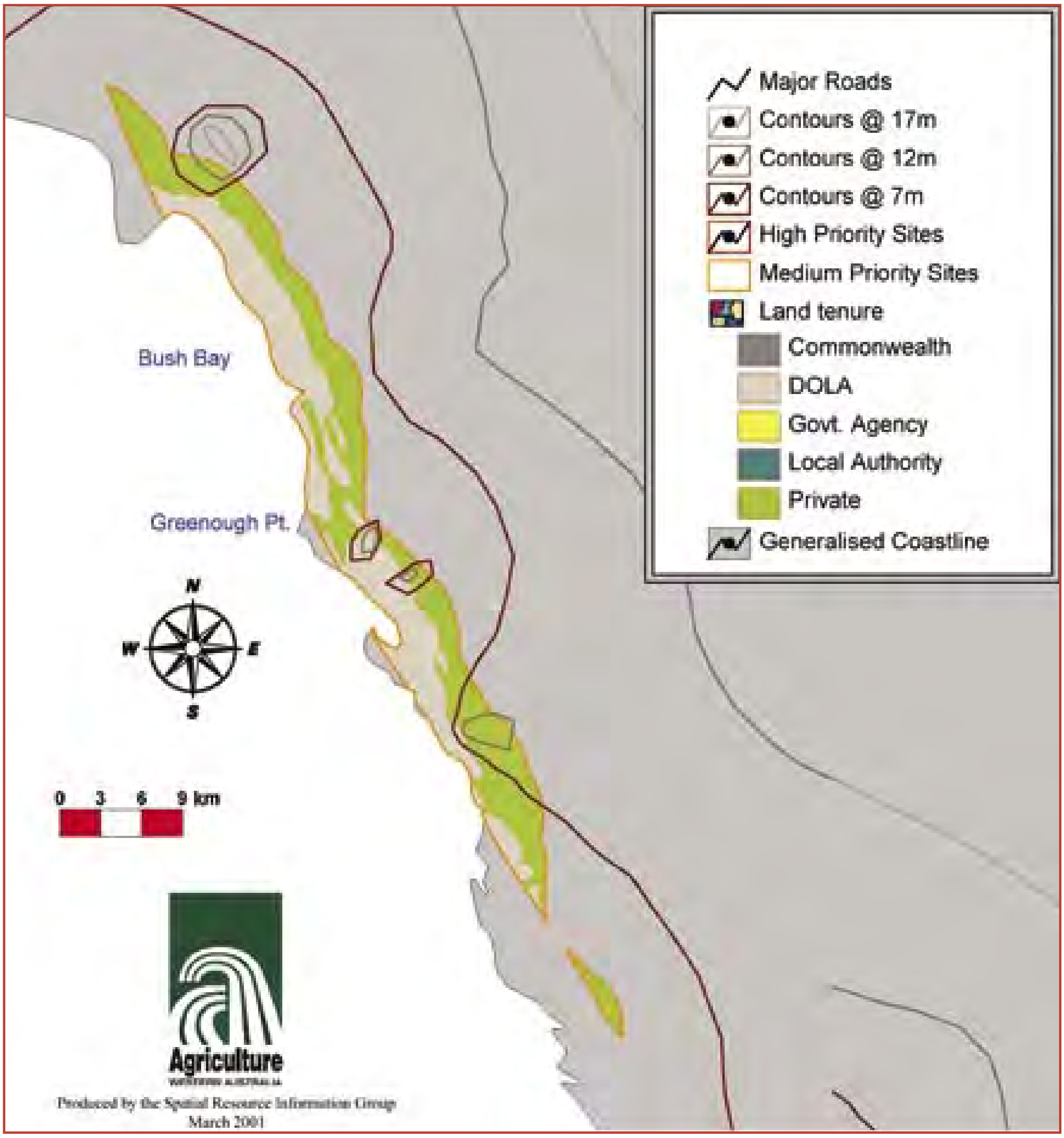
Site no.	Latitude	Longitude	Description
1	-28:18:18	114:23:22	Lynton (south of Hutt Lagoon)
2	-25:14:58	113:50:43	Carnarvon south
3–8	-22:03:06	114:07:01	Exmouth
9	-20:18:49	118:37:38	Port Hedland
10	-20:43:20	116:49:37	Karratha

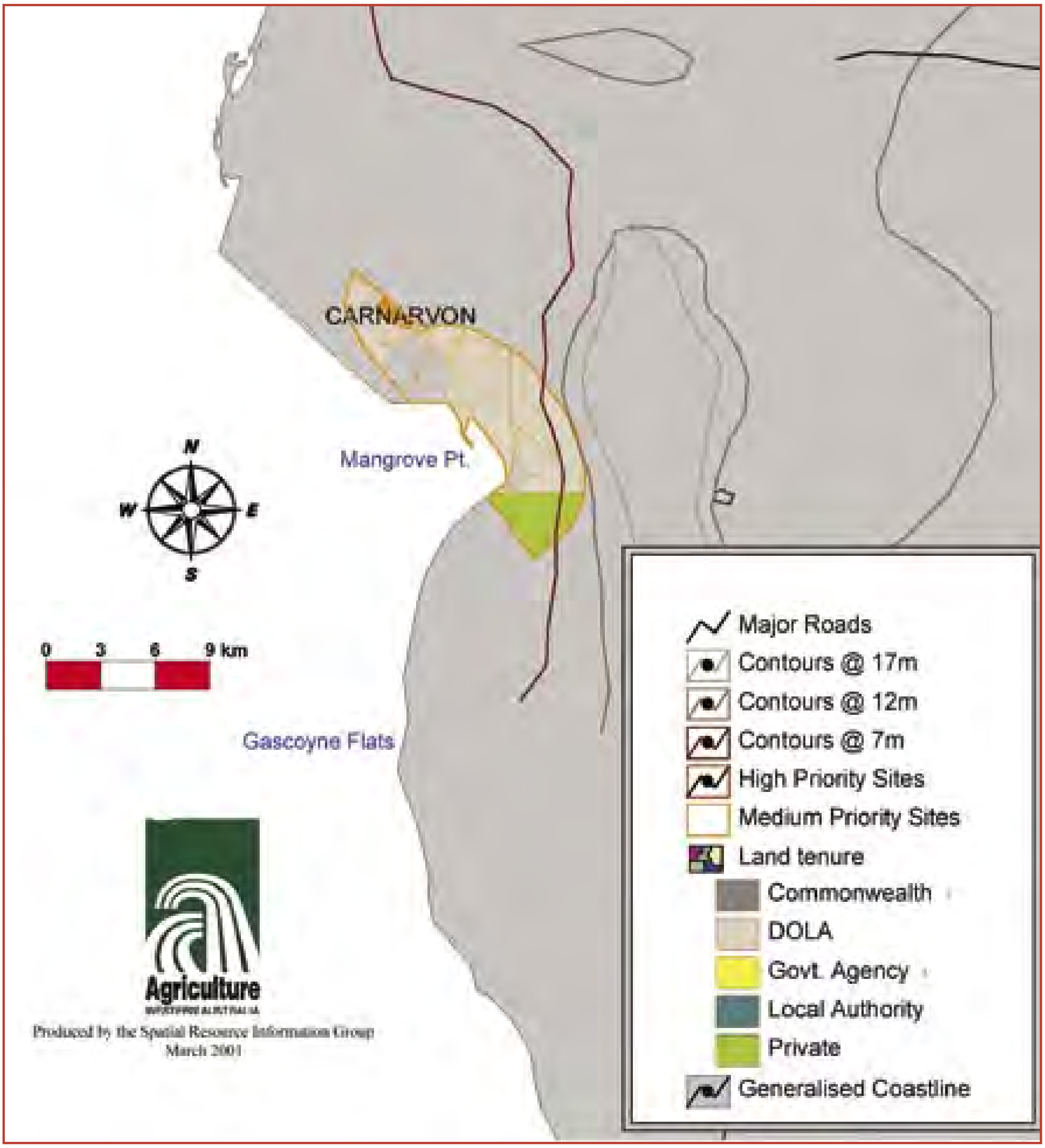
APPENDIX 2: SITE AND LOCATION MAPS FOR PRELIMINARY SITES

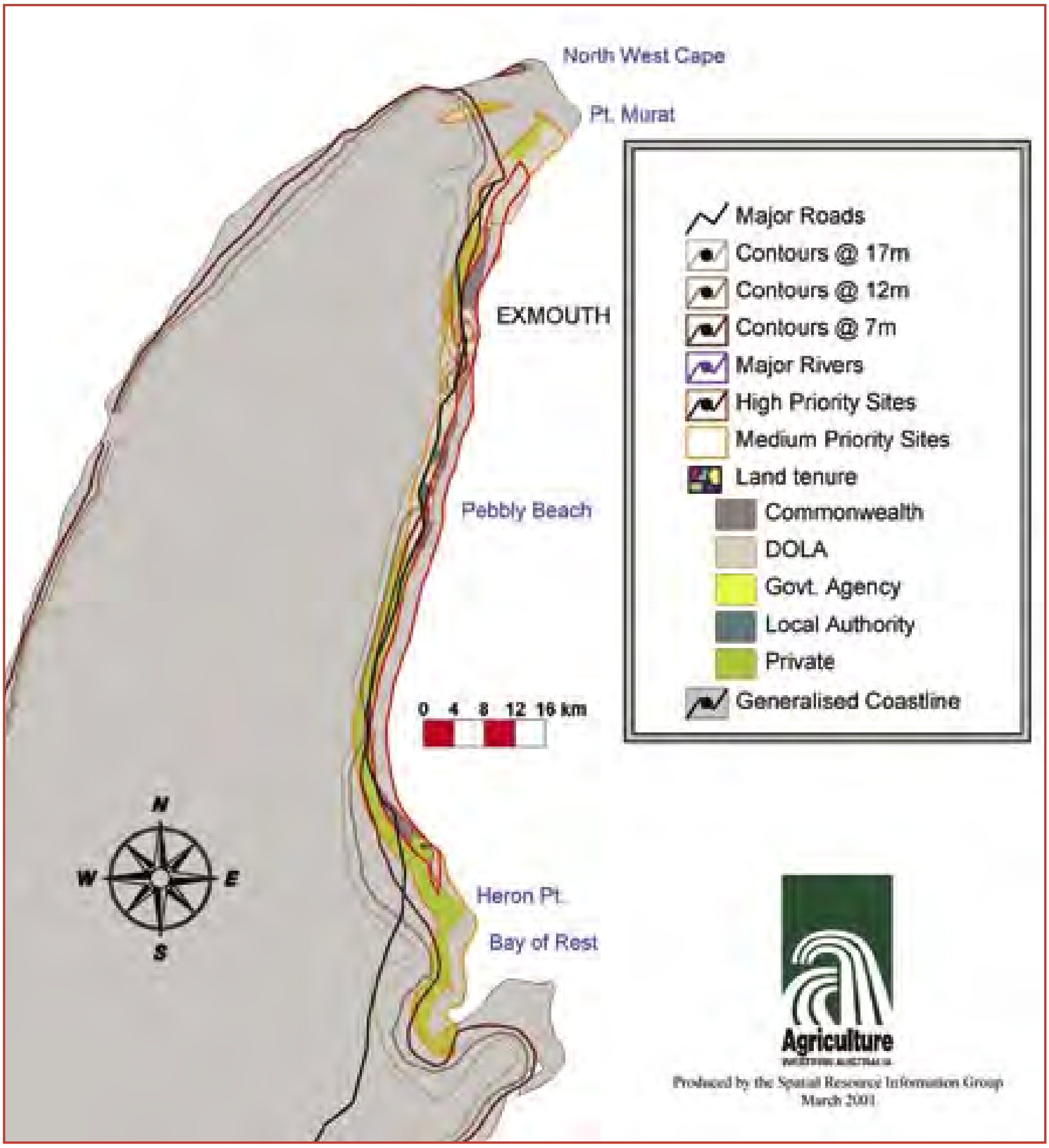


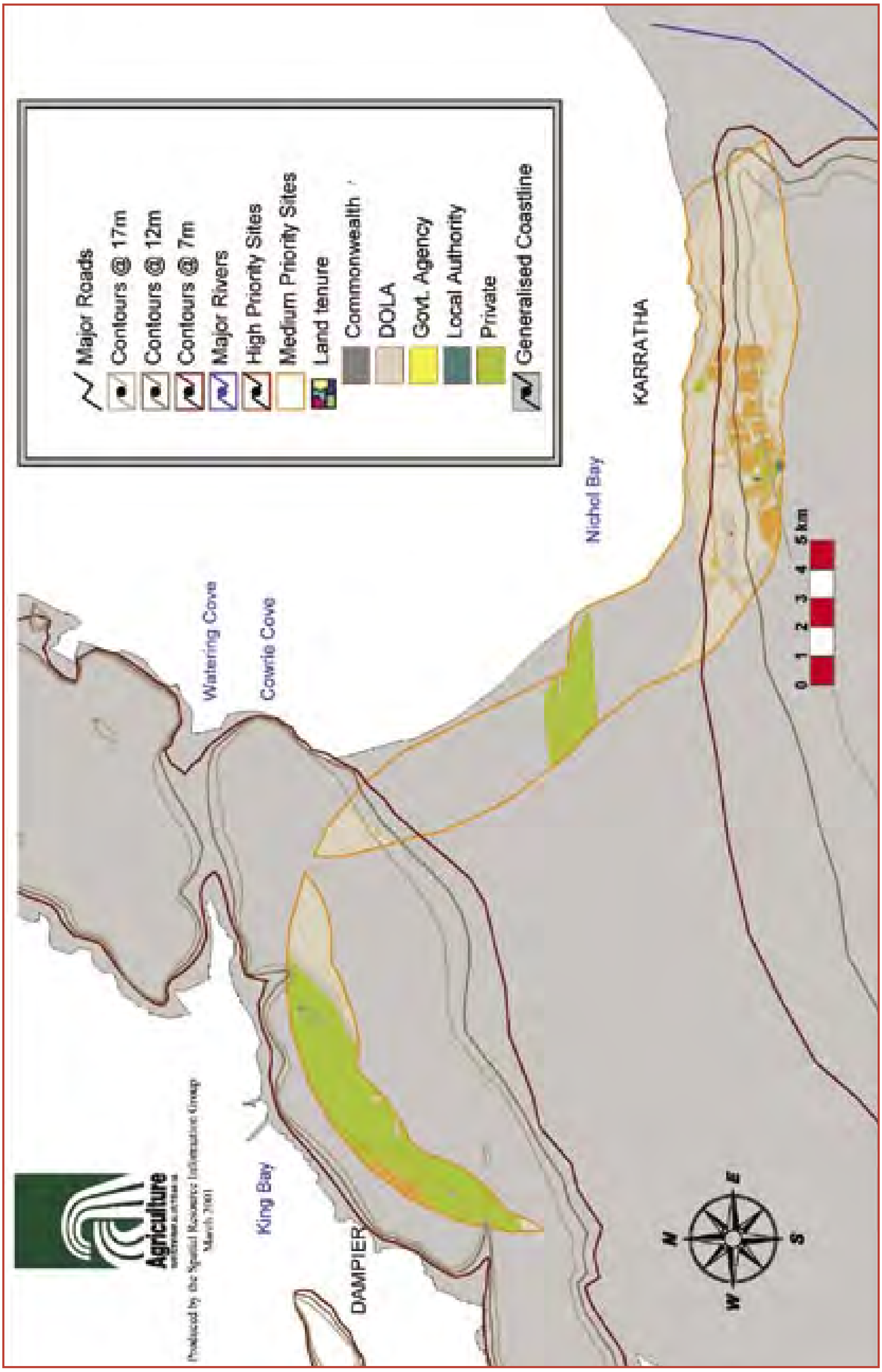
0 1 2 3 km
N
W
E
S
Champion Bay
Pt. Moore
GERALDTON
Separation Pt.
Major Roads
Contours @ 17m
Contours @ 12m
Contours @ 7m
High Priority Sites
Medium Priority Sites
Land tenure
Commonwealth
DOLA
Govt. Agency
Local Authority
Private
Generalised Coastline
Agriculture

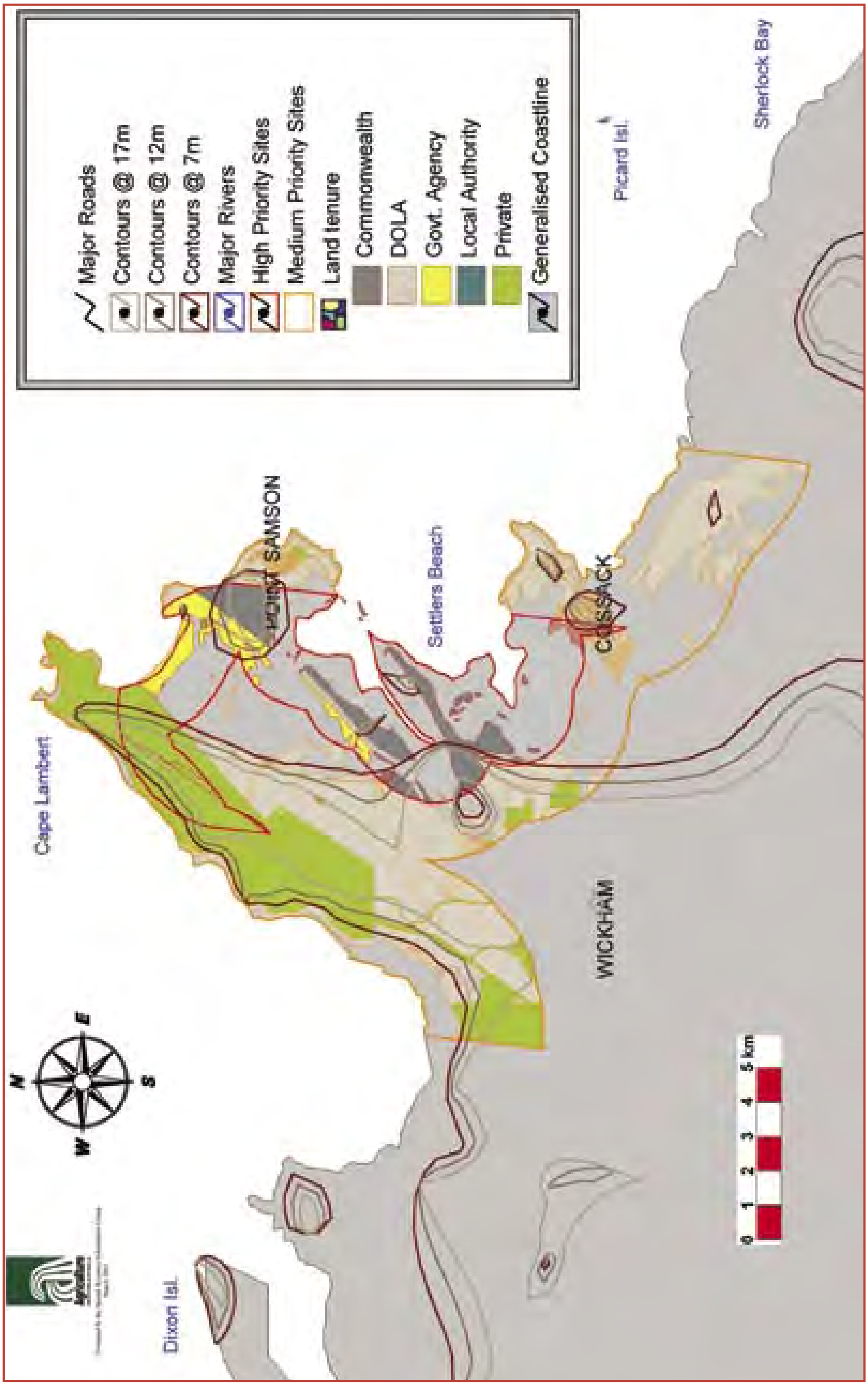

Contours @ 17m
Contours @ 12m
Contours @ 7m
High Priority Sites
Medium Priority Sites
Other potential sites
Land tenure
Commonwealth
DOLA
Govt. Agency
Local Authority
Private
Generalised Coastline
Leander Passage
GREGORY
LYNTON
Broken Anchor Bay
N
W
E
S
0
4
8
12
16 km
Agriculture
Produced by the Spatial Resource Information Group
March 2001

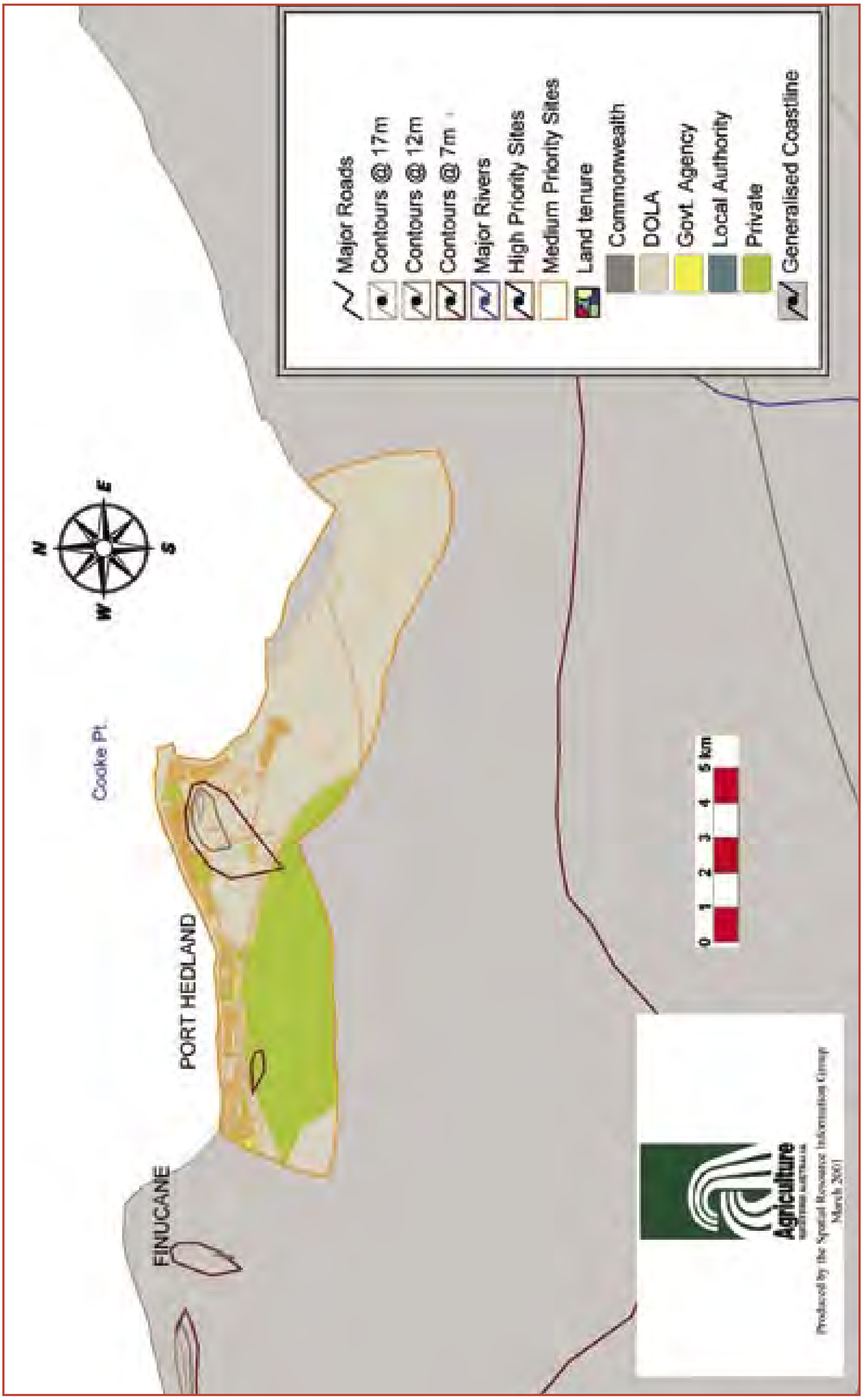

Major Roads
Contours @ 17m
Contours @ 12m
Contours @ 7m
High Priority Sites
Medium Priority Sites
Land tenure
Commonwealth
DOLA
Govt. Agency
Local Authority
Private
Generalised Coastline
Bush Bay
Greenough Pt.
N
W
E
S
0 3 6 9 km
Agriculture
Produced by the Spatial Resource Information Group
March 2001

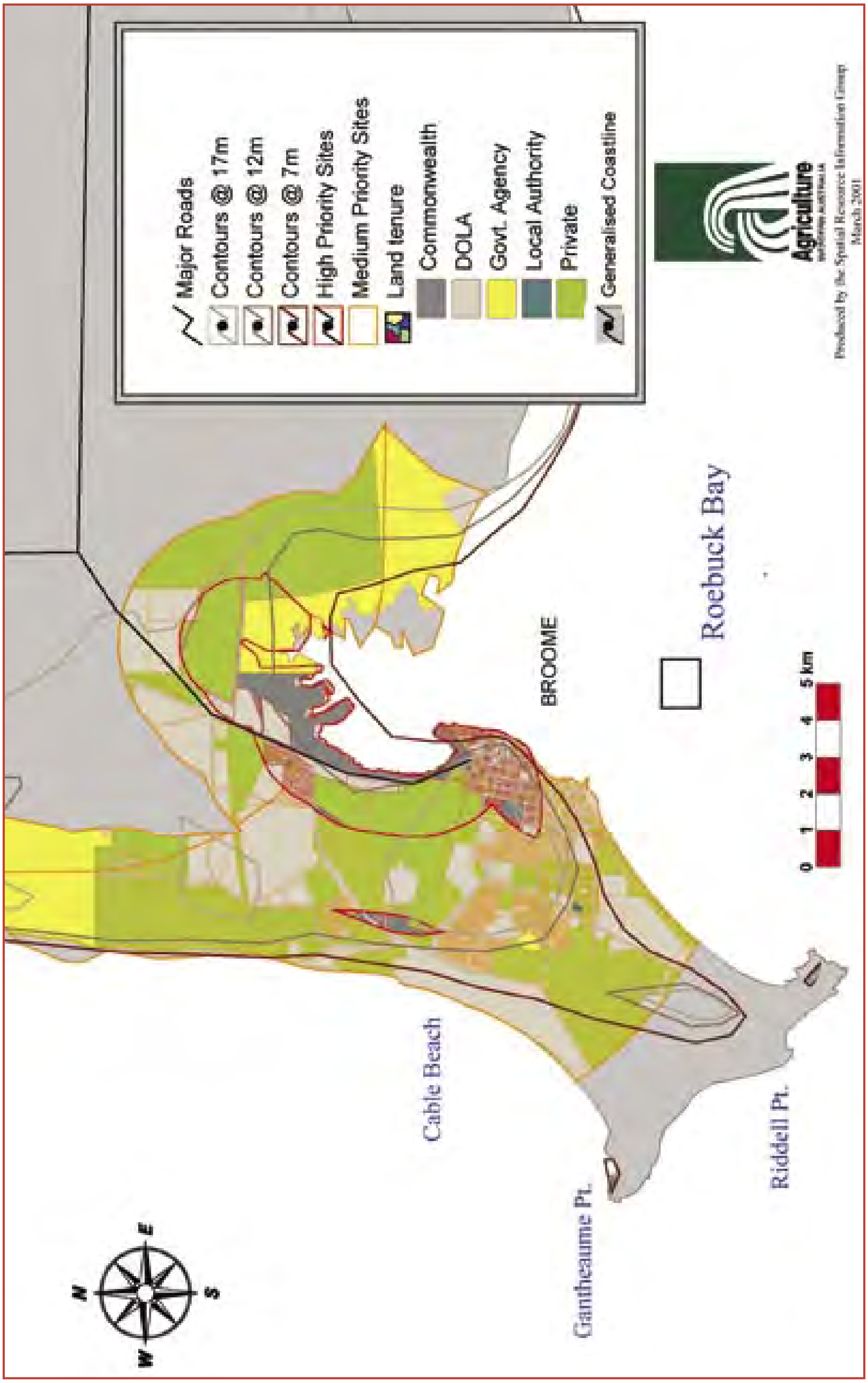

CARNARVON
Mangrove Pt.
Gascoyne Flats
N
W
E
S
0 3 6 9 km
Major Roads
Contours @ 17m
Contours @ 12m
Contours @ 7m
High Priority Sites
Medium Priority Sites
Land tenure
Commonwealth
DOLA
Govt. Agency
Local Authority
Private
Generalised Coastline
Agriculture
Produced by the Spatial Resource Information Group
March 2001

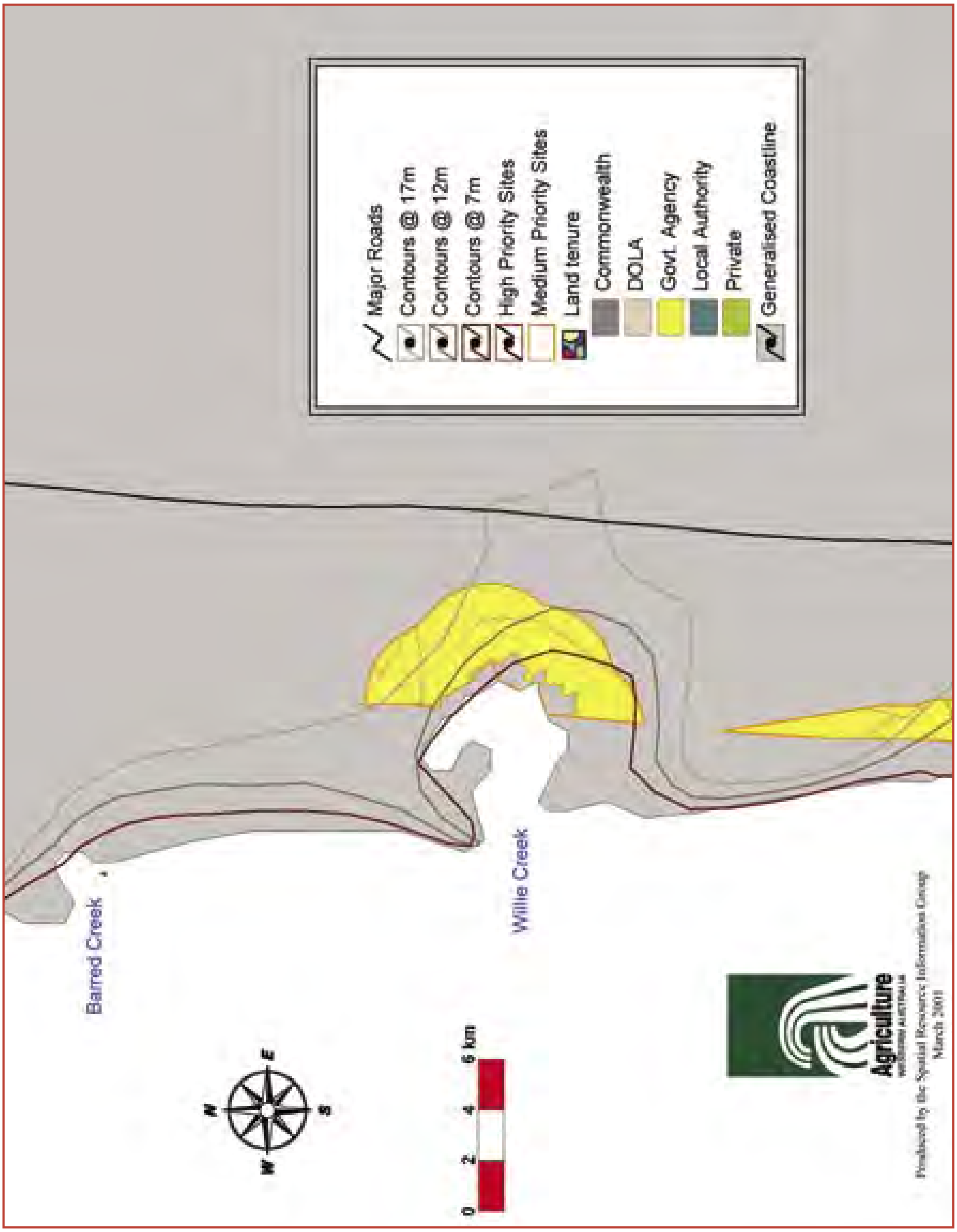

North West Cape
Pt. Murat
EXMOUTH
Pebbly Beach
Heron Pt.
Bay of Rest
0 4 8 12 16 km
N
W
E
S
Major Roads
Contours @ 17m
Contours @ 12m
Contours @ 7m
Major Rivers
High Priority Sites
Medium Priority Sites
Land tenure
Commonwealth
DOLA
Govt. Agency
Local Authority
Private
Generalised Coastline
Agriculture
Produced by the Spatial Resource Information Group
March 2001


Major Roads
Contours @ 17m
Contours @ 12m
Contours @ 7m
Major Rivers
High Priority Sites
Medium Priority Sites
Land tenure
Commonwealth
DOLA
Govt. Agency
Local Authority
Private
Generalised Coastline
KARRATHA
Nichol Bay
Watering Cove
Cowrie Cove
King Bay
DAMPIER
Agriculture
Produced by the Spatial Resource Information Group
March 2001
0 1 2 3 4 5 km
N
E
S
W

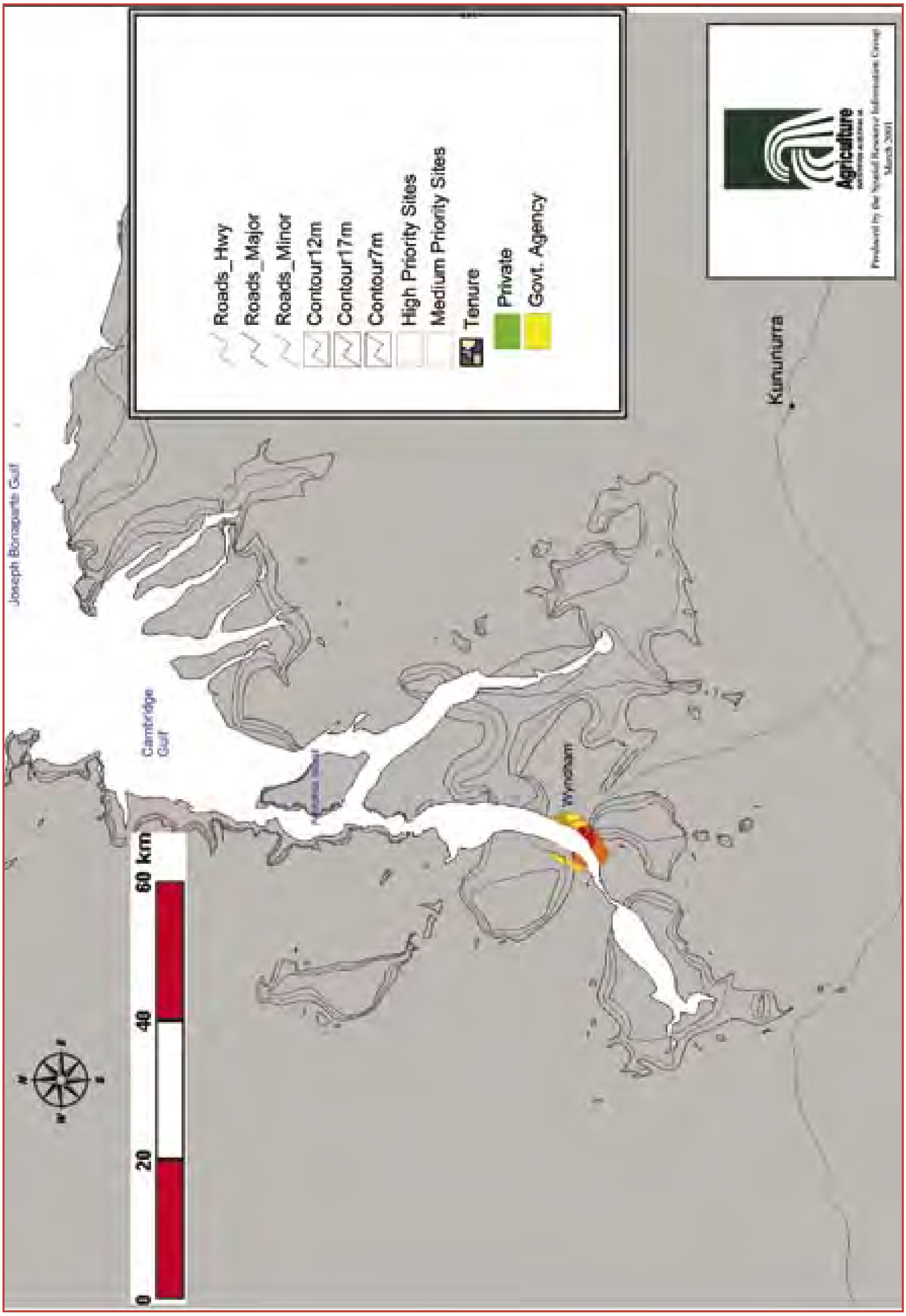

Major Roads
Contours @ 17m
Contours @ 12m
Contours @ 7m
Major Rivers
High Priority Sites
Medium Priority Sites
Land tenure
Commonwealth
DOLA
Govt. Agency
Local Authority
Private
Generalised Coastline
Picard Isl.
Sherlock Bay
Cape Lambert
POINT SAMSON
Settlers Beach
COSSACK
WICKHAM
Dixon Isl.
N
E
S
W
0 1 2 3 4 5 km


Major Roads
Contours @ 17m
Contours @ 12m
Contours @ 7m
Major Rivers
High Priority Sites
Medium Priority Sites
Land tenure
Commonwealth
DOLA
Govt. Agency
Local Authority
Private
Generalised Coastline
Cooke Pt.
PORT HEDLAND
FINUCANE
N
S
E
W
0 1 2 3 4 5 km
Agriculture
Produced by the Spatial Resource Information Group
March 2001


Major Roads
Contours @ 17m
Contours @ 12m
Contours @ 7m
High Priority Sites
Medium Priority Sites
Land tenure
Commonwealth
DOLA
Govt. Agency
Local Authority
Private
Generalised Coastline
Agriculture
Produced by the Spatial Resource Information Group
March 2001
Roebuck Bay
BROOME
Cable Beach
Gantheaume Pt.
Riddell Pt.
0 1 2 3 4 5 km
N
E
S
W



Major Roads
Contours @ 17m
Contours @ 12m
Contours @ 7m
High Priority Sites
Medium Priority Sites
Land tenure
Commonwealth
DOLA
Govt. Agency
Local Authority
Private
Generalised Coastline
Barred Creek
Willie Creek
N
E
S
W
0
2
4
6 km
Agriculture
Produced by the Spatial Resource Information Group
March 2001


Joseph Bonaparte Gulf
Cambridge Gulf
Wyndham
Kununurra
Roads_Hwy
Roads_Major
Roads_Minor
Contour12m
Contour17m
Contour7m
High Priority Sites
Medium Priority Sites
Tenure
Private
Govt. Agency
Agriculture
0
20
40
60 km

APPENDIX 3: GROUNDWATER PROSPECTS FOR PRELIMINARY LAND-BASED MARICULTURE SITES

Location*	Aquifer	Groundwater salinity	Yield	Temp. Deg C	Remarks
Geraldton	Superficial	Brackish to saline		23	Thin layer of brackish groundwater in coastal dunes overlying sea water.
	Mesozoic	Saline 10–20 ppt?		23+ to 33	High yields from Yarragadee and Cockleshell Gully Formations to depths of 500m
Port Gregory	Superficial	Brackish-saline	Low-moderate	23	
	Tumblagooda Sandstone	Hypersaline nr Hutt Lagoon, brackish elsewhere	Low-moderate	23	Yields dependent on intersection of fractures
Carnarvon	Superficial lder alluvium	Brackish to saline		26	Not investigated
	Birdrong sandstone	Brackish 5 ppt		50	Depth 500 m
Exmouth	Tulki Limestone	Saline -seawater	High	30	Thin layer of brackish water over sea water
Pilbara - Nichol Bay	Fractured rock	Saline	Very low	30	Very low yields from fractured and weathered granitic bedrock
Port Hedland	Superficial	Saline -seawater		31	Untested, likely to be seawater in superficial sediments
Broome	Broome Sandstone	Brackish to saline	High	30	Thin lens of brackish groundwater overlying seawater
	Wallal Sandstone	Brackish 5 ppt	High	35+	Depth 300m
Willie Creek	Broome Sandstone	Brackish to saline	High	30	Thin lens of brackish groundwater overlying seawater
	Wallal Sandstone	Brackish 5 ppt	High	35+	Depth 300m
Wyndham	Fractured rock	Saline	Low	28	Maybe small yield of low salinity away from estuary

* as supplied localities

APPENDIX 4: STATE & FEDERAL GIS DATASETS

Data	Format (electronic, hard copy, scale etc.)	Agency	Time (to get or/and incorporate into DOF system)
Infrastructure-roads	Maps 1:250,000 1:10,000 electronic	DOL/WALIS	DOF currently has AGD84 roads, 1 week required to complete conversion
Infrastructure-power	Maps 1:250,000 1:10,000 electronic	Western Power	Dependant on supply agency and format supplied
Infrastructure-sewerage and fresh water	Electronic	Water Corporation	Dependant on supply agency and format supplied
Infrastructure-airports, ports	Electronic	DOL, DOT, AUSLIG/ WALIS	DOF currently has AGD84 airports, 1 week to complete, Not Shipping Ports
Statistics and data on ur an centers Population, schools, transportation, workshops, services	Electronic/ text	ABS CENSUS/AUSLIG Other commercial organizations refer Yellow pages	ABS data available online – data format and volume will determine ease of integration – allow at least 1 week
Topography	Maps 1:250,000 1:5,000 Electronic and Aerial photos	DOL, AUSLIG/WALIS	DOF currently has AGD84 relief, 2 weeks required to complete conversion

Sea surface temperature	Electronic	CSIRO, DOL,UWA	Dependant on supply agency and format supplied
Catchments, rivers and water bodies	Electronic	WRC/DOE	DOF currently has AGD84 rivers & catchments
Soil type	Electronic	AGWEST	Dependant on supply agency and format supplied
Geology	Electronic	DOIR	Dependant on supply agency and format supplied
Terrestrial vegetation Mangroves, Parks and Reserves	Electronic	CALM, DOL AUSLIG (1988)	DOF currently has AGD84 CALM parks and reserves Terrestrial vegetation– AUSLIG – 1 week to convert.
Marine parks and reserves, wetlands.	Electronic	CALM WRC wetlands	DOF currently has AGD84 CALM parks and reserves and previous RAMSAR wetlands
Rare and endangered flora and fauna.	Electronic	CALM	Dependant on supply agency and format supplied

Tides and currents	Electronic	CSIRO, DOT, WNI Science & Engineering (Steedmans)	Dependant on supply agency and format supplied
Climate Air temperature Wind Rain	Electronic	BOM / DOL	Dependant on supply agency and format supplied
Bathymetry	Electronic	DOT, RAN (AUSLIG)	DOF currently has AGD84 DOT-RAN(AUSLIG) bathymetry
Bird Rookeries	Electronic	CALM, Museum WA	DOF currently has some CALM seabird dist'n data
Benthic habitat mapping: sediment type, presence of sea grass or coral.	Electronic	DOF, CALM, CSIRO, UWA, DEP	DOF currently has some CALM & CSIRO AGD84 benthic data
Mineral and Oil exploration or leases	Electronic	DME	DOF currently has AGD84 Mineral and Petroleum Tenements
	Electronic	DOL	Dependant on supply agency and format supplied

FISHERIES OCCASIONAL PUBLICATIONS

No. 1 Field Identification Guide to Sharks and Shark-like Rays
R. McAuley, D. Newbound, R. Ashworth (2002)

No. 2 Scientific Workshop on the Margaret River Marron
Edited by B. Molony (2002)

No. 3 Site suitability assessment for land-based temperate Marine Aquaculture from Shark Bay to South Australian Border (Makaria Pty Ltd) (2002) Available as publication on website only.

No. 4 Research Project Assessment – Decision Framework, version 1.3, November 2002.

No. 5 Australian Society for Fish Biology Workshop Proceedings. Towards Sustainability of Data-Limited Multi-Sector Fisheries, Bunbury, WA 23-24 September 2001. Newman, S. J., Gaughan, D.J., Jackson, G., Mackie, M. C., Molony, B., St. John, J. and Kailola, P. (2003)

No. 6 Anglers guide to assessing reproductive stage in fish (2004)

No. 7 Marron Farming Workshop and Field Day, April 5, 2003. Compiled by Greg Maguire (2003)

No. 8 Department of Fisheries Stakeholder Survey 2003 by Tara Baharthah and Neil R. Sumner (July 2003)

No. 9 Draft Report of the Statutory Management Authority Advisory Committee (November 2003)

No.10 Marron Farming Workshop, Field Day and Trade Show, March 13, 2004. Compiled by Greg Maguire (2004)

No.11 Broadscale Survey of Coral Condition on the Reefs of the Easter Group of the Houtman Abrolhos Islands, by Elizabeth Dinsdale James Cook University and Luke Smith Australian Institute of Marine Science. (in press)

No. 12 Aquaculture Checklist. (in press)

No. 13 Identification and Evaluation of Sites for the Development of Large Scale, Land Based Marine Aqua culture in Western Australia. Prepared by Dr. Sagiv Kolkovski and Dan Machin on behalf of The Aquaculture Development Council (December 2004)

FOOTNOTES

1 Fish is used in a broad sense of finfish and invertebrates.

2 The pH and concentration of dissolved gases, such as oxygen and carbon dioxide, in sea water extracted from beach wells may vary from natural levels, according to factors such as the depth of the wells and their distance from the coast. For the purpose of this study, it is generally assumed that beach wells located close to the shore are more likely to yield high-quality sea water with physical and chemical properties that approximate those of the adjacent ocean; however, it is emphasised that this factor needs further consideration and, if beach wells are to be used, the quality of the sea water they deliver needs to be ascertained by testing water pumped from test wells.

3 The iterative process used to select the sites considered best suited for land-based marine aquaculture was based principally on the knowledge of the areas in question collectively possessed by the authors, and other Department of Fisheries staff including the Regional Aquaculture Development Officers, research staff and members of the Aquaculture Program. During the on-site inspections, knowledge provided useful information about the accessibility, seasonal and otherwise, of various sites.

Notes