THE AQUACULTURE DEVELOPMENT COUNCIL

AQUACULTURE PLANNING IN WESTERN AUSTRALIA

PART A: SYNOPSIS AND REVIEW

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1 INTRODUCTION

1.1 Background

The Aquaculture Development Council ("ADC") has been established under the *Fish Resources Management Act* 1994 to advise the Minister for Fisheries on issues affecting aquaculture and on issues relating to aquaculture and the management of aquaculture.

As a function of this role, the ADC has commissioned a review of aquaculture planning and development in Western Australia.

Information about the current status of aquaculture planning and development within Western Australia may then be used to document existing and potential aquaculture sites and species within the State.

1.2 Objectives

The principal objectives of the study are to:
- review and document existing and proposed planning studies that have some relevance to aquaculture in Western Australia;
- identify areas or zones that have been identified as current or potential sites for aquaculture in existing planning and associated studies; and
- prepare a document with mapped illustrations delineating current and potential aquaculture sites and identifying species compatible with such sites.

To attain the above objectives, this study determines the status of aquaculture planning in Western Australia by:
- compiling a list of existing and proposed planning strategies that have some relevance to aquaculture in Western Australia;
- providing a review of the aquaculture-oriented planning studies;
- collating the available data in relation to the location and delineation of current aquaculture licensed areas and species intended for aquaculture;
- extracting the relevant data from planning documents that identify potential sites for aquaculture development;
- identifying and enumerating the species considered compatible with the sites identified as having potential; and
- producing a series of maps illustrating current and potential aquaculture sites.

It is envisaged that the study will provide a synopsis of:
- sites already highlighted as being suitable for aquaculture development;
- areas considered to have potential for aquaculture development; and
- locations that are constrained for aquaculture development due to other competing or incompatible uses.

The mapped component of the study will be developed in a digital format to allow continuous updating of aquaculture and other pertinent information as it becomes available.

1.3 Document Structure

The document that constitutes the outcome of this *Aquaculture Planning in Western Australia* study comprises two stand-alone parts. *Part A: Synopsis and Review* essentially constitutes the main text and detail of the study and *Part B: Sites and Maps* an overview of the sites, the maps and some associated information. The structure and content of these two parts are described in more detail below.

Parts A and B of the document are provided in loose-leaf form, to permit the efficient insertion of new information as it becomes available and for relevant sections to be made separately available to regional areas if required.

1.3.1 Part A: Synopsis and Review

Chapter 1 outlines the background to the study and its objectives.

For the purpose of this study, the coastal areas of Western Australia are divided into ten principal regions, according to their geomorphological features, and the inland areas into four, according to the three principal drainage basins and a ground-water region. Chapter 2 provides the rationale for these classifications and identifies the specific coastal and inland regions and their boundaries.

Chapter 3 outlines the existing and proposed Western Australian planning studies that have some relevance to aquaculture. Planning strategies that have been completed are provided in section 3.1 and those either currently being undertaken or proposed in section 3.2; these sections also provide brief synopses of each of the existing planning studies and the objectives of each of the current ones. The chapter terminates with a review of the planning studies according to region and their relevance to aquaculture in Western Australia.

The site selection criteria described in chapter 4 are those that have been used to select and evaluate sites considered suitable for aquaculture in Western Australia and elsewhere. Aquaculture sites are categorised according to their physical and biological features and economic, social and legal factors; each of these categories comprises several selection criteria.

Chapter 5 begins by providing lists of (a) the species currently produced by aquaculture in Western Australia and (b) those that have been identified in the various planning and other aquaculture-oriented studies as having potential for commercial production. Information is then provided about the criteria used in the various studies to determine the suitability of and select a species for aquaculture. The species-selection criteria are sorted into four categories; *viz.*: marketing factors, culture technology, production efficiency and commercial viability. The species identified as aquaculture candidates by the various planning and other studies are then classified according to their perceived potential. The rationale for this classification process is described and a brief account provided of the status of each selected species.

Chapters 6 and 7 deal respectively with Western Australia's coastal and inland aquaculture regions. The general features of each region are described briefly, followed by an account of

the aquaculture sites it encompasses and the species that are considered compatible. The sites are classified according to whether they are:

- existing (existing sites are those for which aquaculture licences have already been issued; proposed sites, for which applications have been made but licences not yet issued, are not included in this document);
- potential (these sites are those described in the various planning and other studies as having potential for commercial aquaculture and that are not in areas considered sensitive or prohibited); and
- sensitive or prohibited (the former are in areas considered to have environmental or other sensitivities; prohibited sites include areas such as navigational channels, anchorages and zones of Marine Parks that exclude aquaculture).[1]

Chapter 8 provides an account of the various sources of information specifically relevant to aquaculture planning and development and chapter 9 various recommendations in relation to this study.

Numerous Government agencies and other organisations are mentioned throughout this document. To avoid unnecessary repetition, these are occasionally referred to by their acronyms or other abbreviations, the key to which is provided below.

ACWA:	Aquaculture Council of Western Australia
ADC:	Aquaculture Development Council
AgWest:	Agriculture Western Australia
CALM:	Department of Conservation and Land Management
DEP:	Department of Environmental Protection
DOLA:	Department of Land Administration
DoT:	Department of Transport
EPA:	Environmental Protection Authority
FDWA:	Fisheries Department of Western Australia
MfP:	Ministry for Planning
PPA:	Pearl Producers Association
WADoT:	Western Australian Department of Training
WRC:	Waters and Rivers Commission

1.3.2 Part B: Sites and Maps

Part B: Sites and Maps is structured as a stand-alone document. It principally comprises brief descriptions of the sites and maps for each of the coastal and inland regions in Western Australia.

Chapter 1 provides a brief introduction about the main objectives of the study and includes the rationale for dividing the State into regions.

[1] Two areas within Western Australia that have not been specifically identified in any planning studies but which are considered to have good potential for aquaculture development are introduced in this document as *Special Significance Areas*. These areas occur near Exmouth and Esperance and are discussed briefly in *Part A: Synopsis and Review* in sections 6.4.2 and 6.10.2, respectively, the Pilbara Coast and the Eucla Coast. Additional information about these areas and their commercial aquaculture potential is provided in the relevant chapter in *Part B: Sites and Maps*.

A brief summary of the general features of the coastal and inland aquaculture regions in Western Australia and the sites they encompass is presented in chapter 2 (only limited material about potential sites is provided in this section: for further information the reader is referred to *Part A: Synopsis and Review*). Chapter 3 contains preliminary information about two areas (Exmouth and Esperance) considered to have special significance for aquaculture development but that have not been specifically identified or described in any of the planning studies.

Chapter 4 begins by providing a list of the site maps that follow. The maps are numbered in such a way that the future insertion of new maps is facilitated. The maps are scaled according to the amount of information available for each region.

Part B: Sites and Maps concludes with chapter 5, which provides an inclusive list of the species considered suitable for aquaculture in Western Australia. Each species has accompanying notes that include information such as the areas or regions to which they may be considered best suited for commercial aquaculture development.

2 AQUACULTURE REGIONS IN WA

The principal aquaculture regions are first classified according to whether they are considered *coastal* or *inland*. Coastal regions include all offshore (nearshore and open ocean) and onshore sites within 1 km of the high water mark. Inland regions include all areas landward of a line approximately 1 km from the high water mark.[2] Organisms cultured within the coastal regions are generally marine or brackish-water species; those cultured within the inland regions are generally fresh and brackish-water species.

2.1 Coastal Regions

Conventionally, for the purpose of coastal planning, the WA coast is divided into 10 areas or regions according to geomorphology. The aquaculture industry in WA is in an early stage of development: some large coastal areas currently feature little or no aquaculture development and some may have little future potential for reasons that include poor site suitability and high conservation value. Accordingly, there is an argument that the coastal aquaculture regions should be divided into fewer categories, each comprising one or more geomorphological regions. However, because one purpose of this document is to provide a framework that will accommodate the efficient inclusion of future information, the principal coastal aquaculture planning regions adopted for this study maintain 10 geomorphological divisions. These are:

- the Kimberley Coast: from the Northern Territory border to Cape Leveque on the Dampier Peninsula;
- the Canning Coast: from Cape Leveque to Cape Missiessy at the northern end of Eighty Mile Beach;
- Eighty Mile Beach: from Cape Missiessy to Cape Keraudrin;
- the Pilbara Coast: from Cape Keraudrin at the southern end of Eighty Mile Beach to the North-West Cape;
- the Ningaloo Coast: from the North-West Cape to Point Quobba;
- the Shark Bay Coast: from Point Quobba to Kalbarri;
- the Central West Coast: from Kalbarri to Perth;
- the Leeuwin-Naturaliste Coast: from Perth to Walpole Inlet;
- the South Coast: from Walpole Inlet to Esperance; and
- the Eucla Coast: from Esperance to the South Australian border.

2.2 Inland Regions

The inland regions are divided principally according to surface drainage patterns; namely, the Leichardtian, Greyian and Vlaminghian regions. Aquaculture sites included within these regions are characterised by the use of surface waters only; a separate category is provided for those using ground water.

[2] To avoid any confusion, for the purpose of this document, onshore sites within 1 km of the coast that are used exclusively to culture fresh water species are classified as inland.

Western Australia has vast ground water resources that are considered to have significant aquaculture potential.[3] The salinity of these ground waters ranges from fresh to hypersaline and in many cases the water quality characteristics and the quantities that are available have been documented. Due to the high potential of this resource for inland aquaculture development and because the aquaculture production systems that exploit ground water are generally distinct from those using surface water, an additional inland region, the Ground Water region, is included in this document as a separate category.

The inland regions are delineated as follows:

- Leichardtian Region: the Kimberley region (biogeographically, this region extends beyond the Western Australian border into the Northern Territory and northern Queensland);
- Greyian Region: the De Grey River in the north to the Murchison River in the south;
- Vlaminghian Region: the inland rivers and waters of south-west of Western Australia; and
- the Ground Water Region: includes all of Western Australia, so overlaps the above inland regions but is distinguished by the use of ground water only.

[3] As an example of the large ground-water reserves of some inland areas of Western Australia, the Waters and Rivers Commission has estimated that the ground-water reserve in the Dampier Peninsula region is up to 550 GL.

3 EXISTING AND PROPOSED WA AQUACULTURE PLANNING STUDIES

Some studies in relation to aquaculture and aquaculture planning in Western Australia have been completed; some are currently being carried out; others have not yet begun but are considered likely to proceed.

This chapter identifies the existing, current and proposed studies that have some relevance to aquaculture. It begins by providing brief synopses for the existing studies, outlines the objectives or likely objectives of the remainder and ends with a review of aquaculture planning studies in Western Australia.

3.1 Existing Studies

Each of the existing planning studies that have some specific relevance to aquaculture in Western Australia is listed below according to region, together with a brief synopsis.[4] Some of those listed are not considered planning studies; however, they are included since they have some other specific relevance to aquaculture in WA. The references for these works are provided in alphabetical order according to title in chapter eight.

3.1.1 Western Australia

State Planning Strategy. November 1996.

> The *State Planning Strategy* provides a strategic guide for land-use planning; it is aimed at developing a land-use planning system to achieve key goals that include generating wealth, preserving and enhancing the environment and building safe, vibrant communities. The Strategy has minimal reference to aquaculture; however, many relevant issues are raised such as infrastructure development and resource use and planning.

Final Report of the Review of Coastal Management in Western Australia. May 1995.

> The *Final Report of the Review of Coastal Management in Western Australia* considers the efficiency and effectiveness of the State's existing coastal management system and provides recommendations in relation to a more focused, cross-agency approach to coastal planning and management activities.
>
> An earlier draft to this Final Report, the *Review of Coastal Management in Western Australia* (September 1994), constitutes an issues and options paper that summarises the initial findings of the review and outlines a series of recommendations in relation to

[4] As far as possible, the planning and other studies are classified according to the regions used in this study as they are identified in chapter 3, while those that relate to the State or the country are classified separately. A difficulty associated with this method is that some studies based on political boundaries tend to overlap the geomorphological boundaries; in these cases, the study in question is placed in the most sensible or logical category. For example, the Kimberley Aquaculture Development Plan is placed in *The Kimberley Coast* and not *The Canning Coast* or *Eighty Mile Beach*. Due to the relative paucity of aquaculture planning studies dealing with inland areas in Western Australia, these are pooled in one category entitled *Inland Regions*.

coastal management. Options for improving coastal management in Western Australia drawn from previous submissions are proposed for the various terms of reference.

The terms of reference of the draft report deal with: a definition for the coastal zone; State Government objectives for coastal zone management; administrating and co-ordinating coastal zone management; and funding sources, requirements and distribution.

New Horizons in Marine Management. November 1994.

Promulgated from the earlier Wilson Report, *New Horizons in Marine Management* elucidates a strategy for the development and conservation of the State's marine resources. The stated objectives of the marine conservation reserve system embraced by the document are to preserve representative ecosystems and provide for the management of the various uses of marine reserves. The fundamental proposal involved the expansion of the existing system of marine conservation reserves and the creation of a new category of reserve: the main categories are now Marine Nature Reserves, Marine Parks and Marine Management Areas. The document provides a brief description of these categories and the activities that they may or may not support.

Marine Nature Reserves are created for conservation and scientific research; aquaculture is not permitted in these areas.

Marine Parks comprise four zones:

- Sanctuary Zones (managed for conservation and low-impact tourism; aquaculture is not permitted);
- Recreation Zones (managed for recreational fishing);
- Special Purpose Zones (managed for priority uses; aquaculture is permitted where it is compatible with conservation and subject to the Acts under which it is administered); and
- General Use Zones (these make up the areas of Marine Parks not included in the other three categories; conservation in these Zones is still a priority but aquaculture is permitted where it is compatible with conservation and subject to the Acts under which it is administered).

Marine Management Areas comprise the new category of reserve; while they are selected on the basis of biological and recreational values, their potential to support commercial activities such as aquaculture is recognised.

A Representative Marine Reserve System for Western Australia: Report of the Marine Parks and Reserves Selection Working Group. June 1994.

The *Representative Marine Reserve System* for Western Australia document (generally known as the *Wilson Report*) has as one of its principal goals the establishment of a system of conservation reserves representative of the flora, fauna and habitats of Western Australian coastal regions.

Reserve selection was based on recognition of major distinctive coastal types using geomorphological criteria: the Report selected areas that contained the greatest variety and best examples of the characteristic habitats of each coastal type as candidates for

reservation. The Wilson Report describes 10 primary geomorphological coastal zones and several major marine ecosystems along the Western Australian coast; the ecosystems are considered to serve the purpose of the Report because they define practical units of management (such as seagrass meadows, coral reefs and tidal flats). For defined zones along the coast, the Report describes the coastal geomorphology, marine flora and fauna, tourist potential and fisheries; provides details of existing reserves; and makes recommendations for future marine reserves.

It is noted that the Wilson Report constitutes a series of recommendations and is not a statement of Government policy.

National Strategy on Aquaculture in Australia. March 1994.

Identifying the increasing contribution by aquaculture to Australia's seafood industry, a 1988 report entitled *Casting the Net* by the Australian Science and Technology Council recommended the preparation of an overview of the status and future potential of aquaculture on a national level. As a result, the *National Strategy on Aquaculture in Australia* was prepared by the Working Group on Aquaculture.

The National Strategy document aims to overcome current constraints on the aquaculture industry and create the environment in which aquaculture can capitalise on its advantages. To achieve these aims, the Strategy establishes 10 goals. It then develops the key issues and strategies associated with each goal.

Aquaculture: Development Strategies for the Industry in Western Australia. 1994.

Aquaculture: Development Strategies for the Industry in Western Australia is a document prepared by the Aquaculture Development Advisory Council. Containing recommendations that ensued from a joint industry and government workshop, it identifies several tasks considered central to industry development. These include identifying the potential for aquaculture development in Western Australia; evaluating the current state of the existing industry; determining the constraints to industry development; and formulating a suitable development strategy.

The document provides a total of 69 recommendations, which relate to issues such as market development, research, education, training and security of tenure. Key recommendations in relation to industry development included the formation of the Aquaculture Development Council, the establishment of an Aquaculture Development Unit within FDWA, the development of aquaculture-oriented regional infrastructure, funding for technology parks in different climatic zones and the provision of reasonable security of tenure for aquaculture operations.

Interdepartmental Submission by the Coastal Management Co-Ordinating Committee, Other Departments and Agencies to the Resource Assessment Commission Inquiry into Coastal Zone Management. August 1992.

The *Interdepartmental Submission by the Coastal Management Co-Ordinating Committee , Other Departments and Agencies to the Resource Assessment Commission Inquiry into Coastal Zone Management* document principally identifies regulatory

instruments and the institutional arrangements used at the time of its publication for coastal management in Western Australia and includes numerous departmental submissions.

The document notes that Western Australia has no specific coastal legislation and that the statutory components of coastal management are consequently dealt with by the Acts governing the various Government agencies. Describing the development of coastal planning and management in Western Australia as "the province of several, intertwining and interrelated spheres of management: estuarine, coastal, marine, local and conservation management", it describes a coastal management structure that incorporates an Interdepartmental Aquaculture Committee under the auspices of FDWA. References to aquaculture in the document are brief.

Marine Resources Map of Western Australia: Part 1, The Resources; Part 2, The Influence of Oil on Marine Resources and Associated Activities with an Emphasis on those found in Western Australia. 1986.

In the event of an oil spill on the Western Australian coast, marine resources may be at risk: the *Marine Resources Map of Western Australia* was compiled to provide economic, ecological, scientific and other information on which decisions about appropriate clean-up methods could be based.

Part 1 of the document describes the marine resources and the geomorphological, hydrological and meteorological features of the Western Australian coastal environment. This information is considered useful for aquaculture planning. Part 2 deals with the effects of oil on marine resources and associated commercial and recreational activities.

A Selected Bibliography of Marine and Estuarine Studies (other than Physical Oceanography) in Western Australia. 1985.

The *Selected Bibliography of Marine and Estuarine Studies (other than Physical Oceanography)* in Western Australia provides numerous references on marine and estuarine studies, other than physical oceanography, in Western Australia. Although not specifically relevant to aquaculture, the document is included here because it provides a valuable guide to information about marine coastal biology and geology that can be used to identify potential coastal aquaculture sites.

A Bibliography of Physical Oceanography in Southwest Australian Waters. 1983.

The *Bibliography of Physical Oceanography in Southwest Australian Waters* lists numerous references that provide information about aspects of the physical oceanography of nearshore areas between the North-West Cape and Cape Leeuwin. Although not specifically relevant to aquaculture, it is included here because it provides a valuable guide to information about water quality parameters, such as salinity and temperature, that can be used to identify potential coastal aquaculture sites in an easy-to-use format.

3.1.2 The Kimberley Coast

Kimberley Aquaculture Development Plan. October 1996.

The *Kimberley Aquaculture Development Plan* identifies, describes and assesses the aquaculture-oriented resources of the Kimberley Region of WA in some detail. It provides a reasonably subjective evaluation of finfish and shellfish species considered suitable candidates for aquaculture. To focus resources and assist in the direction of key decisions for aquaculture development, the document adopts a strategic planning approach, an important component of which is a process for implementing its recommendations. A primary recommendation is the formation of a group to oversee and drive the development of the Kimberley aquaculture industry.

The Kimberley Plan identifies several aquaculture management zones, each one of which is subdivided into sectors. The management of each zone is discussed with a view to aquaculture development and a list provided of species considered to have aquaculture potential. Each sector within the management zones is considered in relation to the aquaculture sites it may contain and the production systems considered compatible.

Nature Conservation Reserves in the Kimberley. 1991.

Nature Conservation Reserves in the Kimberley constitutes a submission by CALM that deals with the perceived need to declare national parks, nature reserves and conservation parks in the Kimberley Region.

Although it does not refer to aquaculture, the document is included in this study because it provides a significant amount of valuable information about several areas considered elsewhere to have potential for aquaculture development in the Kimberley. In particular, it provides information relevant to aquaculture about the geomorphology, flora and fauna of various areas and their conservation values. For example, the importance of some offshore islands for nesting seabirds and turtles is declared, as is the scientific and conservation value of some of the coral reefs and their rich fauna. The potential value of these areas for aquaculture lies in the rich gene pools they support.

3.1.3 The Canning Coast

No planning studies with specific relevance to aquaculture have been identified for the Canning Coast.

3.1.4 Eighty Mile Beach

No planning studies with specific relevance to aquaculture have been identified for Eighty Mile Beach.

3.1.5 The Pilbara Coast

Karratha Area Development Strategy. April 1997.

The *Karratha Area Development Strategy* provides recommendations for activities such as pastoral use and agriculture, fishing and aquaculture, tourism, industrial development and sub-regional infrastructure. It notes that pearling and aquaculture are emerging as viable enterprises in the area, refers to the Driscoll Report (1996) within the context of current and proposed pearling leases offshore and mentions the limited onshore aquaculture operations aiming to produce algae and redclaw crayfish.

The Strategy's recommendations for fishing and aquaculture involve the preparation of a management plan for fish resources in the area with the continued involvement of professional and recreational fishers and the preparation of an overall aquaculture document and management plan for the Karratha study area.

Pearling and Aquaculture in the Dampier Archipelago: Existing and Proposed Operations. September 1996.

The key objective of the *Pearling and Aquaculture in the Dampier Archipelago: Existing and Proposed Operations* discussion paper is to provide information about pearling and aquaculture in the area. Ensuing from an earlier report entitled *A Report on the Issues affecting the use of the Dampier Archipelago* (March 1996), which is more commonly known as the *Driscoll Report*, the discussion paper is part of an ongoing consultative process to enable public comment on existing and proposed pearling and aquaculture activities. It deals with one of the categories of recommendations provided in the Driscoll Report entitled *Immediate Actions*.

The discussion paper deals with pearling (*Pinctada maxima*) and the aquaculture of non-*P. maxima* pearl species. In addition to providing policy guidelines for the former species and development strategies for the latter species group, the paper outlines the assessment processes for proposals, describes the general conditions and restrictions placed on each industry sector and provides the current status of operations and proposals in north-west Western Australia. A later chapter outlines issues of concern to the public and to the pearling and aquaculture industry in the area.

A Report on the Issues Affecting the Use of the Dampier Archipelago. March 1996.

The *Report on the Issues Affecting the Use of the Dampier Archipelago* (the Driscoll Report) was commissioned by the Minister for Fisheries following concerns about resource sharing, allocation of licences and leases for pearling and aquaculture, recreational and commercial fishing opportunities and access to the region's islands and marine areas. Its purpose is to provide FDWA and the Minister for Fisheries with a scoping document for a marine planning study for the Dampier Archipelago.

The Driscoll Report outlines the potential and current status of pearling and aquaculture in the region in some detail and provides information about related issues such as the current status of leases and lease proposals. It also supplies a description of other industries and relevant issues, including summaries of their potential benefits. To resolve current issues and formulate future planning requirements, the Report concludes by

providing three categories of recommendations: immediate actions; the preparation of a draft management plan for setting aside a fish habitat protection area for public comment; and the preparation of a planning and management strategy for the islands and marine areas of the Dampier Archipelago.

Pilbara/Gascoyne Islands Ecotourism Management Strategy. 1995

The two volumes that together comprise the *Pilbara/Gascoyne Islands Ecotourism Management Strategy* represent detailed studies that were undertaken and the resultant strategies developed; volume 2 provides the raw material for the implementation of the strategy outlined in volume one. Encompassing about 200 islands, the coastal waters of the Pilbara and Gascoyne regions are subject to a variety of uses, including significant oil and gas drilling, exploration and production and some aquaculture development. This study was undertaken to derive a management strategy for the area, with particular emphasis on the islands and with a view to the development of an ecotourism industry.

The Strategy identifies aquaculture as an industry with an opportunity to gain commercially from tourism because of the potential for operations to become part of a tourism product. Several existing aquaculture ventures and locations are named and suggestions made in relation to possibly setting aside onshore areas for future aquaculture support activities.

Marine Environment of Dampier Archipelago. 1985.

Woodside Petroleum Pty Ltd has made the technical report entitled *Marine Environment of Dampier Archipelago* available for public reference; it provides results of an investigation of the marine fauna and flora of the Dampier Archipelago. The organisms studies were selected on the basis of their vulnerability to development activities; accordingly, while aquaculture is not specifically mentioned in the report, the information provided is relevant to the industry, particularly when assessing its potential impact on the local aquatic fauna and flora. The organisms identified as being the most vulnerable to development included nearshore and benthic fishes, zooplankton, corals, molluscs, crustaceans, algae and mangroves.

3.1.6 The Ningaloo Coast

Gascoyne Aquaculture Development Plan. November 1996.[5]

The purpose and structure of the *Gascoyne Aquaculture Development Plan* are similar to those described for the *Kimberley Aquaculture Development Plan*, a synopsis of which is provided in section 3.1.2 above. The Gascoyne Plan adopts a strategic planning approach and promotes a staged process to aquaculture development in the Region. Some differences are evident between the aquaculture development plans for the Gascoyne and

[5] The Gascoyne Region of Western Australia overlies several of the geomorphological regions adopted for this study; namely the Pilbara, Ningaloo and Shark Bay coasts. The principal aquaculture planning document that deals with these areas is entitled the *Gascoyne Aquaculture Development Plan*. For convenience, the synopses for this document and that for the Gascoyne Region Economic Development Strategy are provided in the Ningaloo Coast section of this study.

Kimberley regions, such as the respective species considered to have aquaculture potential; however, the fundamental approaches to aquaculture development adopted by each document are essentially the same.

The Gascoyne Plan also provides, as appendices, information about species selection for aquaculture, market briefs for several selected species and a theoretical analysis of investment feasibility for one species (estuary cod) considered to have good potential for commercial production in the region.

Gascoyne Region Economic Development Strategy. October 1996.

As its title suggests, the *Gascoyne Region Economic Development Strategy* describes the economic development strategy for the Region. The Strategy has specific reference to aquaculture and as one of its objectives proposes to foster the development of a commercially-significant aquaculture sector at appropriate locations. It identifies key issues and outlines several strategies, the more important of which are to implement the recommendations of the *Gascoyne Aquaculture Development Plan*; to develop important and fundamental resources such as a hatchery; and to provide for aquaculture planning in local government planning schemes in the region.

Coral Bay Planning Strategy. August 1992.

The *Coral Bay Planning Strategy* was developed to guide the future use, development and conservation of land at Coral Bay. While it contains no specific reference to aquaculture, the document is cited here because aquaculture and other developments in the area have been previously mooted elsewhere. The Strategy proposes low-key recreational land usage only.

Coral Bay Draft Coastal Management Plan. July 1984.

The *Coral Bay Draft Coastal Management Plan* provides information about the physical and biological environment in the vicinity of Coral Bay. While it has no specific reference to aquaculture, some of its recommendations in relation to the marine environment advise against the construction of structures or works such as groynes and breakwaters, such as those that may be required for aquaculture. In any case, given its high conservation value and the negative impact natural biological events such as coral spawning may have on some forms of aquaculture, the Ningaloo Reef area is best avoided for the purpose of aquaculture development using offshore production systems.

3.1.7 The Shark Bay Coast

Shark Bay Aquaculture: Community Consultation. April 1997.

The purpose of the *Shark Bay Aquaculture: Community Consultation* study was to undertake a public consultation process to determine which areas in Shark Bay could be used for aquaculture without infringing upon existing values. The goal was to produce a draft report identifying parts of Shark Bay that could be used for aquaculture and areas of high conservation, cultural, commercial and recreational significance.

The draft report identifies areas of interest and provides summaries of the views expressed by the parties concerned. It also points out the limitations inherent in a study of this nature, emphasises that it should be used as a guide only and recommends that further consultation should take place when considering specific sites for aquaculture development.

Shark Bay Regional Strategy. March 1996.

The *Shark Bay Regional Strategy* essentially constitutes a review of an earlier plan, which identified planning and environmental issues at Shark Bay. *Inter alia*, the document considers the provision of security for resource-based industries such as fishing and aquaculture.

The Regional Strategy document asserts that several onshore and offshore sites identified by the *Gascoyne Aquaculture Development Plan* have potential for aquaculture development, while recognising that more detailed assessments of the proposed sites are needed. Several objectives detailed in the document refer to utilising aquaculture resources within ecologically-sustainable limits; supporting economic development by the establishment of aquaculture enterprises; and locating and developing aquaculture ventures so they do not conflict with areas of high conservation value. Various actions are proposed in the document to achieve these objectives, by identifying sites suitable for commercial-scale and low-impact aquaculture developments and generally encouraging the development of appropriate aquaculture activities.

Shark Bay Finfish Aquaculture Project. August 1995.

The *Shark Bay Finfish Aquaculture Project* is not considered a planning study; however, it is included here because it provides a preliminary assessment of the feasibility of commercial aquaculture in Shark Bay, with specific reference to nine selected marine finfish species. The study assesses the potential of the species with reference to the current status of their respective culture technologies.

The study also introduces several other marine finfish and shellfish species, in addition to the initially-selected species, that may have some potential for aquaculture in the area.

Shark Bay World Heritage Area Draft Management Plan for Fish Resources. November 1994.

The *Shark Bay World Heritage Area Draft Management Plan for Fish Resources* deals with the management of fish resources and associated social values that are the responsibility of FDWA in the Shark Bay World Heritage Area. Among other issues, the Draft Management Plan describes the roles of FDWA, CALM and other agencies within the context of legislative and administrative arrangements. It describes the World Heritage Area's physical environment and hydrology and provides information about its natural resources. Consideration is given to recreational use, marine infrastructure and commercial fishing operations.

One of the goals developed to manage the fisheries values aims to "realise and maintain the Area's recreational, commercial and aquaculture fisheries values". Several recommendations are provided in the Draft Management Plan that have specific reference to aquaculture and its potential impact on World Heritage values. A notable recommendation proposes that aquaculture "may be permitted in all areas of the World Heritage Area but not in Recreation and Sanctuary Zones in the Marine Park, the Hamelin Pool Marine Nature Reserve, and the Recreational Fishing and Reef Observation Areas in the proposed Fish Habitat Protection Area".

Monkey Mia Reserve Draft Management Plan. 1993.

The *Monkey Mia Reserve Draft Management Plan* provides policies and strategies for the joint management of the Monkey Mia Reserve by CALM and the Shire of Shark Bay. It documents the conservation significance of Monkey Mia within Shark Bay, but makes no reference to aquaculture. It is included here because a subsequent Shark Bay Regional Strategy (March 1996) refers specifically to the establishment of low-impact aquaculture operations that could be established in the vicinity of Monkey Mia.

3.1.8 The Central West Coast

Technical Evaluation of Sites for Land-Based Marine Aquaculture in the Mid-West Region. June 1997.

The *Technical Evaluation of Sites for Land-Based Marine Aquaculture in the Mid-West Region* provides a description of sites considered technically suitable for the commercial development of marine aquaculture in onshore systems for potential investors and proponents. It identifies and evaluates species and production systems considered compatible with the selected sites.

The document first establishes the selection criteria to be used to evaluate the proposed sites, then considers each site with reference to these criteria. Of the 16 sites initially proposed for evaluation, four were considered to have potential for commercial aquaculture development immediately or in the short term (primary sites); three to have some potential in the short to medium term (secondary sites); and the remaining nine to have little potential in the short to medium term (tertiary sites). The study provides criteria for selecting and evaluating aquaculture candidate species, identifies several candidates considered suitable for commercial aquaculture in the Mid-West Region and provides preliminary evaluations for several marine finfish and shellfish species. It then provides comment on the compatibility of the sites, species and production systems.

Marine Reserve Implementation Programme: Central West Coast. December 1996, March 1997.

The CALM Act specifies a statutory process for the reservation of marine reserves; commercial activities that include aquaculture would be acceptable within specific zones of marine reserves.

As a part of this process, areas recommended for reservation are being identified and mapped in a Geographical Information System by the Marine Conservation Branch of CALM, as part of the *Marine Reserve Implementation Programme*. Field Programme Reports to date are:

- *Marine Reserve Implementation Programme: Jurien Bay and Adjacent Waters. Oceanographic Field Programme for Jurien Bay and Adjacent Waters* (December 1996);
- *Marine Reserve Implementation Programme: Central West Coast. Biological and Spatial Validation of the Major Benthic Habitats off the Central West Coast*. (December 1996); and
- *Marine Reserve Implementation Programme: Central West Coast. Biological Survey of the Major Benthic Habitats of Jurien Bay and Surrounding Waters*. (March 1997).

Field programmes have been developed for the Central West Coast between Cervantes and Cliff Head; and Jurien Bay and adjacent waters. Among other activities, these programmes involve benthic habitat mapping and studies of hydrodynamics within the recommended areas. Information generated from these studies would be used to assess the likely impacts of various activities, such as aquaculture, in the marine reserves and allocate areas for sanctuary and other zones.

Shire of Dandaragan Development Plan. March 1996.

The aim of the *Shire of Dandaragan Development Plan* is to provide a description of development objectives for each of several major community sectors, one of which is aquaculture.

The section of the Plan dealing with aquaculture refers to the previous *Dandaragan Aquaculture Planning Strategy* (July 1995) and summarises the current status of the industry and its growth potential. It concludes with a series of future planning strategies, which essentially support the recommendations of the *Dandaragan Aquaculture Planning Strategy* and aim to promote the requisite feasibility studies and attraction of funding for research, development and other aquaculture-oriented activities.

Dandaragan Aquaculture Planning Strategy. July 1995.

The *Dandaragan Aquaculture Planning Strategy* was prepared to create planning guidelines for the establishment of an aquaculture industry within the Dandaragan Shire. The Planning Strategy provides an outline of the region's natural resources and information about social, economic and other factors that may influence, or be influenced by, the development of a local aquaculture industry. It describes opportunities and potential for marine and fresh-water aquaculture and proposes a relevant planning strategy, which embraces the concepts of the conservation and sustainable development of natural resources.

The document contains several useful maps that, *inter alia*, illustrate habitats, the occurrence of seagrass meadows, soil structures and types and potential sites considered suitable for marine and fresh-water aquaculture in the short, medium and long terms.

Abrolhos Islands Aquatic Reserve: Final Report. May 1993.

The *Abrolhos Islands Aquatic Reserve: Final Report* recommended that the future administration of the Islands should reflect their multiplicity of uses, the nature of the resource and its management requirements. While it makes no specific reference to aquaculture, this recommendation does allow for future aquaculture development.

Abrolhos Islands Planning Strategy. July 1988.

The objective of the *Abrolhos Islands Planning Strategy* was to prepare a planning strategy for the Islands with the major aim of resolving conflicts between fishing, tourism and conservation on and around the islands.

The report of the Task Force commissioned to prepare the study proposes that the planning strategy should form the basis for a future policy on the islands. It contains no findings on aquaculture; those on fishing relate to the importance of conserving the reef areas and securing the future of onshore facilities for the local fishing industry.

Geraldton Mid-West Regional Development Study: The Way Ahead. October 1987.

The portion of the *Geraldton Mid-West Regional Development Study* that deals with fishing identifies the increasing attention being paid to aquaculture but notes that more work needs to be done to establish the economic viability of the industry. The study identifies potential sites and species in the region as well as providing a series of requirements and actions necessary to develop aquaculture in coastal and inland areas. These requirements include surveying and evaluating the potential of several sites, carrying out marketing work and streamlining the applications and approvals processes.

3.1.9 The Leeuwin-Naturaliste Coast

Southern Metropolitan Coastal Waters Study (1991-1994). November 1996.

The final report of the *Southern Metropolitan Coastal Waters Study* (a separate summary document of which has also been published) synthesises the results of many other inter-related technical and scientific investigations and aims to satisfy a need for a better technical basis from which to manage existing and projected waste inputs to the marine environment in the vicinity of Perth.

While it has no direct reference to aquaculture, the Coastal Waters Study deals with several issues of importance to aquaculture within the study area. It considers nutrient inputs, water quality and seagrass health both in core areas and in the wider areas. Generally, it finds that the concentrations of toxic substances in sediments and shellfish are relatively low. The report also considers the microbiological quality of coastal waters and beaches, the introduction of foreign organisms, impact of shell sand mining and management issues.

Shoalwater Islands Marine Park: Draft Management Plan. 1995.

The Shoalwater Islands Marine Park comprises the coastal waters from Becher Point to the Garden Island causeway and encompasses Warnbro Sound. The *Shoalwater Islands Marine Park: Draft Management Plan* deals with management in the Park for purposes that include conservation, recreational, commercial, educational, research and scientific values. The commercial values include marine habitats that support a commercial fishing industry, of which mussel aquaculture is a part.

An objective of the Draft Management Plan is to allow aquaculture operations to the extent that they are compatible with the maintenance of other Park values. The Plan declares that the area within the Park available for aquaculture is limited due to the effect of mussel farming on recreational and other users; visual aspects of operations; seagrass bed disturbance; the ability to guarantee safe navigation; and the industry's processing and debris-disposal requirements.

Marmion Marine Park Management Plan 1992-2002. January 1992.

The *Marmion Marine Park Management Plan* recognises the Marmion Marine Park, which occupies about 9 500 ha of coastal waters between Trigg Island and Burns Rocks, as having outstanding conservation value. As a consequence of its location close to the metropolitan area and the increasing demand to access to the Park, a management plan was necessary to sustain biological resources and for other purposes defined in the document. Conservation, recreational, commercial and educational constraints were identified. A major part of the Management Plan was to implement a system of zones that permitted the defined management goals to be achieved. The framework included general use, recreation and sanctuary zones.

The Management Plan does not refer specifically to aquaculture: the Marine Park's commercial users are identified as fishing (rock lobster, abalone and beach seining) and concessions (fishing charter). However, the Plan is included here due to the potential the area has to support aquaculture-oriented activities that have minimal environmental impact and so are considered suited to the area, such as research.

3.1.10 The South Coast

Albany Harbours Planning Strategy. June 1997.

The stated primary goals of the *Albany Harbours Planning Strategy* are to provide: a clear and planned use of the waterways and related land-based activities; and a streamlined and simplified approvals process. To achieve these goals, the Strategy proposes a framework for the managed, multiple use of the Albany harbours in an environmentally-sustainable manner.

After identifying the range of existing and proposed uses of the harbours, with due consideration to the views of the community, stake holders and relevant authorities, the Strategy contemplates the division of the harbours into seven Policy Areas. These are multi-use marine conservation, conservation, aquaculture, port activities,

historical/cultural conservation, motorised active recreation and general purposes. After describing the background to the study and the public consultation process, the Strategy outlines: the conceptual planning framework; the vision, goals and objectives; the activities, policy areas and compatibilities; and policy areas. It then proposes an implementation model.

Aquaculture Management Strategy for Albany Harbours: First Draft. August 1996.

The *Aquaculture Management Strategy for Albany Harbours: First Draft* was produced to derive an equitable strategy for the management and development of aquaculture within the Albany harbours. Its other objectives include the maintenance of the ecological stability and genetic diversity within the harbours, the provision of a managed marine environment, the encouragement of widespread involvement in planning leases and the promotion of regional economic growth generally. The Strategy comprises three main parts, entitled: *Aquaculture Development in Albany Harbours*; *Aquaculture Management Strategy*; and *Implementation*.

The first part describes the Albany harbours and the aquaculture activities they currently support and provides an overview of aquaculture management requirements and processes. A brief description of species considered suitable for the area is followed by an outline of the main features of the aquaculture strategy, which is based on zoning. The second part describes the main features of and aquaculture development within each of the eight identified aquaculture zones and concludes with a summary of the relevant lease conditions. The features described for each zone include location, environmental conditions, aquaculture history, existing uses, restrictions, impacts and potential. Part three provides a brief overview of issues related to the administration of the proposed aquaculture strategy.

Bremer Bay Coast Aquaculture Feasibility Study. August 1996.

The *Bremer Bay Coast Aquaculture Feasibility Study* documents a strategic planning exercise carried out to determine opportunities and constraints for the development of marine and fresh water aquaculture in the vicinity of Bremer Bay in the Jerramungup Shire. It provides various selection criteria for aquaculture and, among other relevant issues, considers environmental impacts; land tenure, planning, social and legislative issues and requirements; economic factors; and infrastructure needs.

The Study identifies and evaluates various onshore marine and fresh-water sites for commercial aquaculture and provides recommendations on suitable species and compatible production systems. After describing the physical and social environment in the Bremer Bay area and assessing several sites considered to have some potential for marine and fresh-water aquaculture, the Study summarises opportunities and constraints for aquaculture development in the Shire.

3.1.11 The Eucla Coast

No planning studies with relevance to aquaculture have been identified for the Eucla Coast.

3.1.12 Inland Regions

Summary Report of the Freshwater Aquaculture Task Force. April 1996.

The Freshwater Aquaculture Task Force was formed to assist the development of aquaculture in the south-west of Western Australia. Its objective was to develop a strategic plan, which would include identification of suitable land and water areas and a climatic risk assessment, to assist the development of aquaculture within the South-West Land Division.

The *Summary Report of the Freshwater Aquaculture Task Force*, which is the first of several related documents, lists the recommendations considered necessary by the Task Force for its objectives to be achieved. A second document proposes a programme for implementing the recommendations and allocates responsibilities. Two additional works commissioned by the Freshwater Aquaculture Task Force have been produced, entitled: *An Overview of the Issues Involved in the Integration of Marron Farming on to Terrestrial Farms in the Southwest Irrigation Area*; and *A Financial Analysis of a Semi-Intensive Marron Farm*.

Bremer Bay Groundwater Protection Plan. June 1995.

The *Bremer Bay Groundwater Protection Plan* was prepared to promote discussion about water quality issues in the Bremer Bay Water Reserve. The need to protect the Bremer Bay ground water resource from contamination is an important issue because he water supply for the town is drawn from a well field. A purpose of the Plan is to identify areas where future developments may occur within the Water Reserve that will not risk the quality of water in the aquifer.

The Plan describes a priority classification system that is used as a basis for describing acceptable and unacceptable land uses. It considers commercial aquaculture (excluding that in farm dams) as an unacceptable land use in priority-one areas, which are the most important for public water supplies; however, it fails to mention aquaculture as being either acceptable or unacceptable for the other priority-two and priority-three areas.

3.2 Current and Proposed Studies

Several planning strategies with some specific relevance to aquaculture in Western Australia are either in the process of being carried out by various consultants or Government agencies or are being proposed. These are listed below, together with a brief outline of the objectives (or proposed objectives) of each study.

Review of the Marine Farm Planning and Consultation Process for the Fisheries Department of Western Australia.

The Review of the Marine Farm Planning and Consultation Process is currently being carried out by Everall Consulting Biologist. The purpose of the study is to review the existing planning and consultation processes for pearling and aquaculture in Western

Australia; recommend how they may be improved and incorporated into a single process; and advise on an appropriate mechanism for incorporating the aquaculture industry's requirements into the marine park planning process.

Research of WA Aquaculture Priorities.

The Research of WA Aquaculture Priorities study was commissioned by WADoT, which has identified and targeted the emerging aquaculture industry for skills research. The study is aimed towards developing medium to long-term directions and priorities for training delivery and provide input to the State Training Strategy currently being determined by WADoT. The terms of reference elucidate the need for a coordinated approach to aquaculture industry development in Western Australia.

The principal objective of the research is described as obtaining input from key industry stake holders to identify priorities and opportunities for aquaculture training, research and development facilities within Western Australia. WADoT anticipates that the final report would identify aquaculture development priorities and opportunities according to the defined objectives; describe the factors that may influence the establishment of training and other aquaculture facilities; and provide recommendations concerning their location and the pertinent training, research and development programmes.

Review of WA Coastal and Estuarine Waters Productivity Levels for Mariculture Planning Purposes.

Knowledge of the productivity of coastal waters is important for properly locating aquaculture activities such as mussel and oyster farming. Western Australian coastal waters are generally characterised by low productivity; however, localised productivity does occur in areas with significant terrestrial run-off or industrial nutrient input.

While information about the productivity of Western Australian coastal waters has been collected, no overview is available in a form that assists the developing aquaculture industry. This study proposes to collate the available information; provide an overview of chlorophyll levels for coastal waters; compile the available chlorophyll data for key identified sites; provide an atlas of chlorophyll levels; and provide a reference list of data sources and their status for further analysis if required.

A Review of Aquaculture Candidate Species (Fisheries Department of Western Australia).

The Review of Aquaculture Candidate Species is a manuscript in preparation by Dr J. Penn and Mr C. Lawrence of FDWA. The purpose of the document is to provide a database of information about species considered suitable for aquaculture in Western Australia. It also includes other information relevant to aquaculture, such as coastal maps, temperatures, salinities, productivity and frequency of cyclones.

Jurien Bay Habitat Mapping Study.

The Jurien Bay Habitat Mapping Study is being carried out by FDWA in conjunction with industry. The purpose of the exercise is to generate data that can be used in a submission to the Marine Parks Committee in relation to aquaculture in the Marine Park.

Planning for Environmental Management in the Pilbara: The North-West Shelf Marine Environmental Management Study.

As a result of the significant industrial and commercial development that is expected to take place in the Pilbara Region of Western Australia, the DEP is seeking to put an environmental infrastructure in place that will permit a timely response to the various applications that are anticipated. The DEP is currently dealing with four major components in planning for environmental management in the Pilbara, one of which is the initiation of a marine environmental management study of the North-West Shelf region.

The study anticipates rapid growth in marine-based industry sectors. It refers in particular to aquaculture and expresses the need for development to take place within an integrated, ecologically-based management framework. Designed to deal with two spatial scales (a broad regional scale encompassing the continental shelf between Port Hedland and the North-West Cape and a smaller scale, centred on identified key development nodes), the broad goals of the study are to contribute to the ecologically-sustainable development of marine-related industries and the management of multiple use in the region. More specific study goals are to ensure that an effective environmental management framework is developed for the area and that adequate environmental data are available to support decision-making and assist strategic planning for environmental protection and sustainable development.

Development of an Atlas of WA Ground Water Resources that may be Suitable for Aquaculture Purposes.

The proposed study entitled *Development of an Atlas of WA Ground Water Resources that may be Suitable for Aquaculture Purposes* is at an early formulation stage and has not yet been submitted for funding. The preliminary proposal recognises that Western Australia has significant ground water reserves that could constitute an important resource for aquaculture development in inland areas. It further recognises that a significant amount of data already exists about the quantity and quality of ground water in many areas of the State.

In its current form, the study has as its principal objective the collation and review of data with a view to identifying any ground water reserves in the State that could support aquaculture development. It would also aim to recommend the species that may be best suited for development in specific areas using identified water sources of known quality.

Further, many inland areas of the State with access to ground water reserves are characterised by having no permanent surface water and being isolated from other drainage basins. The study proposal identifies this situation as an opportunity to develop aquaculture ventures that use these resources to commercially produce non-native species that have known culture technologies and are characterised either by high value or low production costs.

3.3 Review of WA Aquaculture Planning Studies

The following review of the planning studies is carried out according to the categories into which the various studies have been placed in section 3.1 above. Since no planning studies with relevance to aquaculture were identified for the Canning Coast, Eighty Mile Beach and the Eucla Coast, these regions have been excluded from this section.

3.3.1 Western Australia

The *National Strategy on Aquaculture in Australia* (1994) is broadly compatible with the planning studies carried out for aquaculture development in Western Australia. *Aquaculture: Development Strategies for the Industry in Western Australia* (1994) essentially recapitulates the key issues provided in the national strategy document and provides numerous other recommendations with specific reference to aquaculture industry development in Western Australia.

The 10 reasonably-generic key issues identified in the former document are:
i. developing a professional industry structure and organisation;
ii. establishing a co-operative relationship between aquaculture and the wild-capture fishery;
iii. providing a co-ordinated government framework to support industry development;
iv. planning environmental management to ensure aquaculture development is sustainable;
v. planning water and land use to ensure allocations are equitable;
vi. providing research and development to meet the needs of industry and the market place;
vii. developing market intelligence and ensuring industry is in tune with market requirements;
viii. providing an appropriate level of education and training;
ix. providing effective extension services to industry; and
x. developing and implementing suitable quarantine and movement controls.

Documents such as the *State Planning Strategy* (1996), the *Review of Coastal Management in Western Australia* (1994); the *Final Report of the Review of Coastal Management in Western Australia* (1995) and the *Interdepartmental Submission by the Coastal Management Co-Ordinating Committee, Other Departments and Agencies to the Resource Assessment Commission Inquiry into Coastal Zone Management* (1992) provide information about the legislative framework, particularly that of relevance to coastal areas, within which the aquaculture industry needs to work. They identify key agencies and place emphasis on the need for planning to ensure that the State's resources are used in a sustainable and equitable manner. A paradigm is evident in these and many other planning documents in that they are relevant to aquaculture but rarely mention the industry or include it in the planning processes; however, this is mainly true of the older documents and the more recent studies refer increasingly to aquaculture. A current study, the *Review of the Marine Farm Planning and Consultation Process for the Fisheries Department of Western Australia*, refers specifically to aquaculture and, among its other objectives, aims to review the existing planning and consultation processes for aquaculture in Western Australia. Given the increasing importance and recognition of aquaculture in coastal and inland areas, it is anticipated that few future planning documents will ignore the industry.

The coastal studies carried out by CALM are consequential for aquaculture in Western Australia. The *Representative Marine Reserve System for Western Australia* (1994), while not a statement of Government policy, promulgated the *New Horizons in Marine Management*

(1994) document, which deals with the establishment of a marine conservation reserves system. The documents have positive implications for aquaculture industry development since they make specific provision for commercial aquaculture in Marine Parks (Special Purpose Zones and General Use Zones) and Marine Management Areas, subject to the compatibility of aquaculture with conservation and the Acts under which the areas are administered. The *Marine Reserve Implementation Programme* that ensued from the *New Horizons* document aims to generate information that will be used to assess the likely impacts of aquaculture in marine reserves and define the zones accordingly. Studies have since been carried out on the Central West coast and in the vicinity of Jurien (section 3.3.6).

The establishment of Marine Nature Reserves, Marine Parks and Marine Management Areas and the ensuing Marine Reserves Implementation Programmes could be perceived as an obstacle to aquaculture development; however, a more positive, longer-term perspective is that they will benefit the industry for two principal reasons. Firstly, the aim of the system is to conserve and ensure the equitable and sustainable use of resources. This objective is consistent with the long-term success of legitimate aquaculture operations, which essentially comprise a part of the whole ecosystem whether they are undertaken in onshore or offshore production systems. Accordingly, the maintenance of a healthy ecosystem has positive production and marketing implications for aquaculture development. Secondly, most *bona fide* investors and aquaculturists would be prepared to accept additional costs and restrictions, provided that they are rational, spread across the board and the rules are both pre-determined and adhered to, so they can be included and provided for in analyses of investment feasibility. The marine reserves system aims to eliminate or reduce uncertainty, which is currently considered a significant impediment to investment in aquaculture.

The *Marine Resources Map of Western Australia* (1986), *Selected Bibliography of Marine and Estuarine Studies* (1985) and *Bibliography of Physical Oceanography* (1983) are useful documents in that they provide a significant amount of information and information sources useful for assessing technical aspects of aquaculture development in Western Australia.

3.3.2 The Kimberley Coast

The *Kimberley Aquaculture Development Plan* (1996) constitutes a reasonably comprehensive planning document for aquaculture development in the Kimberley Coast Region. The *Nature Conservation Reserves in the Kimberley* (1991) document provides information about conservation issues and values that need to be taken into account when planning aquaculture development. While both the above documents consider the entire Kimberley Region, they deal with the coastal areas and offshore islands separately: this study considers the offshore islands as a part of the Kimberley Coast Region.

Following the publication of the Plan, the Kimberley Aquaculture Development Group was established to act on the vision created by the document, oversee and guide the development of the aquaculture industry in the Kimberley Region and to steer and review the implementation of the Plan. A key recommendation of the Plan is to identify a limited number of specific sites and, for each site, identify compatible species and production technologies. Aquaculture development resources and efforts may then be focused on these selected sites and species.

The aquaculture management zones identified in the Plan that occur within the Kimberley Coast as it is defined in this study are the coastal and offshore zones and coastal areas of the Dampier Peninsula. The Tropical Aquaculture Park has recently been established in Broome, in the Dampier Peninsula. The Plan also includes the Canning Coast in the Dampier Peninsula Zone; however, it anticipates no significant aquaculture development in this area.

3.3.3 The Pilbara Coast

The Pilbara Coast Region is an area in which planning for pearling and aquaculture is currently active, particularly in the Dampier Archipelago.

A relatively large amount of information is available about the marine environment of the Dampier Archipelago as a result of studies carried out by the petroleum industry. Planning studies such as the *Pilbara/Gascoyne Islands Ecotourism Management Strategy* (1995) and *Karratha Area Development Strategy* (1997) provide for the anticipated growth of various industries and activities in the area while recognising the potential for conflict between users competing for scarce resources.

A study proposed by DEP, *Planning for Environmental Management in the Pilbara: The North-West Shelf Marine Environmental Management Study*, will cater for future development in the Pilbara from an environmental perspective by ensuring that future and current activities are environmentally sustainable.

Other planning studies have been commissioned to deal with issues such as policy guideline and strategy development and to enable public comment on existing and proposed pearling and aquaculture activities in the area. The first planning study to deal with these issues was the Driscoll Report (1996). One of the recommendations contained in the Driscoll Report resulted in the publication of the Fisheries management paper *Pearling and Aquaculture in the Dampier Archipelago: Existing and Proposed Operations* (1966). A study currently being carried out, *Review of the Marine Farm Planning and Consultation Process for the Fisheries Department of Western Australia*, is likely to provide additional input to aquaculture planning and development in the Pilbara Coast.

Due to the existing conflict between resource users and the potential for the conflict to be exacerbated, a moratorium has been placed on the issue of new aquaculture licences and leases until the current study has been completed.

According to the geomorphological divisions adopted in this study, the eastern coast of the North-West Cape and Exmouth Gulf comprise the southern end of the Pilbara Coast. The *Gascoyne Region Economic Development Strategy* (1996) and *Gascoyne Aquaculture Development Plan* (1996) provide clear planning strategies for aquaculture development in the area described as the Exmouth Gulf Zone. The Plan identifies several potential aquaculture sites along the southern and western shores of the Gulf. The Shire of Exmouth has adopted a planning policy (Planning Policy No. 5: Aquaculture) specifically for aquaculture: one of the Shire's stated objectives is to encourage the introduction of aquaculture uses to the area subject to the maintenance of the relevant planning principles and environmental standards.

3.3.4 The Ningaloo Coast

The planning studies dealing exclusively with areas within the Ningaloo Coast Region are the *Coral Bay Draft Coastal Management Plan* (1984) and the *Coral Bay Planning Strategy* (1992). These planning documents emphasise the high conservation value of the area and are significant in that they generally preclude aquaculture development other than low-impact activities.[6]

In the section of the *Gascoyne Aquaculture Development Plan* (1996) that deals with the Ningaloo Coast Region, the level of potential for aquaculture development from Point Murat on the North-West Cape southwards to Point Quobba is considered low to zero.

3.3.5 The Shark Bay Coast

The Shark Bay Coast Region includes the Shark Bay World Heritage area and, as would be expected, many of the planning studies undertaken in the area deal principally with conservation issues. Various Government departments including FDWA and CALM have management responsibilities in the area. The *Monkey Mia Reserve Draft Management Plan* (1993), the *Shark Bay World Heritage Area Draft Management Plan for Fish Resources* (1994) and the *Shark Bay Regional Strategy* (1996) provide policies and strategies for the joint management of Shark Bay and identify planning and environmental issues, particularly in respect of the development of activities such as aquaculture.

The *Draft Management Plan for Fish Resources* document recommends that aquaculture projects may be permitted in all areas of the World Heritage Area but not in Recreation and Sanctuary Zones in the Marine Park; the Hamelin Pool Nature Reserve; and the Recreational Fishing and Reef Observation Areas in the proposed Fish Habitat Protection Areas. This recommendation is consistent with the *Gascoyne Aquaculture Development Plan* (1996), which identifies potential aquaculture sites at Monkey Mia, Denham and Useless Loop and considers Dirk Hartog Island and its eastern shoreline to have very high aquaculture potential.

The *Shark Bay Aquaculture: Community Consultation* (1997) study provides submissions from the various groups consulted about the impact that they perceived aquaculture may have in the area and the locations they considered suitable for aquaculture development. The views expressed were wide-ranging and generally did not oppose aquaculture development in the area, subject to various provisions in relation to environmental protection and avoiding conflict with professional and recreational fishers. The consultant proposes that the study be used as a guide only. This view is commended for two main reasons: firstly, the basis on which the participants identified areas suitable for aquaculture development was not defined; and secondly, the document does not make the important point that aquaculture should be recognised as a legitimate user of the resources.

3.3.6 The Central West Coast

[6] It is worth noting that a strong argument could be made that a well-regulated aquaculture operation may have less impact on the environment than some tourist-oriented and recreational activities; in fact, some aquaculture activities could be environmentally neutral or positive..

None of the planning studies that deal with the Abrolhos Islands off the Central West Coast Region refer to aquaculture; however, the industry may be considered a legitimate user of the resources and there is provision in the *Abrolhos Islands Aquatic Reserve: Final Report* (1993) for future aquaculture development under appropriate conditions.

The Marine Reserve Implementation Programmes being undertaken by CALM constitute an outcome of the earlier Wilson Report and the subsequent *New Horizons in Marine Management* document, which aim to establish, in coastal areas, conservation reserves representative of the flora, fauna and habitats in Western Australia. The objectives of the *Marine Reserve Implementation Programmes* include the generation of quantitative data that will be used to delineate the various management zones within the Marine Park. The outcomes of these studies have clear implications for future aquaculture development, since aquaculture will only be permitted under certain conditions in Special Purpose Zones and General Use Zones of Marine Parks. The current *Jurien Bay Habitat Mapping Study* is being undertaken to provide the data necessary for a submission in relation to aquaculture in the vicinity of Jurien.

The *Technical Evaluation of Sites for Land-Based Aquaculture in the Mid-West Region* (1997) and the *Dandaragan Aquaculture Planning Strategy* (1995) are significant planning documents for aquaculture development in the Central West Coast. The latter study provides general information about aquaculture prospects in coastal areas of the Dandaragan Shire; opportunities and constraints for marine aquaculture development; potential species and sites; marketing and development strategies. The former study goes one stage beyond many fundamental planning studies for aquaculture: it may be considered a precursor to commercial development in that it evaluates several specific sites for their aquaculture potential and discusses species and production systems that are considered compatible with the optimum sites.

3.3.7 The Leeuwin-Naturaliste Coast

Due to its inclusion of the Perth metropolitan area, the Leeuwin-Naturaliste Coast Region is characterised by many planning studies; however, few of these deal with aquaculture. From existing studies it is apparent that any establishment of new aquaculture operations or the expansion of existing ones would be subject to the relevant provisions and recommendations contained in studies such as the *Shoalwater Islands Marine Park: Draft Management Plan* (1995) and the *Marmion Marine Park Management Plan* (1992). The *Southern Metropolitan Coastal Waters Study* (1996) provides a basis for the future management of coastal waters and their use by industries such as aquaculture.

3.3.8 The South Coast

Aquaculture-oriented planning studies in the South Coast Region are principally restricted to the areas in the vicinities of Albany and Bremer Bay.

The Albany harbours already support a significant aquaculture industry. Some conflict has arisen in the area as a consequence of the use scarce or limited resources by various groups. The *Aquaculture Management Strategy for Albany Harbours: First Draft* (1996),

commissioned to minimise conflict between user groups, aims to establish an equitable aquaculture management strategy. The management document that ensued from the draft, the *Albany Harbours Planning Strategy*, furnishes a conceptual planning framework that, for aquaculture development, aims to "provide for the ecologically-sustainable development of an aquaculture industry within the (Albany) harbours".

While the area currently supports no coastal aquaculture operations, the prospects of commercial aquaculture development in the Bremer Bay area appear encouraging. The *Bremer Bay Coast Aquaculture Feasibility Study* (1996) identifies several sites considered suitable for commercial aquaculture, principally using onshore production systems, and identifies suitable species and discusses other aspects of aquaculture development. Characterised by very-high-quality sea water close to shore, the area has significant infrastructure and other attributes.

3.3.9 Inland Regions

Other than the *Summary Report of the Freshwater Aquaculture Task Force* (1996) and the *Bremer Bay Groundwater Protection Plan* (1995), there exist few planning studies that deal exclusively with inland regions and that have specific relevance to aquaculture; however, several studies cited under coastal regions above were undertaken over wide areas that include inland regions. Principally, these are the *Kimberley Aquaculture Development Plan* (1966), the *Gascoyne Aquaculture Development Plan* (1966), the *Dandaragan Aquaculture Planning Strategy* (1995) and the *Bremer Bay Coast Aquaculture Feasibility Study* (1996).

Due to its very large quantities of permanent, high-quality surface water and temperatures highly conducive to aquaculture, the Leichardtian Region probably has more potential for inland aquaculture development than any other area in Western Australia. Planning for aquaculture development in the region is mainly encompassed in the *Kimberley Aquaculture Development Plan*, which identifies Lake Argyle as being capable of supporting a major aquaculture industry. Other planning strategies relevant to inland aquaculture using surface water that are outlined in the Plan deal with the Ord River Irrigation Area, which principally comprises Lake Kununurra and the irrigation channels.

Planning for inland aquaculture using surface water in the Greyian Region is dealt with in the *Gascoyne Aquaculture Development Plan*, which identifies two inland aquaculture management zones within the region: the Horticulture-Carnarvon Zone and the Pastoral Zone. Both these areas are characterised by having no permanent surface water, so any aquaculture development would be dependent upon ground water reserves.

Inland aquaculture using surface water in the Vlaminghian Region is predominantly associated with the production of fresh water species such as rainbow trout, marron and yabbies. The planning studies for this region establish site selection criteria and identify a range of sites considered suitable for fresh water aquaculture; the Dandaragan Aquaculture Planning Strategy outlines a fresh water aquaculture planning strategy that deals with issues such as suitable species, environmental sustainability, training, marketing and research. The documents provide useful background information; however, as they stand, the various recommendations are considered unlikely to provide further benefit to the developing industry unless they are acted upon or implemented.

Throughout the inland regions of Western Australia there exist ground water reserves that may be considered significant in terms of aquaculture development. The qualities and quantities of these waters vary in terms of possible abstraction rates, temperature, salinity and other physical and chemical parameters. A large amount of information is currently available in relation to the quantity and quality of the water in ground water reserves in many different parts of Western Australia; however, these data have not yet been collated in a form that is of use to aquaculture planning. A study is currently being proposed that will collate and assess the relevant data. The respective Aquaculture Development Plans for the Kimberley and Gascoyne Regions (which comprise the Leichardtian and Greyian Regions respectively) identify several sites considered suitable for fresh water aquaculture and propose planning strategies for the development of these resources. The aquaculture potential of ground water reserves in the Greyian region is currently being evaluated by way of a pilot aquaculture project.

4 WA AQUACULTURE SITES AND SELECTION CRITERIA

4.1 Classification of Sites

For the purpose of this study, three categories of sites are considered within each of the identified regions. these sites are described as:

- existing and proposed (sites on which aquaculture is currently being carried out under an aquaculture licence and those on which aquaculture is proposed under a current application);
- potential (sites identified in existing aquaculture planning documents as having some potential for aquaculture and that are not considered sensitive); and
- sensitive or prohibited (sites that may have aquaculture potential but that are characterised by some environmental, social or other sensitivity and sites considered "no-go" areas, such as navigation channels and Marine Nature Reserves).

The sites considered to have some potential for aquaculture are generally identified and assessed according to a set of "fundamental" selection criteria. These criteria will identify sites (and associated species) considered to have good aquaculture potential: for planning purposes, it is logical to focus first on those sites.

4.2 Site Selection Criteria

The selection of a suitable site is of critical importance for successful aquaculture: finfish and shellfish production is both influenced and constrained by physical, biological and other characteristics of the site. Any potential aquaculture site can be characterised by a series of factors or site selection criteria, which may be categorised according to their relative importance.[7] The cost of solving the problems associated with less favourable or unsuitable conditions and the inherent risks are important considerations when evaluating site features. When assessing potential sites, an aquaculture proponent usually needs to distinguish between critical factors (that is, those that must be satisfied for the project to succeed) and less important factors. Sites with good potential for aquaculture are usually distinguished by being able to satisfy the fundamental biological requirements of the species, particularly its water quality needs, and by having viable, economic solutions for less favourable or unsuitable features.

Because there is a definite relationship between site features and project costs, different site features and parameters can have varying effects on an aquaculture operation: these should be evaluated in a feasibility study, which can indicate the relative effects of different parameters and hence allocate site selection priorities. For example, under favourable biological conditions, some physical site deficiencies may be acceptable; however, good physical site conditions may not compensate for poor biological or environmental conditions.

[7] The importance of different site selection criteria varies according to the features of a given site; for example, in the Kimberley Region hydrology becomes significant for coastal aquaculture operations as a result of the extreme tidal ranges and currents.

In aquaculture, trade-offs usually exist between various elements of capital and operating costs. It is often difficult to define absolute values for specific site features, as there may be cases where higher yields or more intensive production can offset additional capital and operating costs. However, these improved yields or production levels need to be defined if sites with below-optimum features are being contemplated for aquaculture.

The major site selection criteria for commercial aquaculture encompass certain physical, biological, economic, social and legal factors. These are discussed in more detail below.

4.2.1 Physical Features

Location

The physical location of an aquaculture site may be either onshore (land-based) or offshore (water-based). Onshore locations may be coastal or inland and offshore locations divided into nearshore and open ocean or, in the case of large lakes, open water. Where a certain species has already been chosen for aquaculture, the selection of a suitable site would be governed by the biological and other requirements of the species and by the requisite production system. Alternatively, where a specific site has been selected for aquaculture, the physical and biological features of that site would determine the species and production systems most suitable for the site's location.

Topography

The topography of a site includes its size and shape as well as its general configuration, features and elevation above mean sea level (or, for inland systems, its gradient) to permit efficient and cost-effective water supply systems and water discharge by gravity. Consideration of a site's topography should also include its proximity to the shoreline or water source and exposure.

Because it can significantly influence development and operating costs, topography is an important determinant of site suitability. Land with a fairly even surface is usually better suited for development. The shape and size of a proposed site can govern its suitability to accommodate proposed operations and their future expansion: if it is difficult to arrange or orient various facilities, infrastructure and equipment, such as buildings and tanks, in relation to each other, the overall operational efficiency of an aquaculture enterprise can be affected.

Hydrology

Fundamentally, site hydrology refers to the properties of the water supply and its movement. Consequently, for offshore and onshore production systems, hydrology includes factors such as water movement, the depth of water close to shore, the nature and stability of the sea bed and sediments and sustainable water flow rates.

For offshore and onshore aquaculture sites in coastal areas, the tidal range, wave action and range and characteristics of tidal and other currents can be critical. These factors are particularly significant in the Kimberley, which is renowned for its extreme tidal range and the occurrence of major tidal streams and currents.

Water Supply and Discharge

Aquaculture is usually water-intensive; the quantity of water available and the various methods of its economical supply and discharge need to be examined critically and in detail when selecting a site.[8] Water quantity and quality are the most important features in any aquaculture operation and these factors are therefore critical determinants of site suitability and selection (water quality is dealt with in the assessment of biological features in section 4.4.2).

Water can be obtained from a variety of sources, the two most common of which are subterranean or ground water (including salt water intrusions) and surface water. Ground water may be extracted through wells; usually high in quality, it can be more dependable than surface water. Generally free from aquatic organisms, parasites and predators, ground water is often less polluted than surface water and its temperature less variable. Within the context of site selection, the construction cost of ground-water or beach wells and the water pumping costs are the principal factors that govern the economy and viability of this water source.[9] Flowing artesian wells and springs can also be used for aquaculture. Surface water sources include rivers, lakes, estuaries and the ocean. Site selection considerations include pumping needs; fouling of supply and discharge lines; the presence of wild fish, parasites and predators; and the potential for contamination of the water source.

Water supply and discharge costs can have a significant impact on capital and operating costs, with scale having an important influence; pumped water supplies to easily-constructed and efficient sites may be more viable than tidal systems where earthmoving and other costs are high. One of the fundamental processes for aquaculture site selection is therefore the consideration of water. The relevant factors are the definition of the water source, the quantity of water available and the determination of an economic and efficient supply and discharge system.

The ability to establish a supply and discharge system that will satisfy the water requirements of a proposed aquaculture operation is partly governed by site features. A wide variety of water supply and discharge systems is currently used by aquaculture operations. Fresh-water systems using surface water usually locate their intakes near the surface of the supply, to use the oxygen-rich, surface water and limit the intake of floating debris and pollutants. The most common sea-water intakes are from marine systems and beach wells. Marine intake and discharge structures can deliver large quantities of water but are usually the most difficult and expensive to establish: wind and wave action can exert considerable forces and destroy poorly-located or designed structures. Marine intakes can include offshore sea-water wells and submerged intakes that protrude above the sea bed. Onshore beach wells can be used to extract sea water from salt water intrusions. The performance of beach wells is governed by the permeability of the underlying rock or sand, so the determination and evaluation of these factors forms a component of site selection studies.

[8] The quantity of water needed for aquaculture is governed by factors such as the production system, the species being cultured, management practices, stock densities and loading.

[9] In the case of salt water intrusions, the quality of the sea water and the rate at which it can be extracted are governed by site conditions such as the geology of the water-bearing strata. Beach wells can provide clean, highly-filtered sea water for marine aquaculture at construction and operating costs that can be significantly lower than those of open marine intake systems.

Soil and Vegetation

Surface and sub-surface soil characteristics (edaphic features) are important site-selection determinants when semi-intensive ponds are to be constructed, but less critical where the proposed production system is more intensive and relies on tanks or raceways for growout.

The nature and extent of the local vegetation also governs site suitability; in addition to providing an indication of soil type and water table depth, sites vegetated by low shrubs and grass are preferred to dense vegetation and forests since they are easier and less expensive to clear.

Climate

Meteorological information can help determine site suitability. Knowledge of wind direction and strength, average monthly air temperatures, rainfall, evaporation, humidity and storm and flooding events assists in the site selection process. These factors are less important for intensive production systems.

4.2.2 Biological Features

Water Quality

Water quality is often the single most important factor that governs the ultimate success of aquaculture and hence is a critical site selection criterion. A comprehensive analysis of the physio-chemical and biological parameters that define water quality needs to be carried out at an early stage of site evaluation. The relevant parameters include temperature, salinity, turbidity and various chemical variables.

Water temperature, expressed as degrees Centigrade (°C), is a critical environmental variable that affects aquaculture. It affects growth rate and influences parameters such as oxygen solubility, food conversion efficiency and fish health, so may be considered a major factor influencing the commercial viability of an aquaculture operation and hence site selection. The water temperature characteristic of a potential aquaculture site should be suitable for the species being considered for culture and within the desired range for the growing season.[10]

Salinity, expressed as either grams per litre (g/L) or parts per thousand (ppt), can vary from zero in fresh water to above 300 g/L in hypersaline water. Waters can be roughly classified according to their salinity.[11] As with temperature, each species is characterised by having optimum and maximum salinity ranges, so the salinity of the water at a given site will govern the selection of species suited for that site. Alternatively, the salinity requirements of a species already selected for aquaculture will be an important determinant of site selection.

[10] The growing season is defined by the period during the year that allows the production of a market-sized fish within a reasonable time. As such, a growing season for a particular species may extend over more than one year.

[11] The terms *fresh*, *brackish*, *sea* (or *marine*) and *hypersaline* generally refer to waters with salinities of <2, 2-32, 32-38 and >38 g/L respectively. The salinities of inland waters in areas with high rainfall are usually low; those of waters in arid areas often higher. The salinity of sea water is usually between 33-36g/L, with an average of 35 g/L, while that of salt lakes can exceed 300 g/L.

Turbidity, which results from dissolved and suspended substances in the water, measures water clarity using a secchi disk or various meters that measure the straight-line path or scattering of light in water. Usually a less-important site-selection criterion, turbidity can assume importance where species are being considered for culture outside their natural range; for example, the high turbidity of coastal waters in parts of the Kimberley may preclude the aquaculture of some pelagic or reef species more accustomed to oceanic-quality water.

Chemical variables that need consideration when evaluating the water-quality parameters of any proposed aquaculture site include dissolved oxygen, pH, carbon dioxide, nitrogenous compounds, hydrogen sulphide, heavy metals and pesticides.

Dissolved oxygen is a critical parameter (it and temperature may be considered the dominant variables in aquaculture production systems); however, for site selection purposes it is seldom a limiting factor. The pH of water expresses the intensity of its acidity or alkalinity; the preferred pH for most species is within the range 6.5-8.5 and this variable is seldom a limiting factor in site selection. Similarly, high carbon dioxide concentrations are uncommon, particularly in surface waters, and this variable is rarely a limiting factor for aquaculture. Nitrogenous compounds of concern in aquaculture systems are principally un-ionised ammonia (NH_3) and ionised ammonia or ammonium (NH_4^+).[12] In general, ammonia and ammonium are not limiting factors in site selection processes where surface waters are used; they may occur in some cases, however, and their concentrations should be determined. Hydrogen sulphide, heavy metals and pesticides can be toxic to fish and so severely limit aquaculture; their presence and concentrations are important determinants of site suitability.

Environmental Factors

The use of suitable site-selection criteria can reduce potentially-adverse effects of aquaculture on the environment as well as those of the environment on aquaculture. Aquaculture systems are almost invariably an integral part of the environment: flow-through, onshore aquaculture systems generally drain into and so can affect rivers, lakes and coastal areas, while offshore marine systems such as sea cages can affect coastal and oceanic areas.

Inland aquaculture can impact on the environment principally in terms of demand for resources (such as land use, water use and seed requirements) and waste outputs (such as uneaten food, faecal and soluble excretory products and chemicals and drugs). Coastal and offshore aquaculture can have negative impacts on the environment by destroying wetlands, increasing nutrient loads, increasing toxicity and antibiotic resistance, diminishing environmental biodiversity and having adverse socio-economic and health implications.

Site selection should include consideration of the positive and negative impacts that aquaculture may have on the environment: in many cases, ongoing environmental monitoring may be mandatory to the approval and licensing of a proposed aquaculture venture.

[12] Ammonia in aquatic systems results principally from normal metabolic processes and the decay of organic matter that contains nitrogen. It exists in two states: un-ionised and ionised, which are commonly referred to as *ammonia* and *ammonium* respectively. In solution, these two substances occur in an equilibrium that is shifted according to several factors, the most dominant of which is pH. Ammonia is extremely toxic to fish, while ammonium is not.

Pollution and Contamination

Any site selection investigations should consider the risk to the aquaculture project from existing and possible future sources of pollution and contamination. It is important to identify the presence and proximity of any pollution sources and gather available information about development plans and biological or industrial events, such as fish kills or oil spills. Details about the previous usage and history of the site should be sought, particularly in relation to any previous use of pesticides and herbicides, which are extremely toxic to aquatic life in very small concentrations. Consideration should be given to not only the effect a polluted environment may have on the proposed aquaculture enterprise, but also the pollutive effects the aquaculture operation may have on the environment.

Parasites and Predators

Aquatic protozoan or metazoan parasites can seriously threaten aquaculture operations; unfortunately, it can be very difficult to identify and evaluate potential threats from these sources as part of a site selection process. While some parasites that could pose a risk to aquaculture may be evident, the threat posed by other potential parasites often only becomes apparent after the farm is established. Fish kills and previous pathological studies carried out on local wild fish can be used to indicate potential pathogens.

Predators include fish and other aquatic species that may be introduced to the production system through its water intake, as well as predatory birds, reptiles and mammals. The occurrence and abundance of potential predators in the vicinity of a site needs to be estimated and methods for their control determined.

4.2.3 Economic Factors

Infrastructure and Services

The infrastructure of an aquaculture operation describes the installations, equipment and services required for production and related activities. Infrastructure costs usually constitute a significant component of the capital costs of an aquaculture operation and so constitute an important site selection criterion.

Buildings that already exist and that can be used as a hatchery, store room or office may increase the value and potential of a proposed aquaculture site. Similarly, existing roads within and leading to a proposed site generally add to its value, particularly if they are sealed and in good condition. The availability, installation cost and supply cost of services such as suitable transformers, electrical power, potable water, telephone lines, sewerage and security services are also important determinants of site suitability. Unless they are already available or in close proximity to a site under consideration for aquaculture, the cost of providing certain essential services to the site may be prohibitive.

Key trades needed during the construction and operational stages include electricians, plumbers and builders: the availability and proximity of qualified trades persons are significant site-selection factors.

Labour

Staff with the requisite biological and management skills are generally essential to ensure the success of aquaculture operations. Some aquaculture operations need only semi-skilled and unskilled labour, while others need highly-skilled and experienced staff: the availability of the requisite skilled, semi-skilled and unskilled labour is an important determinant of site suitability, as is the availability of various levels of training courses that may be provided by local or regional institutions.

Feed and Raw Materials

For hatchery and growout operations, most aquaculture projects use a variety of feeds, most of which are acquired from external sources and comprise a significant portion of total operating costs, particularly in intensive operations. The availability and quality of feeds and other essential raw materials required for the operation of an aquaculture venture are significant determinants of site suitability, particularly in some of the more remote regions of Western Australia for which the proximity of reliable feed suppliers assumes increasing importance.

Hatchery feeds are usually significantly more expensive per unit weight than growout feeds, but smaller quantities are required. For hatchery feeds, the proximity of the supplier is therefore less critical. Growout feeds can be expensive to purchase and transport to a remote site (commercial growout operations can use hundreds of tonnes of pellets each year). The proximity of a proposed site to a reliable source of growout pellets is therefore an important consideration when evaluating a potential site.

This site selection criterion is clearly governed by the type of aquaculture production system. Some extensive and semi-intensive aquaculture growout operations, such as oyster culture as it is usually practised, do not depend on any supplementary feeding by the aquaculturist, while, by definition, other semi-intensive and intensive operations do.

Processing and Packaging

Research carried out to identify the species and product form or forms preferred by the market will determine the type of processing and packaging needed. According to the degree of vertical integration in an aquaculture operation, some or all processing and packaging may take place on site; alternatively, separate specialist facilities can be employed to undertake these functions.[13] A decision to use external companies or contractors for processing and packaging would be influenced by the availability, proximity and quality of relevant facilities.

Transportation and Markets

Site selection studies should consider the means and associated costs of transporting the product to market. Ideally, to minimise transportation costs, the proposed site should be as close as possible to the market. If a site is remote from the target market, the cost of getting the product to the market will clearly form an important component of site selection studies.

[13] Frequently, the equipment and methods that are used for processing and packaging can be both specialised and expensive and it is usually only large-volume, vertically-integrated aquaculture operations that undertake these activities in-house. Smaller operations often depend, at least to some extent, on external processors and packagers.

The production of high-value species can offset high transportation costs; similarly, a proposed site or region may be distinguished by some local, competitive advantage that compensates for high transportation costs.

Other Factors

Other economic or financial factors influencing site selection include the availability of specialised equipment and diagnostic services.

Suppliers of specialised aquaculture equipment should be identified: some equipment items not available locally may need to be carried by the aquaculturist as spare parts, the immediate availability of which allows failed equipment or machinery to be replaced or repaired without the loss of essential services for a protracted period.

Any efficient aquaculture operation requires an array of diagnostic services ranging from water quality analyses to pathology. The proximity of a competent fish health laboratory to aquaculture operations is considered a distinct advantage: chronic and acute mortalities due to disease and other factors can often pose serious threats to aquaculture and effective diagnoses and treatments can make the difference between the success and failure of commercial aquaculture. FDWA has a Fish Health Section located in Perth that provides a high level of fish health services to the aquaculture industry in Western Australia.

4.2.4 Social and Legal Factors

Urban Proximity

The closeness of resources and facilities afforded by urban centres forms an important, but not necessarily critical, site selection criterion. Consideration needs to be given to providing accommodation for staff, as well as to their social and recreational needs include the location and standard of educational, medical, transport, shopping and other services.

Competing Resource Use

Competing resource use is becoming increasingly important to aquaculture development, particularly in coastal areas near major urban centres. The allocation and utilisation of scarce resources, whether land, labour, capital, technical or management, constitutes an important site selection consideration: in aquaculture, the major resources usually considered scarce or limiting are land and water. Aquaculture can be considered a legitimate user of scarce resources, particularly in regional areas, where it contributes to regional development and employment.

Competition for resources may arise from both within the aquaculture industry and from other industries, organisations or interest groups. Internal competition can arise between different sectors of the industry, such as proponents who wish to culture mutually-exclusive species within a limited area. External competitors include other industries such as the commercial and recreational fishery and tourist developments.

Licensing and Legislation

An important component of any site selection study is an understanding of all the licensing and legislative requirements of the local, state and federal government authorities. A site plan is usually required, together with information about the species to be cultured, water source and quantities, discharge point and waste-water treatment. There may be a requirement for some form of environmental impact study to be carried out in environmentally-sensitive areas. In Western Australia, the Inter-Departmental Committee for Aquaculture has been established to expedite the approvals process.

Land Ownership

Aquaculture site selection studies should consider issues such as land ownership; legislative and other requirements for land acquisition or leasing; and rights of access.

Prospective aquaculturists who possess their own freehold land generally have fewer social or cultural problems associated with project development than those who lease or otherwise gain access to public or crown water and land.

The issue of Native Title can influence the use and management of sites in areas subject to claim. These claims need not constrain aquaculture development: access and management agreements can often be negotiated between the relevant Aboriginal representatives and aquaculture proponents.

5 WA AQUACULTURE SPECIES AND SELECTION CRITERIA

5.1 Aquaculture Species: Current and Potential

Two species categories are listed in this section:
- those currently being produced by aquaculture (section 5.1.1); and
- those considered by the various planning studies to have potential for aquaculture in Western Australia (section 5.1.2).

The latter list is inclusive, not exclusive: it names the species considered likely to have aquaculture potential but does not claim to be exhaustive.

5.1.1 Species Currently Produced by Aquaculture

The following species are currently produced by aquaculture in Western Australia.

Marine Finfish:

- black bream (*Acanthopagrus butcheri*);
- snapper (*Pagrus auratus*).

Marine Shellfish:

- pearl oyster (*Pinctada maxima*);
- blacklip oyster (*Pinctada margaritifera*);
- Shark Bay pearl oyster (*Pinctada albina*);
- wing oyster (*Pteria penguin*);
- blue mussel (*Mytilus edulis*);
- western rock oyster (*Saccostrea commercialis*).

Diadromous Species:

- barramundi (*Lates calcarifer*).

Fresh Water Species:

- Argyle bream (*Hephaestus jenkinsi*);
- marron (*Cherax tenuimanus*);
- yabby (*Cherax destructor*);
- rainbow trout (*Oncorhynchus mykiss*);[14]
- brown trout (*Salmo trutta*);
- silver perch (*Bidyanus bidyanus*);
- aquarium species (various).

[14] In Western Australia, rainbow trout are currently produced in fresh water systems only; however, there is growing interest in producing sea trout, which are rainbow trout acclimatised to and grown out in sea water. Accordingly, sea trout is included later in this document as a potential species for aquaculture.

Algae:

- beta-carotene (*Dunaliella salina*).

5.1.2 Species with Potential for Aquaculture

This section records the species considered by the various planning and other aquaculture-oriented studies described in chapter 3 to have potential for aquaculture in Western Australia, but which presently are not cultured commercially. The species are not listed in any order of priority, but are categorised according to whether they are finfish or shellfish and according to their habitat.[15] Further, only species and genera are represented below: species groups, such as grouper, that are occasionally identified in the studies are not included as such because they can be diverse and include species with poor aquaculture prospects (the only exception to this rule is aquarium species). Some species, such as kuruma prawn and redfin perch, are not native to Western Australia and translocation issues would need to be considered before they could be introduced.

It is reiterated that the following species are those identified by various planning studies as having potential for aquaculture. The potential of some species may be very low; for example, the low fecundity of cobbler and the very low current market value of southern Australian herring are considered significant constraints to the successful aquaculture of these species.

Despite the difficulties and pitfalls inherent in the process, it is important to identify a limited number of the species considered to have the greatest potential for aquaculture development: limited resources may then be focused on these selected species. Section 5.3 of this document classifies aquaculture candidate species according to a defined rationale.

Marine Finfish:

- barramundi cod (*Cromileptes altivelis*);
- mangrove jack (*Lutjanus argentimaculatus*);
- coral trout (*Plectropomus* spp.);
- bar-cheeked coral trout (*Plectropomus maculatus*);
- red emperor (*Lutjanus sebae*);
- milkfish (*Chanos chanos*);
- yellowfin tuna (*Thunnus albacares*);
- southern bluefin tuna (*Thunnus maccoyii*);
- estuary cod (*Epinephelus coioides*);[16]
- mahimahi (*Coryphaena hippurus*);
- bald chin groper (*Choerodon rubescens*);[17]

[15] Since many estuarine and brackish-water species also occur in the marine environment, for the sake of convenience these species are included in the marine finfish category.

[16] The estuary cod or greasy grouper has often been incorrectly referred to as *Epinephelus tauvina* or *Epinephelus suillus*. The correct scientific name of the estuary cod is *Epinephelus coioides*. This is the species currently being cultured in Singapore, Malaysia and Taiwan and is the species that occurs in Western Australian waters: a similar but different species is the malabar cod, *Epinephelus malabaricus*, which may also have aquaculture potential.

- western yellowfin bream (*Acanthopagrus latus*);
- silver bream (*Rhabdosargus sarba*);
- sea mullet (*Mugil cephalus*);
- Westralian dhufish (*Glaucosoma hebraicum*);
- yellowtail kingfish (*Seriola lalandi*);
- King George whiting (*Sillaginodes punctata*);
- western school whiting (*Sillago vittata*);
- yellow-finned whiting (*Sillago schomburgkii*);
- large-toothed flounder (*Pseudorhombus arsius*);
- small-toothed flounder (*Pseudorhombus jenynsii*);
- greenback flounder (*Rhombosolea tapirina*);
- mulloway (*Argyrosomus hololepidotus*);
- cobbler (*Cnidoglanis macrocephalus*);
- southern Australian herring (*Arripis georgianus*);[18]
- trevally (*Pseudocaranx* spp.);
- breaksea cod (*Epinephelides armatus*);
- marine aquarium species.

Marine Shellfish:

- trochus (*Tectus niloticus*);
- tropical abalone (*Haliotis asinina*);
- trepang or sea cucumber (*Holothuria* spp.);
- tiger prawn (*Penaeus monodon*);
- kuruma prawn (*Penaeus japonicus*);
- artemia or brine shrimp (*Artemia* spp.);
- mud crab (*Scylla serrata*);
- giant clam (*Tridacna gigas*, other *Tridacna* spp.);
- edible oysters (*Saccostrea* spp., *Crassostrea* spp., *Ostrea* spp.)
- Roe's abalone (*Haliotis roei*);
- greenlip abalone (*Haliotis laevigata*);
- brownlip abalone (*Haliotis conicopora*);
- western rock lobster (*Panulirus cygnus*);
- saucer scallop (*Amusium balloti*);
- blue swimmer crab (*Portunus pelagicus*).

Diadromous Species:

- eels (*Anguilla* spp.).

[17] Two different species that occur along the Western Australian coast are called "bald chin groper". One species is abundant in the hypersaline waters of Shark Bay; the other is less common in Shark Bay but widespread in temperate coastal waters. It is the latter species, *Choerodon rubescens*, that is identified as having some aquaculture potential.

[18] As for the other species, the southern Australian herring is included in this list because it has been identified in a planning study as having some aquaculture potential (as a result of anecdotal reports that wild-caught herring grown out in sea cages may have a high lipid content and consequently a high value in export markets). At present, however, the low value of the species is likely to restrict its aquaculture potential and, in any case, the Western Australian salmon (*Arripis truttaceus*), which is not identified in any of the planning studies, may be a better candidate.

Fresh Water Species:

- catfish (*Arius* spp.);
- redclaw crayfish (*Cherax quadricarinatus*);
- cherabin or fresh water shrimp (*Macrobrachium rosenbergii*);
- redfin perch (*Perca fluviatilis*);
- Murray cod (*Maccullochella peeli*);
- golden perch (*Maquaria ambigua*);
- Australian bass (*Maquaria novemaculeata*);
- fresh-water aquarium species.

Algae:

- Spirulina (*Spirulina* spp.).

5.2 Species Selection Criteria

Aquaculture candidate species should be selected and evaluated according to certain criteria, which can be categorised according to the relevant marketing, culture technology, production efficiency and commercial viability factors. The species selection criteria that collectively comprise each of these categories are discussed below; each criterion can be considered for a range of aquaculture candidate species, with particular reference to the relevant region.

5.2.1 Marketing Factors

Marketing factors that are considered as an element of a species selection process should not be confused with the more extensive marketing work that needs to be carried out as part of a detailed feasibility study. The species selection criteria relevant to marketing are product features, market economics and market place features.

Product Features

Product features include physical characteristics, form and quality.

The product's physical characteristics refer to its size and texture: these features vary between species and may be considered more acceptable in either larger or smaller form. From a marketing perspective, it is essential that the product is always presented at each point of sale in the way that is most appealing to the customer.

The product's form refers to the number of ways in which it can be presented, such as live, fresh-chilled, frozen, smoked, salted, canned, sashimi, surimi and other forms of value-adding.

High product quality is an essential marketing features; at each point in its marketing chain, the quality of the product must be maintained, since the end product will only be as good as the extent to which suitable quality-control measures are implemented.

Market Economics

The volume and price demands of the market place have a significant influence on the choice of a species for aquaculture. While the demand for most seafoods is generally increasing, it varies according to species and seafood has several other competing foodstuffs. A clear assessment therefore needs to be made of the likely market returns for the species under consideration for aquaculture and the volumes likely to be able to be placed in the market to ensure that an adequate return can be received.

Market Place Features

Features such as structure, competition and segmentation need to be considered when selecting a species for aquaculture. Aquaculture operations often have to supply distant markets with high-value products that command a premium price in the market place to offset the disadvantage of distance. These products have to be able to withstand and overcome competition from other cultured and wild-caught products; it is useful to identify and evaluate competition that may exist in the market place from other producers and sources. Consideration also needs to be given to the influence of similar or substitute species. Market segmentation also needs consideration: liaison needs to be maintained with agents operating in the market place to identify the product features that are the most desired by the different market segments.

5.2.2 Culture Technology

Culture technology describes the technical procedures used to culture a species through the various stages of its life history. The procedures involve broodstock maintenance, control of spawning, egg production, larviculture, weaning, juvenile rearing, live food production and growout. The species selection criteria that pertain to culture technology can be classified accordingly.

Broodstock

An important requirement for reliable commercial aquaculture is the ability to control the maturation and spawning of a species in captivity; without this ability, reliance is placed on the repetitive collection of wild seed or wild broodstock in or near spawning condition. Captive spawning and other related broodstock features are therefore considered important species-selection criteria.

Factors that influence broodstock management include the occurrence of wild broodstock, their ease of capture or acquisition, the behaviour of captive and domesticated fish, their response to stress and susceptibility to diseases.

Spawning and Egg Quality

Successful captive spawning and the reliable production of good-quality eggs are important determinants of the suitability of any particular species for commercial aquaculture. The species-selection process should therefore include consideration of the reproductive

characteristics of the species in captivity, its fecundity, the size of the eggs that are produced and their quality.

The ability to fully control the sexual maturation and spawning in captivity of the species being cultured is an important species selection criterion. Any ongoing reliance on wild broodstock or juveniles to stock an aquaculture operation results in commercial uncertainty. While the fecundity of finfish and shellfish is usually very high, it varies according to species and habitat (marine species are usually more fecund than fresh-water species). Higher fecundities are usually preferred for aquaculture candidate species, since fewer broodstock and smaller facilities are then required for production purposes. Egg size is also important because, among other things, it influences early larval survival. Egg quality has a major influence on the health and early survival, and therefore the viability, of the embryo developing within the egg. Although little is known about the factors that affect egg quality, some species are distinguished by their ability to consistently produce high-quality eggs in captivity: this ability imparts significant advantages to aquaculture so constitutes an important species-selection criterion.

Development and Behaviour

The early development and behaviour of larvae and juveniles influence the potential of a species for aquaculture. Relevant factors include the size of the newly-hatched larvae, their ease of culture through the successive stages of their life histories, their behaviour and the duration of the larval period.

Various species are characterised by distinctive development and behavioural patterns that can influence the technology employed for their culture and its degree of success. These factors therefore influence the suitability of the species for aquaculture. The duration of the larval period is important: species with shorter larval periods are usually easier to rear to the juvenile stage and therefore considered better aquaculture candidates.

Nutrition and Diet

Information about the nutritional requirements and diet formulation for certain species are important determinants of their suitability for aquaculture, since many cultured species need artificial feeds for growth and maintenance. The formulation of artificial feeds requires some knowledge of the specific nutritional requirements of the species in question (different species usually have distinct nutritional requirements).

The importance of nutrition and diet as species-selection criteria varies according to the production system: species such as mussels being grown on longlines depend on the natural productivity of the water to supply their dietary needs while others, such as marine finfish species cultured in intensive systems, depend entirely on artificial diets.

Hatchery Technology

The supply of adequate quantities of good-quality seed for growout is often a significant constraint to aquaculture development; the status of the hatchery technology available for a species, or one that is closely related, is therefore considered an important species-selection criterion. Commercial aquaculture can be significantly influenced by available hatchery

technology, particularly when there is no source of wild-caught juveniles for growout or when that source cannot be relied upon.

Factors that need to be considered include knowledge of the design and operation of suitable production systems, efficient operating procedures and dietary and feeding procedures that yield suitable survival rates.

5.2.3 Production Efficiency

The species selection criteria relevant to production efficiency include growth rate, FCR, diet, environmental tolerances, hardiness and behaviour.

Growth Rate

The growth rate of a species is one of the most important characteristics that govern its suitability for aquaculture. Rapid growth rates allow a marketable size to be achieved in shorter periods and permit more frequent harvests; some slower-growing species with high market values may be considered good aquaculture candidates, but it can be difficult to culture them economically. The main factors that influence growth rate under culture conditions are temperature, dissolved oxygen concentration, ammonia concentration, salinity, competition, food availability and composition, age and maturity. Consideration and evaluation of these factors and their interaction with each other and the production system constitutes an important aspect of the species selection process.

Temperature is one of the more important variables that control growth rate: within a certain temperature range that is species-specific, growth rate increases with increasing temperature. Water temperature also influences appetite and ration.[19] Dissolved oxygen concentrations play an important role in the growth rate of aquacultured species; as they fall below certain levels, significant reductions in growth rates and food conversion efficiencies can be experienced. The presence of ammonia and other pollutants in high concentrations but at sublethal levels will also reduce growth rates. Other factors that can influence growth rate include salinity, competition for feed (where feed is of poor nutritional value or its availability is limited), age and maturity.

Food Conversion Ratio

The food conversion ratio ("FCR") is an expression of the efficiency with which the species under consideration converts feed into flesh. Usually expressed as the ratio of the dry weight of the feed to the wet weight of the animal, FCR varies significantly according to species, size, diet and culture conditions.

Because the cost of feed usually comprises a major component of total operating costs, the efficiency with which it is converted is an important species-selection criterion: species with more efficient FCRs are likely to be better aquaculture candidates.

[19] The relationship of temperature and ration influences the food conversion ration that is achieved. At any given temperature there is often an optimum feed ration that allows maximum growth; any feed provided and consumed in excess of this optimum ration will be used inefficiently.

Feeds and Feeding

The selection of a species for aquaculture should include consideration of the feeds that may be commercially available, together with the feeding habits of the species being considered. Most feeds in contemporary aquaculture are dry pellets that are either compressed or extruded and manufactured to be floating or sinking, according to the feeding preferences of the species. The palatability, size, shape and texture of pelletised diets are all important factors that influence acceptability and hence feeding rates and growth.

Information about the principal dietary ingredients (protein, lipid or fat, carbohydrate, certain micronutrients and some non-nutritive components) is important to determine the suitability of currently-available feeds and to select the most appropriate one. Selection of the cheapest feed may not result in the lowest production costs, since poor-quality feeds are often associated with inefficient FCRs, slow growth and poor health. Suitable feeds for marine fish usually include high-quality protein, lipids, vitamins and minerals and limit carbohydrate, fibre, ash and moisture.

Feeding rates vary according to fish size and species; small fish and those with relatively small stomachs usually need to be fed more frequently than larger fish that can ingest a daily ration at one feeding. More frequent feeding may be necessary in intensive systems to ensure that the less aggressive fish will also consume their ration.

Environmental Tolerances, Hardiness and Behaviour

The environmental tolerances a species has to water quality parameters and other environmental variables characteristic of a site being considered for its aquaculture constitute a critical species-selection criterion. A species is best suited to culture in an environment characterised by variables that are within its optimum or ideal range. The main environmental variables to which different species may have varying degrees of tolerance are water temperature and salinity; others include turbidity, pH and other water-quality parameters.

Some culture species are hardier than others: their ability to withstand stress, crowding, handling and poor water quality is greater and consequently they are less prone to disease. Similarly, the habit of a species may determine its suitability to a particular culture system.

5.2.4 Commercial Viability

The commercial viability of aquaculture is governed principally by profitability; the selling price of the product needs to more than compensate for its production costs, while the demand volume must be able to take up the output without excessive price erosion. The species selection criteria relevant to production efficiency can be classified according to profitability and other factors such as infrastructure, competitiveness, regulation and support.

Profitability

The profitability of an aquaculture operation is significantly influenced by the species being produced. One method of determining the potential profitability of a candidate species is to

analyse the costs and returns that can realistically be expected for it, then carry out an analysis of investment feasibility. This procedure is considered an important species-selection criterion.

Performance indicators used to measure the economic feasibility of an aquaculture project are: net present value ("NPV"); benefit/cost ratio ("B:C"); and internal rate of return ("IRR"). The IRR value provides a single figure that indicates the potential profitability of a specific species grown according to a defined culture technology under a specified production system at a particular site. If calculated according to realistic data, it is considered a powerful indicator of profitability and a significant species selection tool.

Other Commercial Viability Factors

Within the context of species selection, the commercial viability of a species can also depend on the infrastructure that may be necessary for its culture, its competitiveness, potential for integration with other systems or species and the amount of regulation and support that exists for its development.

Some species, particularly certain high-value marine finfish, often require significant infrastructure for their successful culture; others, such as bivalve mussels and oysters cultured in intertidal or subtidal areas require comparatively little infrastructure. Competitiveness is important: the merits of a species needs to be evaluated against those of other candidate species and with a view to competition from other domestic and international producers of the same species. The commercial viability of a species can be improved if it is compatible and can be integrated with some other form of aquaculture or other industry. Finally, certain legal and regulatory factors need consideration when selecting a species for aquaculture.

5.3 Classification of Species with Potential for Aquaculture

5.3.1 Rationale for Classification

The classification of species with potential for aquaculture according to their relevant attributes permits limited resources for aquaculture development to be focused on those species considered to have the best prospects for commercial production.

The various planning and other aquaculture-oriented studies catalogued in section 8.2.1 identify numerous species that are considered to have some potential for aquaculture in Western Australia. Named in section 5.1.2, these potential species are distinct from those that are already cultured commercially. In this section, these "candidate" species are classified according to their perceived aquaculture potential. The placement of candidate species in a particular category (primary, secondary or tertiary) constitutes a purely subjective assessment of their aquaculture potential; the objective is to provide some informed guidelines, not to derive objective, scientific data.

The placement of a species in one of the three categories is governed by:
- its marketing, production efficiency and commercial viability characteristics;
- the state-of-the-art of its culture technology; and
- the compatibility of suitable production systems with the nature of the available sites.

Primary species are those considered to have good prospects for aquaculture development either immediately or in the very near future. They are generally characterised by having:
- favourable marketing, production efficiency and commercial viability factors;
- either well-known or reasonably-well-known culture technologies; and
- production systems compatible with the nature of the available sites.

Secondary species are those considered to have aquaculture potential in the future, subject to the development of suitable culture technologies. They are generally characterised by having:
- favourable marketing, production efficiency and commercial viability factors;
- poorly-known culture technologies; and
- production systems generally compatible with the nature of the available sites.

Tertiary species are those considered to have poor aquaculture prospects now and in the future, unless significant changes occur in their culture technologies, production systems or market prices. They are characterised by generally having:
- less favourable marketing, production efficiency or commercial viability factors;
- poorly-known culture technologies; and/or
- production systems that are incompatible with the nature of the available sites.

Sections 5.3.2, 5.3.3 and 5.3.4 below include all the species identified in the various studies as having aquaculture potential in Western Australia and classified respectively as primary, secondary or tertiary species according to the rationale provided in section 5.3.1 above (species already produced by aquaculture in Western Australia are listed separately in section 5.1.1 above and are not included in the following lists).[20] The natural range of each species within Western Australia is given in parentheses alongside its name.

5.3.2 Primary Species

The primary species listed below are those considered to have good prospects for aquaculture development either immediately or in the very near future.

It is contemplated that scarce resources for aquaculture development should be focused principally on these primary aquaculture species.

Marine Finfish:

- southern bluefin tuna (offshore oceanic waters in all Western Australian seas);
- estuary cod (coral reefs and estuaries, Rottnest Island northwards);
- mahimahi (oceanic waters in all Western Australian seas);
- yellowtail kingfish (coastal waters, Shark Bay southwards);
- Westralian dhufish (offshore reefs between Shark Bay and Recherche Archipelago);
- greenback flounder (estuaries and coastal bays along the southern coast);
- marine aquarium species (Western Australian coastal waters, according to species);

[20] Only the actual species or genera identified in the planning studies are included. In some studies, species groups, such as groupers, are identified. These species groups are not included in this study because they often encompass many different species, some of which may be excellent aquaculture candidates while others may not.

- sea trout (introduced species, cold temperate areas, south coast).[21]

Marine Shellfish:

- trochus (high-energy intertidal reefs in the Kimberley region);
- giant clam (coral reef waters shallower than 20 m, Tropic of Capricorn northwards);
- artemia (introduced species, abundant in Shark Bay and other salt-farming operations);
- edible oysters (reef platforms, ranges vary according to species);
- Roe's abalone (high-wave-energy reef platforms, Shark Bay southwards);
- greenlip abalone (deeper water, southern coast, Cape Naturaliste southwards);
- brownlip abalone (deeper water, mainly southern coast, Rottnest Island southwards).

Fresh Water Species:

- redclaw crayfish (introduced species, occurs in tropical northern Australia but not WA).

Southern bluefin tuna is considered a priority species despite having a poorly-known culture technology, because it has a very high market value and its commercial production has been shown to be commercially viable within Australia. Currently, southern bluefin tuna aquaculture is dependent upon the growout or fattening of wild-caught juvenile fish; however, hatchery production techniques for the species are being developed overseas and commercial juvenile production appears imminent.

The culture technology for estuary cod has been proved overseas but is still being developed in Australia. The production efficiency and commercial viability of the species have been proved elsewhere and its commercial aquaculture in Australia may be imminent. The species may have high value in export markets, particularly in live form.

Mahimahi is considered to have good commercial aquaculture prospects; the culture technology for the species has been developed privately; however, its commercial viability has not been proved.

The culture technology for yellowtail kingfish has yet to be developed under Australian conditions. A closely-related species is produced by aquaculture in very large quantities in Japan (over 300 000 t/yr); however, the industry there depends on the growout of wild-caught juveniles. Yellowtail kingfish aquaculture in Australia would be dependent on the development of hatchery techniques for supplying juveniles for growout. The species has favourable biological and market characteristics and could be an excellent species for commercial aquaculture.

Westralian dhufish is a high-value species in Western Australia but unknown in other markets. The culture technology for the species is being developed and early results encouraging in relation to its hatchery production. The production efficiency and commercial viability of the

[21] Sea trout are rainbow trout that have been acclimatised to and are grown out in sea water. The species has not been identified in aquaculture planning studies as having commercial aquaculture potential; however, it is included in this category because it is considered by various authorities to have significant potential for aquaculture development.

species are unknown at this stage; its commercial success may be dependent upon its acceptability in the South-East Asian market place.[22]

Culture techniques are well developed for greenback flounder and the species is generally considered to have good aquaculture potential. The commercial aquaculture potential of the species is currently being explored in Tasmania and Victoria and it is considered to have some potential in South Australia. Warmer waters on the western coast of Western Australia may be conducive to improved growth rates and yield competitive advantages over producers of this species in southern and eastern Australia.

Marine aquarium species are included because the culture technology for some species is well known and, while it is very competitive internationally, this sector of the aquaculture industry is considered to have good growth potential.

Sea trout may be an excellent candidate for commercial aquaculture in cold-water areas of the State near Esperance and in the Recherche Archipelago. Since they are not influenced by the warm Leeuwin Current, it is possible that these areas may be characterised by sea water temperatures cold enough to support rainbow trout growout. The necessary culture technology is well known, fingerlings are available in commercial quantities from existing hatcheries and sea trout are likely to have domestic and export market values that approach those of the high-value Atlantic salmon.

Trochus is considered to have good aquaculture prospects in areas of the Kimberley and its culture technology is well known. While the species may initially have poor commercial prospects, its aquaculture would have significant socio-economic benefits for Aboriginal communities in coastal areas.

Giant clams may have excellent aquaculture prospects in clear oceanic waters in tropical areas of Western Australia. The culture technology for the species has been developed at James Cook University of North Queensland and is at a “turnkey” stage.

Artemia is considered to have high aquaculture potential, particularly in the more arid areas of the State. The procedures associated with the extensive production and harvesting of artemia on a large scale are well known.

The production efficiency, commercial viability and culture technologies for various species of edible oysters are well known. Pacific oysters (*Crassostrea gigas*) do not occur naturally in Western Australia but may be a good aquaculture candidate subject to translocation issues being resolved.

Roe’s abalone, greenlip abalone and brownlip abalone are considered good aquaculture candidates; their production efficiencies and commercial viabilities are good in other areas and likely to be similar in Western Australia and their culture technologies are generally well known and established under Australian conditions. Abalone are generally amenable to onshore and offshore production systems and have a high market value. Their culture in offshore

[22] Anecdotal evidence suggests that Westralian dhufish may not have a particularly high value in South-East Asian markets because the fish reputedly does not steam well. It may have good prospects in other export markets in Europe and the USA.

production systems in Western Australia using barrels and cages suspended from longlines is likely to be quite profitable.

Redclaw crayfish are not endemic to Western Australia; however, subject to translocation issues being resolved, the species is likely to be an excellent candidate for aquaculture in tropical areas in general and the Kimberley region in particular. The production efficiency, commercial viability and culture technology of the species are well known.

5.3.3 Secondary Species

The secondary species listed below are those considered to have aquaculture potential in the future, subject to the development of suitable culture technologies.

Marine Finfish:

- barramundi cod (coral reefs, Dirk Hartog Island, Shark Bay, northwards);
- mangrove jack (inshore and offshore reefs, Dampier Archipelago northwards);
- coral trout (coral reefs, Dongara northwards; mainly occurs in the western Pacific);
- bar-cheeked coral trout (coral reefs, Abrolhos Islands northwards);
- red emperor (coral reefs, Shark Bay northwards);
- yellowfin tuna (offshore oceanic waters in all Western Australian seas);
- western yellowfin bream (coastal reefs, Shark Bay northwards);
- silver bream (coastal and estuarine waters between Coral Bay and Albany);
- sea mullet (coastal and estuarine waters, entire Western Australian coast);
- King George whiting (coastal and estuarine waters, Jurien Bay southwards);
- western school whiting (deeper coastal waters, Coral Bay to Geographe Bay);
- yellow-finned whiting (estuarine and inshore waters, Shark Bay southwards);
- large-toothed flounder (estuaries and bays along the western coast);
- small-toothed flounder (estuaries and bays along the western and southern coasts);
- mulloway (coastal and estuarine waters, Exmouth Gulf southwards);
- cobbler (estuarine and coastal waters, Abrolhos Islands southwards);
- trevally (generally common in all Western Australian coastal and estuarine waters).

Marine Shellfish:

- tropical abalone (nearshore reefs, tropical waters in north-western Australia);
- mud crab (sheltered estuaries, mud flats and mangroves, Exmouth Gulf northwards);
- trepang (coral reef waters, north-west coast northwards);
- tiger prawn (estuarine waters, Shark Bay northwards);
- kuruma prawn (non-native species);
- western rock lobster (coastal and offshore reefs, mainly Shark Bay to Cape Leeuwin);
- blue swimmer crab (estuarine and inshore waters, mainly south-western WA).

Diadromous, Fresh Water and Algal Species:

- eels (coastal drainage areas in northern, eastern and south-eastern Australia);
- Murray cod (eastern Australian species, Murray-Darling distribution);
- golden perch (eastern Australian species, extensive range);

- catfish (fork-tailed catfishes, tropical and sub-tropical fresh, brackish and marine water);
- cherabin (fresh and brackish tropical waters, northern Western Australia);
- fresh water aquarium species (widespread in tropical and temperate fresh waters);
- Spirulina (not native to and currently does not occur in Western Australia).

Barramundi cod, mangrove jack, coral trout, bar-cheeked coral trout and red emperor are considered to have high aquaculture prospects in Western Australia; however, the necessary culture technology is still being developed in various areas. Due to their almost-invariably-high market values, particularly for live product, the commercial aquaculture of some of these species is considered likely within several years.

Yellowfin tuna has a high market value, but its culture technology is poorly known and its commercial production, which is currently dependent upon the growout or fattening of wild-caught juvenile fish, has yet to be demonstrated.

Western yellowfin bream and silver bream will probably be comparatively simple to culture since procedures developed for black bream would probably be suitable. These species are considered secondary mainly due to marketing and commercial viability considerations.

Sea mullet have been produced by aquaculture elsewhere. The market value of the fish in Australia is low, but that of its roe can be high: it is for this reason that it is considered a secondary and not a tertiary species.

King George whiting, western school whiting and yellow-finned whiting have not been produced by aquaculture in Western Australia, but similar species have been cultured elsewhere. Fertile eggs are relatively simple to acquire from wild-caught adults and the culture technologies for the species appear comparatively uncomplicated. Some limited work carried out on King George whiting in South Australia indicated that it may have a more difficult culture technology and slower growth rate than other whiting species; however, the evidence is inconclusive and the species is considered as viable for aquaculture development as the other whiting species. In markets where it is known, King George whiting is a highly-regarded species with a high value and is considered to have good export potential.

Large-toothed and small-toothed flounder have not been produced by aquaculture in Western Australia, but similar species have been cultured elsewhere. Flounders generally are considered comparatively uncomplicated marine fish to produce by aquaculture and these species may have high values as live product in some export markets.

Mulloway have been successfully cultured at a laboratory scale and the commercial production of the species on the east coast may be imminent; however, the commercial viability of the species will depend on its market value being improved.

Cobbler and trevally are included in this category because, despite their poorly-known culture technologies, they are considered likely to have favourable marketing, production efficiency and commercial viability features.

Tropical abalone are not considered priority species alongside the other temperate abalone because the production efficiency and commercial viability of producing the species in tropical areas is unknown.

Mud crabs are considered secondary species: the culture technology for the species is still being developed and its production efficiency and commercial viability are poorly known.

Trepang has a high market value; however, its production efficiency and commercial viability under culture are unknown and its culture technology is at an early development stage. That it is included as a secondary and not a tertiary species is due to its high value and the current efforts being made to develop suitable culture technology.

Tiger (*P. monodon*) prawns and kuruma (*P. japonicus*) prawns have high market values and well-known culture technologies, production efficiencies and commercial viabilities in north Queensland and numerous countries overseas. They are included here as secondary, not primary, species because little is known about their culture under Western Australian conditions. More specifically, their successful commercial culture has not been proved under conditions similar to those that prevail in the Kimberley and Pilbara regions, which are characterised by a macro-tidal regime and possibly unfavourable water salinities. The tiger prawn is the most common Penaeid prawn species produced by aquaculture in Australia: the farms are mainly in Queensland and northern New South Wales. Most farms are on the north Queensland coast where they have access to large quantities of brackish water and the tidal range is moderate. Hatchery and growout procedures are well known; however, broodstock maturation in captivity is a problem and the industry is presently dependent on wild-caught spawning stock to produce fertile eggs.

Western rock lobster has a life history that is not conducive to the mass production of hatchery-reared stock; however, it is considered a secondary, not a tertiary, species due to its very high market value. Interest in growing-out the wild-caught puerulus larvae of western rock lobsters is increasing, as is that for holding live lobsters for later sale.

Blue swimmer crabs have a reasonably-well-developed culture technology and may be amenable to semi-intensive culture. They have previously been cultured successfully in Australia and are produced by aquaculture in Japan and South-East Asian countries; however, the wild-capture fishery for the species in Western Australia is productive and well managed and may be a significant competitor to any cultured product.

While Western Australia does have some native, fresh-water eels, the species currently being cultured in eastern Australia (the short-finned and long-finned eels) do not occur here. The production efficiency and commercial viability of eel aquaculture are generally well known and high-value markets established; however, an eel aquaculture industry in Western Australia would be dependent upon the supply of seed elvers from eastern Australia and subject to translocation approvals being granted. The hatchery technology for eel aquaculture is unknown and likely to stay that way for some time; the industry is entirely dependent upon wild-caught glass eels or elvers for seed. Eel aquaculture could take place in Western Australia in purpose-built, heated, recirculating systems. Shortfin eels are cultured in Victoria and Tasmania using semi-intensive production systems; longfin eels are not yet produced in commercial quantities, but pilot projects are under way.

Murray cod and golden perch may be reasonably good candidates for aquaculture in Western Australia, subject to translocation issues being resolved.

Catfish, cherabin and fresh water aquarium species (other than those already produced by aquaculture) are considered secondary due to their poorly-known culture technologies, production efficiencies or commercial viability.

Fresh water aquarium fish, particularly tropical species, are considered to have very good prospects for commercial aquaculture subject to the requisite technologies being developed.

5.3.4 Tertiary Species

The tertiary species listed below are those considered to have poor aquaculture prospects both now and in the future, unless significant changes occur in their culture technologies, production systems or market prices.

Marine and Fresh Water Species:

- baldchin groper (deeper offshore reefs, Coral Bay to Geographe Bay);
- southern Australian herring (coastal waters, Shark Bay southwards);
- breaksea cod (coastal reefs between Shark Bay and Recherche Archipelago);
- redfin perch (introduced species, widespread distribution includes south-west WA);
- Australian bass (eastern Australian species);
- saucer scallop (inshore waters 10-75 m deep, between Broome and Esperance).

The culture technologies for many of the above finfish species are unknown or poorly known under Australian conditions, some have only moderate market value and others pose translocation problems. They are considered high-risk species for commercial development at this stage. Culture technology developments, production system improvements or significant changes in market factors may lead to their successful, economic aquaculture in the future.

Saucer scallops have a high market value; however, despite some successes at a laboratory scale, their culture technology is poorly developed and some aspects of the life history of the species are not conducive to commercial cultivation (for example, the larval stage does not settle well). The species is further characterised by poorly-known production efficiency and commercial viability factors under Western Australian conditions. The species has been eliminated as an aquaculture candidate in Japan, where its potential was evaluated.

6 WA COASTAL AQUACULTURE REGIONS

The following sections of chapter 6 describe the general features, aquaculture sites and potential species of each of the 10 geomorphological regions along the Western Australian coastline described in chapter three.[23] The Western Australian coastline may be also be described more generally, according to its bio-physical features; *viz.* the areas of the coast that are tide-dominated, surge-dominated and wave-dominated. These areas overlap the boundaries that are determined by coastal geomorphology. Due to the influence these processes may have on coastal aquaculture operations it is worth briefly elaborating on them here.

In the north of the State, from the Northern Territory border to a point south of Port Hedland and near Cape Preston in the Pilbara region, the coast is tide-dominated; that is, most of the coast experiences a high tidal range of more than 4 m.[24] Other features of the tide-dominated coast include low wave energy and moderate to high storm surges. The high tidal regime characteristic of this area has important implications for semi-intensive coastal aquaculture operations using pond production systems. Ponds that are sufficiently elevated to avoid flooding may have a high pumping head, particularly during spring tides. Significant engineering problems may be associated with establishing ponds and economically-viable sea water supply systems in this area.

From Cape Preston to Cape Naturaliste, the coast is surge-dominated; that is, it is dominated by storm surges, or sea level changes caused by changing barometric pressures, winds and waves.[25] Frequently protected by extensive, offshore limestone reefs, the region is characterised by small tidal ranges and a moderate wave energy.

From Cape Naturaliste to the South Australian border, the coast is wave-dominated; that is, the wave heights typically exceed the characteristic small tides and moderate surge activity.[26] The offshore hydrography is complex and the shoreline frequently comprises embayments confined by rocky headlands.

The discussions of potential sites within this chapter are drawn from the planning reports reviewed for the purposes of this study. There may be some cases where no potential sites are identified: this is due to the absence of pertinent information and should not be interpreted as an absence of aquaculture potential in the relevant area.

Most of the areas identified as being sensitive or prohibited for aquaculture are those that comprise marine and nature conservation reserves. The presence of a declared reserve does not in all cases prohibit commercial aquaculture; however, realistically, it is a serious constraint to development.

[23] Many of the descriptions of coastal geomorphology provides in chapter 6 have been modified from information provided in *A Representative Marine Reserve System for Western Australia: Report of the Marine Parks and Reserves Selection Working Group*. Department of Conservation and Land Management, June 1994.

[24] The tide-dominated coastal area encompasses the Kimberley Coast, the Canning Coast, Eighty Mile Beach and part of the Pilbara Coast.

[25] The surge-dominated coastal area of Western Australia encompasses part of the Pilbara Coast, the Ningaloo Coast, the Shark Bay Coast, the Central West Coast and part of the Leeuwin-Naturaliste Coast.

[26] The wave-dominated coastal area encompasses part of the Leeuwin-Naturaliste Coast, the South Coast and the Eucla Coast.

6.1 The Kimberley Coast

6.1.1 General Features

The Kimberley Coast extends from the Northern Territory border to Cape Leveque on the Dampier Peninsula and includes Cambridge Gulf, the north Kimberley coast, King Sound and numerous offshore islands and coral reefs. Nearshore habitats along the Kimberley Coast are generally affected by a macro-tidal regime with tides of over 10 m, low wave energy, seasonal cyclones and large quantities of sediment transported by rivers during the wet season. The region has numerous mangrove forests, wide tidal flats and turbid waters.

Cambridge Gulf is a large seasonal estuary, the water in which can be fresh for several months of the year. The broad tidal mud flats that dominate the Gulf together with its macro-tidal regime and wind and wave conditions result in the water being perpetually turbid. Mangrove formations predominate along the shore line.

The north Kimberley coast between Cambridge Gulf and King Sound generally has poor access and is characterised by many deep embayments and islands. The coast is low energy and, due to its macro-tidal regime and high seasonal rainfall, very turbid.

King Sound is a large gulf with shores characterised by broad tidal flats. It features a macro-tidal regime, lower rainfall than the north Kimberley coast and low wave energy and is the receiving basin for the Fitzroy, May and Meda rivers. As with Cambridge Gulf, the dominance of mud and the extreme tidal range result in high turbidity throughout the year.

While nearshore waters are muddy, conditions become increasingly oceanic towards the edge of the Kimberley Coast's relatively wide continental shelf. The oceanic islands comprise a number of mid-shelf and shelf-edge islands, banks and reefs, many of which are built on platform coral reefs. Along the coast, species-rich fringing reefs grow on rocky substrates. The further-offshore islands and reefs of the Kimberley Coast include Ashmore Reef, Cartier Island, Seringapatam and Scott reefs and Browse Island. Those closer to the coastline include the Holothuria and Long reefs, Cassini Island, Adele Island and Beagle, Churchill, Mavis and Albert reefs.

6.1.2 Aquaculture Sites

6.1.2.1 Existing

The Kimberley Coast accommodates Australia's most valuable aquaculture industry: the culture of south sea pearls. Pearl oysters are cultivated on leases throughout the Kimberley Region, including King Sound, Talbot Bay, Doubtful Bay and Kuri Bay. One licence has been issued for onshore aquaculture in King Sound near Chattur Bay.

6.1.2.2 Potential

The Kimberley Coast has been examined for its aquaculture potential. A range of environments exist within this region, from macro-tidal, coastal bays and sounds to coastal islands and reefs. The macro-tidal regime is a significant factor that would influence aquaculture industry growth. Development is currently impeded by restricted and seasonal access, poor survey data and remoteness from services and infrastructure. Some areas are accessible only by boat or aircraft. The region is considered to have potential if the identified constraints can be overcome.

Offshore aquaculture development may have future potential for sea cage, longline and ranching operations should the restrictions created by limited access, exposure to weather and limited shelter be overcome.

Wyndham and Derby have been identified as areas with potential as special development zones, due to the services and facilities available and the areas of extensive flats, marshes and ground water reserves that may be suitable for aquaculture development.

6.1.2.3 Sensitive or Prohibited

Coastal areas with environmental sensitivity within the Kimberley Coast include the Prince Regent Nature Reserve and the Ord River Nature Reserve on the Cambridge Gulf. Access to the coast in these areas and development of onshore facilities for any aquaculture proposal will be constrained and possibly prohibited. Commercial aquaculture is not an activity that is considered consistent with the stated management objectives of conservation and recreation reserves.

Recommended areas for marine reserves include the eastern half of Cambridge Gulf, Londonderry (Cape Rulhieres to Red Bluff), Vansittart Bay, Lawley Estuary, Mitchell Estuary, Prince Frederick Harbour, Saint George Basin, Walcott Inlet, Montgomery Islands, Secure Bay, and the Buccaneer Archipelago. These recommendations have not been implemented and aquaculture would not necessarily be excluded should the reservations proceed.

6.1.3 Aquaculture Species

Species identified by planning studies as aquaculture candidates for the Kimberley Coast include marine and brackish species of finfish and shellfish (e.g. trochus and mud crabs), according to the location. Macro-tidal regions may be suitable for prawn cultivation if engineering problems associated with delivering water at tidal extremes can be overcome. The waters of some bays and sounds are suited to culture of trochus, clams, marine finfish, mud crab and trepang. Coastal areas with access to reliable supplies of fresh water may be suited to the aquaculture of species such as Argyle bream, barramundi, native aquarium fish, cherabin and redclaw crayfish.

The waters surrounding the offshore islands and reefs are considered suitable for the aquaculture of numerous species of marine finfish and shellfish.

The Wyndham and Derby special development zones have been recommended for culture of native aquarium fish, barramundi and marine prawns.

6.2 The Canning Coast

6.2.1 General Features

The Canning Coast extends from Cape Leveque, at the northern end of the Dampier Peninsula, to Cape Missiessy. There is little or no fluvial run-off. The coast has a very large tidal range and the wave energy varies from moderate along the coast to low within the larger embayments such as Roebuck Bay.

The Coast is characterised by long stretches of sandy beach between large, deeply-indented bays, such as Pender Bay, Beagle Bay and Carnot Bay on the western shore of the Dampier Peninsula. The characteristic V-shaped bays generally include geomorphological features such as rocky headlands, reefs and sand flats at the seaward corners and extensive mud flats that support mangroves at their heads. The open-ocean shores feature very wide intertidal sand flats with little plant growth but a rich fauna. Roebuck Bay, Lagrange Bay and the remainder of the Coast to the south contain a variety of landforms including rocky headlands, shores and intertidal platforms, extensive gravel, sand and mud flats, cliffs and open beaches.

The only offshore islands of the Canning Coast are the Lacepedes, which are sand islands built on a limestone rock platform. Important bird and turtle nesting areas, the Lacepede Islands complex comprises lagoons, rock platforms, mud and sand cays and is surrounded by usually-turbid sea water.

6.2.2 Aquaculture Sites

6.2.2.1 Existing

The Broome Tropical Aquaculture Park is considered an essential component of aquaculture development in the region. Located on a 4.4 ha block of land near Riddell Point, the Park provides sub-lease blocks and essential services such as sea water supplies to aquaculture proponents. Among other objectives, it will provide support for aquaculture ventures that aim to develop technology and provide seed or juveniles for stocking more remote aquaculture projects. The Tropical Aquaculture Park currently supports two major tenants: the site is developed, has one pearl oyster hatchery and a trochus hatchery is being planned by the Kimberley Aquaculture Aboriginal Corporation.

Numerous pearling leases occur throughout the Canning Coast, within the Carnot Bay, Pender Bay and Lacepede Island areas. Pearling leases occur throughout the waters of Roebuck Bay.

The Canning Coast already supports pearl oyster, red claw crayfish and aquarium fish farming operations. One aquaculture licence has been issued for an onshore site near Kelk Creek.

6.2.2.2 Potential

The Dampier Peninsula Zone, as it is described in the Kimberley Aquaculture Development Plan, includes King Sound, the Dampier Peninsula and the Canning Coast. It includes both marine and inland aquaculture prospects (inland areas are discussed in section 7.1.2). The area currently lacks aquaculture-related infrastructure and a supply of seed or juveniles of suitable species for stocking.

No potential sites have been nominated in the Canning Coast, however the overall area is considered to have potential.

6.2.2.3 Sensitive or Prohibited

The Cape Coulomb Nature Reserve will impede access to the adjacent waters and the development of onshore facilities is likely to be prohibited.

The shores and hinterland of Roebuck Bay south of the Broome town site are declared as a *Wetland of International Importance* for migratory shorebirds under the Ramsar Convention and although not specifically prohibited, aquaculture proposals in this area will be environmentally sensitive.

Areas that have been nominated for marine reserve status include the Lacepede Islands, Roebuck Bay and Lagrange Bay.

6.2.3 Aquaculture Species

Species identified by planning studies as aquaculture candidates vary according to the location, with coastal and intertidal areas suited to cultivation of marine prawns, mud crab and clams and offshore areas to the production of marine finfish and shellfish, trochus, and clams.

6.3 Eighty Mile Beach

6.3.1 General Features

Eighty Mile Beach extends from Cape Missiessy to Cape Keraudrin. Gently curving almost continuously for its total length of about 220 km, the white-sand beach is about 100 m wide and slopes to muddy tidal sand flats. Its few small, muddy bays support sparse mangroves. The largely-unvegetated sand flats are very wide, extending seaward up to several kilometres. Its coast has a very large tidal range and moderate wave energy.

6.3.2 Aquaculture Sites

6.3.2.1 Existing

Pearl culture leases occur off Eighty Mile Beach, where seeded oysters are cultured on longlines or in baskets.

6.3.2.2 Potential

No potential sites have been identified within this sector.

6.3.2.3 Sensitive or Prohibited

Eighty Mile Beach has high conservation significance as a habitat for migratory shorebirds. The beach and land, to an elevation of 40 m above high tide level, between Cape Missiessy and Cape Keraudren is designated as a *Wetland of International Importance* under the Ramsar Convention. The sector is classified as sensitive due to the high habitat value and the international recognition accorded the site.

6.3.3 Aquaculture Species

No potential species have been identified specifically for Eighty Mile Beach by the various, relevant planning studies.

6.4 The Pilbara Coast

6.4.1 General Features

The Pilbara Coast extends from Cape Keraudrin to the North-West Cape. With the exception of the Dampier Archipelago, the relief of which is relatively high, the Coast is mainly low relief and comprises long, sandy beaches or mangroves backed by sand dunes; there are also many lagoons, bays, inlets and some rocky headlands and limestone cliffs. The shore line is dominated by long beaches and muddy tidal flats and the Coast characterised by deltas, barrier islands, which are the remnants of eroded shore lines, and lagoons with extensive mangroves backed by wide, supra-tidal flats. The climate is arid; the large rivers in the area are seasonal and flooding infrequent. The Coast features more moderate tidal ranges between 3 and 8 m. Wave energy is low and the coastal environment influenced periodically by cyclones, which are relatively common in this area. Subjected to periodic run-off and strong tidal flows, the nearshore waters are fairly turbid.

The offshore areas of the Rowley Shelf comprise numerous islands and coral reefs, the waters of which are clear. Each of these types of island off the Pilbara Coast has a characteristic form

of shore habitat, determined in part by substrate and exposure to wave action. Islands of the Dampier Archipelago, which are inundated relics of the higher parts of the mainland, lie within the nearshore zone and feature igneous, rocky shores. Barrow Island and North and South Muiron islands are limestone relics; other offshore and nearshore islands such as the outer islands of the Dampier Archipelago comprise limestone while others are sand islands formed on shallow banks. The Rowley Shoals are shelf-edge atolls that arise from deep water, are formed of coralline limestone and feature actively-growing coral reef systems, some with emergent sand cays.

6.4.2 Aquaculture Sites

6.4.2.1 Existing

A number of pearling and aquaculture licences have been granted in the waters of the Dampier Archipelago. In particular, there are existing pearling leases in the lee of Enderby and Gidley Islands, with proposed sites in the lee of Goodwyn and Angel Islands. There is an existing aquaculture licence to the west of West Lewis Island and one in Flying Foam Passage. In total, there are four onshore and offshore aquaculture licences in the region of the Dampier Archipelago.

Pearling leases occur throughout the Pilbara Coast region, including the waters off Port Hedland, Cape Lambert, Cape Preston, Mangrove Passage, Dampier and the Montebello Islands. Onslow provides a land base for a pearling company that operates in the Montebello Islands. Whalebone Island is utilised by Exmouth Gulf Pearling. A pearl oyster hatchery has commenced operation in the Exmouth Gulf area. There are an six pearling leases and three aquaculture licences within Exmouth Gulf.

In addition to those already mentioned in the vicinity of the Dampier Archipelago and Exmouth Gulf, five other aquaculture licences have been issued in various coastal areas of the Pilbara Coast.

A proposal has been made by the Gascoyne Development Commission and Curtin University to develop a Marine Research Operation at Exmouth, which could provide research and development requirements for an aquaculture industry in the region.

6.4.2.2 Potential

The waters off Dampier are already utilised for pearling and aquaculture and have potential for additional development. This issue is discussed within the *Karratha Area Development Strategy*, which recommends the development of a specific Aquaculture Development Plan to accommodate any conflict with shipping, recreation and conservation interests. The *Karratha Area Development Strategy* also defines aquaculture and horticulture zones within the Karratha Town Structure Plan.

The coastline of the Exmouth Gulf is rated as having very high potential for the onshore and offshore aquaculture of marine finfish and shellfish. The area is suitable for pond-

based production systems utilising ground water extracted from bores and can support sea cages, longlines, ranching, racks and pens in the waters of the Gulf. Specific sites within the Gulf are discussed below.

- Onshore hatchery and growout operations may be possible at Point Murat, possibly utilising an open-ocean, flow-through, sea-water supply system. The land is currently vested with the Commonwealth, which may constitute a development constraint for this site.

- Onshore tank cultivation of marine finfish has been identified as possible at Bundegi, within the coastal park.

- The Bay of Rest has been assessed as a potential site for offshore marine shellfish cultivation using rack, longlines and ranching. This may be problematic due to the proposed Marine Park and the existing high levels of recreational use.

- Gales Bay is nominated as a potential location for the offshore aquaculture of marine shellfish using racks, longlines and ranching, with potential for an onshore lease site within the Sandalwood Point town site.

- Wapet Creek is considered to provide opportunities for the onshore pond or tank aquaculture of estuarine finfish and shellfish as well as the offshore aquaculture of molluscs using racks and longlines.

- Point Lefroy and Sandalwood Point are rated as having moderate potential for onshore or offshore shellfish aquaculture.

6.4.2.3 Sensitive or Prohibited

A large proportion of the nearshore islands within the Pilbara Coast are existing Nature Reserves that will be sensitive in relation to the establishment of any onshore support facilities for aquaculture operations. The reserves include:

- Great Sandy Island Nature Reserve, which includes all portions of land above the low water mark;
- Tent Island Nature Reserve;
- Muiron Islands Nature Reserve;
- Barrow Island Nature Reserve; and
- Dolphin Island Nature Reserve.

The Rowley Shoals Marine Park comprises the Mermaid, Clerke and Imperieuse Reefs and should be considered sensitive in relation to aquaculture. Mermaid Reef is a Marine Park under Commonwealth legislation and the Clerke and Imperieuse Reefs are Marine Parks under State legislation.

The Montebello Islands are declared as a conservation park, and the Bundegi Coastal Park within the Exmouth Gulf has a high potential for conflict between commercial aquaculture and recreational use.

The Burrup Peninsula Marine area is sensitive for environmental and recreational reasons. The area is a proposed Marine Reserve and is known habitat for dugongs and turtles. Shipping operations and commercial fisheries also occur in the region and therefore careful planning is required. Much of the region is sensitive but not prohibited. As well as having marine conservation values, the offshore islands are predominantly conservation and recreation reserves and would be sensitive to onshore aquaculture facilities.

Recommended for marine reserves are the waters surrounding Bedout and North Turtle Islands, Cowrie Beach, Dampier Archipelago, Cape Preston, Montebello Islands, Biggada Reef, Bandicoot Bay, Muiron Islands, Semurier and Bessieres Island, the coastal zone between the Fortescue and Cane Rivers, and Exmouth Gulf.

6.4.2.4 Special Significance Area: Exmouth

An area around Exmouth, south of the North-West Cape and on its eastern coast, is considered to have good potential for commercial aquaculture development. The physical, biological and other features of the area are described in additional detail in chapter 3 of *Part B: Sites and Maps*. In particular, the area is characterised by having access to generally-high-quality sea water that can be pumped ashore by way of beach wells and is considered suitable for the onshore production of tropical marine finfish species.

6.4.3 Aquaculture Species

Several candidate species have been recommended for aquaculture at the sites identified as having potential in Exmouth Gulf. These are:

- mullet, grouper, emperors, mahimahi and marine aquarium fish at Bundegi and Point Murat;
- edible oysters, pearl oysters and mud crabs in the Bay of Rest and Gales Bay;
- edible oysters, marine prawns, mud crabs and estuary cod at Wapet Creek; and
- edible and pearl oysters, marine prawns and mud crabs at Point Lefroy and Sandalwood Point.

6.5 The Ningaloo Coast

6.5.1 General Features

The Ningaloo Coast extends from the North-West Cape to Point Quobba. Ningaloo Reef, one of Australia's major coral reef systems, extends from the North-West Cape to Gnarloo Bay. Almost continuous in its northern part, the barrier-fringing coral reef becomes an interrupted fringing reef in its southern part. It is reserved as a Marine Park. The shallow waters and highly-complex coral reefs support an abundant and species-rich coral reef community. Limited sections of mangrove forests are found in the area. Southwards from the reef to Point Quobba, the rocky shore features low to high limestone cliffs exposed to westerly winds and swells and a limited number of partially-sheltered bays.

The marine environment of the Ningaloo Coast features very clear oceanic waters with a relatively low tidal range of less than 2 m and high wave energy. Cyclones are less common here than along the north-west coast. Little sediment or fresh water enters the sea due to the low annual rainfall characteristic of the arid tropics.

6.5.2 Aquaculture Sites

6.5.2.1 Existing

No existing aquaculture sites occur within this sector.

6.5.2.2 Potential

The Ningaloo Coast is a unique environment, with high conservation and recreation value. The coastline is high-energy and aquaculture potential is limited in this region. Some sites have been nominated within the Gascoyne Aquaculture Development Zone as having low potential for aquaculture due to conservation factors and the absence of infrastructure and suitable tenure. The constraints nominated for the zone are diverse and significant and, for the purposes of this report, no sites are nominated as having potential for aquaculture development.

6.5.2.3 Sensitive or Prohibited

The Ningaloo Coast is dominated by the Ningaloo Marine Park, which is a sensitive area due to marine habitat values and recreational use. Aquaculture has been rated as being incompatible with and is therefore prohibited within the Cape Range National Park and the Jurabi Coastal Park. The Point Quobba Reserve will be a constraint for provision of onshore facilities.

6.5.3 Aquaculture Species

Should an aquaculture operation be pursued in this zone, species identified by planning studies as aquaculture candidates include coral trout, grouper, emperors, mahimahi, marine aquarium fish and edible oysters.

6.6 The Shark Bay Coast

6.6.1 General Features

The Shark Bay Coast extends from Point Quobba to Kalbarri; offshore it includes Bernier, Dorre and Dirk Hartog islands. The climate is arid, there are few permanent surface waters and no streams enter the western side of Shark Bay. The principal feature of the region is Shark Bay, a large marine embayment with extensive seagrass meadows that support large populations of marine mammals and reptiles and serve as important nursery areas. A large part of the area is reserved as a Marine Park and Marine Nature Reserve to protect the unique fauna and flora of the area.

Bernier, Dorre and Dirk Hartog islands form the seaward boundary of Shark Bay. The leeward, relatively-sheltered eastern shores of these islands are exposed to moderate wave action. They have shallow bays with curved beaches between headlands of low limestone cliffs. Exposed to strong wave action, the windward western shores of the islands are characterised by high cliffs. The eastern shore of Shark Bay is a low-relief, low-wave-energy shore with mangroves and wide tidal flats. The southern portion contains the hypersaline Hamelin Pool, which supports stromatolites of high conservation value. Sheltered areas within Shark Bay comprise sandy beaches and low limestone cliffs. The seasonal Gascoyne and Wooramel rivers enter the sea on the Shark Bay Coast. The southern section of the Coast comprises steep cliffs that extend southwards to Kalbarri.

Similar to that of the open ocean in the vicinity of the islands that form its western boundary, the salinity of the sea water in Shark Bay gradually increases to hypersaline levels in the inner parts of the Bay. The coral reefs and coral communities of Shark Bay are small and only moderately rich in species; however, the Bay supports the world's largest known seagrass meadow.

6.6.2 Aquaculture Sites

6.6.2.1 Existing

At Oyster Creek in Carnarvon, an existing hatchery is licensed to culture *P. maxima* pearl oyster seed and for aquaculture.

Within Shark Bay, seven aquaculture licences have been issued. Six are for non-*P. maxima* pearl oysters and one for marine finfish (one of the six former licences also permits the aquaculture of finfish).

A 5 ha area for onshore aquaculture operations, including a support area for the existing pearling industry, has been proposed within the Monkey Mia Reserve. The aquaculture precinct would require excision from the reserve, as it is not compatible with the reserve purpose.

6.6.2.2 Potential

The potential for aquaculture on the Shark Bay Coast has been assessed in the *Gascoyne Aquaculture Development Plan*.

In the Carnarvon area, Babbage Island has been assessed as being suitable for a growout or hatchery facility and Oyster Creek is considered to have potential for the aquaculture of brackish-water and marine species using pond production systems.

Within Shark Bay, the following sites are considered to have aquaculture potential:

- Dirk Hartog Island (the Island itself for onshore support facilities and the protected waters off its eastern shore for sea cages);
- Useless Loop and Useless Inlet (opportunities exist for the aquaculture of marine and hypersaline species in association with the salt mining process using onshore production systems);
- Heirrison Prong (where onshore facilities can be established to support sea cages and longlines);
- Wooramel coastal creeks (onshore ponds or tanks, or offshore longlines placed where creek channel scours exist);
- Peron Peninsula western coastline (offshore production systems employing sea cages, longlines, racks and pens);
- Peron Peninsula eastern shoreline (offshore production systems employing sea cages, longlines and racks);
- South Peron and Denham (suitable for onshore tanks and ponds);
- Nanga Station (onshore tank culture, adjacent waters are not in the marine park and suited for offshore sea cages, longlines and racks); and
- Bellefin Prong (the adjacent waters are considered suitable for sea cages, longlines and racks).

6.6.2.3 Sensitive or Prohibited

The Shark Bay World Heritage Area incorporates the marine and terrestrial conservation values and management zones for this area. The management goals include the realisation and maintenance of aquaculture fisheries values, so while aquaculture may be considered sensitive in the area it is not prohibited. However, the World Heritage Area does contain several zones within the Shark Bay Marine Park and the Hamelin Pool Marine Nature Reserve in which aquaculture is not permitted. These are sanctuary zones (proposed Lharidon Bight, Disappointment Research, Surf Point, Mary Anne Island, 18 Mile, Big Lagoon and Gudrun Wreck Sanctuary Zones), recreation zones (Monkey Mia, Dubant Inlet, Little Lagoon Recreation Zones) and special purpose zones (Boorabugatta, Gladstone, Big Lagoon and Cape Peron).

In addition to the marine conservation and recreation reserves, there exist several terrestrial conservation reserves. Aquaculture would be incompatible with the management objectives of these reserves since the industry would not constitute a compatible or consistent use. The areas include the Francois Peron National Park, the Zuytdorp Nature Reserve and the Monkey Mia Reserve. These areas can be considered sensitive, with any aquaculture development requiring excision of land from the reserves.

The Wooramel Seagrass Bank should be considered a sensitive area due to the potential impact of an aquaculture operation on seagrass meadows.

The South Passage navigational channel must be kept open for boating purposes, hence any aquaculture development here would constitute a hazard and not be permitted.

6.6.3 Aquaculture Species

The proposed aquaculture precinct within the Monkey Mia reserve is considered suitable for the culture of edible oysters, pearl oysters, marine finfish and aquarium fish.

Species considered suited for onshore tank culture on Babbage Island include bream, Westralian dhufish, mullet, mahimahi and aquarium fish. Oyster Creek species include edible oysters, pearl oysters, Penaeid prawns, mud crabs, estuary cod and mangrove jack.

Species considered suited for aquaculture on and in the waters adjacent to Dirk Hartog Island include marine finfish (emperors, yellowfin bream, grouper, Westralian dhufish, yellowfin tuna, mahimahi and pink snapper) and molluscs (edible oysters, pearl oysters and scallops).

Useless Loop is considered to have potential for the aquaculture of brine shrimp, microalgae (beta carotene) and milkfish in association with salt mining operations.

Heirrison Prong is believed suited to culture of marine finfish (yellowfin tuna, grouper, pink snapper) and molluscs (edible oysters and scallops) on racks and longlines.

Recommended species for the Wooramel coastal creeks are estuary cod, mangrove jack, prawns, mud crabs, edible oysters and pearl oysters.

The Peron Peninsula western coastline and eastern shoreline are rated as being suitable for the production of marine finfish (Westralian dhufish, pink snapper, mahimahi, yellowfin tuna) and shellfish (edible oysters, pearl oysters and scallops).

The South Peron and Denham region is assessed as suited for the hatchery production and growout of marine finfish (mahimahi, aquarium fish, Westralian dhufish, pink snapper and estuary cod) and ponds for marine prawns, edible oysters and pearl oysters.

Potential aquaculture species for Nanga include marine finfish (Westralian dhufish, mahimahi, pink snapper, estuary cod and aquarium fish) and molluscs (edible oysters).

Bellefin Prong is considered suited for the culture of marine finfish (Westralian dhufish, snapper, bream, mahimahi and yellowfin tuna) and shellfish (edible oysters, pearl oysters and scallops).

6.7 The Central West Coast

6.7.1 General Features

The Central West Coast extends between Kalbarri and Perth and includes the Abrolhos Islands. Generally characterised by a high wave energy and with small tides of less than 1 m, the coastline commonly has long sandy beaches with occasional limestone cliffs and headlands. The sea water is usually very clear due to limited fresh-water run-off from the adjacent, low-rainfall land areas; the main rivers on the Central West Coast are the Murchison, Chapman, Irwin, Greenough, Hill, Moore and Swan rivers. The Coast is further characterised by an extensive system of limestone reefs that parallel the coast; these reefs protect the sandy coastline and permit the growth of extensive seaweeds and seagrasses, which provide an important nursery ground for marine animals.

At Kalbarri, the Coast features a short length of moderately-high-energy coast with high sandstone cliffs, intertidal rock platforms dominated by algal growth and no coral reefs. Between Kalbarri and Port Denison on the Central West Coast, the relatively straight shore has a moderate wave energy and sandy beaches. Seaweed dominates the limestone reefs, seagrass meadows are moderately developed in the more sheltered areas and small, species-poor coral reefs occur in some areas. From Port Denison southwards to Perth, the coastal landforms are similar and the development of offshore limestone reefs more extensive. Seaweeds dominate the more exposed sublittoral zone and seagrasses the lagoons and other more protected areas. There are no coral reefs along this sector of the Coast.

The offshore Abrolhos Islands comprise a series of coral platforms and islands that support prolific coral reef development. Influenced by the warm Leeuwin Current, the Abrolhos Islands support the growth of extensive coral reefs well south of their normal range. The high-energy seaward reefs of the Islands are dominated by algal beds, while seagrass meadows are present in the protected shallow areas of some of the islands. The most diverse and prolific coral growth occurs in the low-wave-energy, leeward areas, along the sides of channels and blue holes; unlike similar coral reefs in the tropics, the seaward reef fronts support poor coral reef development. In terms of habitat and coral species diversity, the reefs of the Abrolhos Islands are the richest of any high-latitude reefs in the world. The reef communities are unusual in that they support a significant number of temperate as well as tropical species. The occurrence of tropical fish species and some hard corals at Rottnest Island, adjacent to Perth, is also due to the influence of the Leeuwin Current.

6.7.2 Aquaculture Sites

6.7.2.1 Existing

Within the Central West Coast region, beta-carotene is produced on an aquaculture licence over Hutt Lagoon. One aquaculture licence has been issued for an offshore site at Green Island, near Cervantes. Two licences have been issued for offshore sea cages near Jurien Bay; one licence is for three sites and the other is for one. Two hatchery licences have also been issued for onshore sites near the Jurien town site.

One licence has been issued for a sea cage near the Geraldton Port and one non-*P. maxima* pearl oyster licence for a site at the Abrolhos Islands.

6.7.2.2 Potential

The Shire of Dandaragan Aquaculture Planning Strategy assessed the area's coastal zone for marine aquaculture potential. Due to current constraints (principally the lack of suitable infrastructure) many sections of the coast in the Shire were rated as having low potential for aquaculture in the short to medium term. Based on its physical characteristics and access to existing infrastructure, the coastal sector between Jurien Harbour and Black Point is considered to have potential for aquaculture development.

The *Technical Evaluation of Sites for Land-Based Marine Aquaculture in the Mid-West Region* (section 3.1.8) assessed the potential of 16 coastal sites between Greenhead and Kalbarri for commercial aquaculture development. Of these, four were considered primary sites, three as secondary and nine as tertiary sites. The primary sites are located at Geraldton Port, Hutt River, South Hutt Lagoon and the proposed Port Kalbarri development. The secondary sites are located at Greenhead, Dumper Bay and a larger zone within the Shire of Irwin. Tertiary sites were considered to have low potential for aquaculture development in the short to medium terms and were not considered further.

6.7.2.3 Sensitive or Prohibited

A number of National Parks and Nature Reserves within the Central West Coast region will inhibit access to the coast for onshore support facilities for aquaculture ventures. These include Kalbarri National Park, Beekeepers Nature Reserve, Nambung National Park, Wanagarren Nature Reserve and the Nilgen Nature Reserve.

The Marmion Marine Park, which has significant conservation and recreational value, encompasses an area of 9,500 ha off the northern Perth metropolitan coast. The sanctuary and recreation zones in the Park will be prohibited for aquaculture, while the remainder of the Park is nominated as sensitive. Commercial fishing activities currently occur within the Park, so aquaculture may be a compatible use, although recreation use conflict is likely to be high.

Although not mapped as such, proposals within the coastal zone of the metropolitan area and extending south to Mandurah should be considered sensitive. This is due to the use pressures placed on this stretch of coastline and the extent of conflict between commercial and recreational users in this area.

Under the *Rottnest Island Reserve Authority Act* 1987, the waters surrounding Rottnest Island are reserved to 800 m offshore for recreational purposes. Commercial aquaculture is likely to be prohibited within this zone.

Additional areas proposed for marine reservation within this sector include:
- the coast between Bluff Point and the mouth of the Murchison River;
- the waters off Port Gregory;
- areas within the Abrolhos Islands;
- Seven Mile Beach and the Beagle Islands; and
- Jurien area between Sandland Island and Booker Rocks.

6.7.3 Aquaculture Species

The following species are those considered in the planning studies and by various authorities to have potential for commercial aquaculture in the Mid-West (Kalbarri to Greenhead) region.[27] The same species lists could be extended to be applicable to the entire Central West Coast Region.

Marine finfish include Westralian dhufish, yellowtail kingfish, black bream, snapper, western school whiting, yellow-finned whiting, large-toothed flounder, small-toothed flounder, mulloway, estuary cod, coral trout, and various marine and fresh water aquarium species.

Marine shellfish include Roe's abalone, western rock lobster, saucer scallop, blacklip oyster, and kuruma prawn.

Species considered suitable for the Dandaragan area include microalgae (*D. salina*), western rock lobster, scyllarids (bugs), Penaeid prawns, marine finfish, abalone and scallops.

6.8 The Leeuwin-Naturaliste Coast

6.8.1 General Features

The Leeuwin-Naturaliste Coast extends from Perth to Walpole Inlet on the south coast. Generally, this Coast is exposed to heavy wave action and its nearshore and open-ocean waters are clear and high in quality. The shoreline is characterised by granitic headlands and sandy beaches. Rainfall is relatively high, particularly in the south-western part of the Coast.

Between Perth and Bunbury, the shores comprise long sandy beaches moderately exposed to wave action and limestone headlands with intertidal rock platforms. The main features of this sector are the two deep-basin embayments of Cockburn and Warnbro sounds, the offshore emergent rocks and limestone islands (Rottnest, Garden and Carnac islands) and the Swan, Peel-Harvey and Leschenault estuaries. The exposed rocky platforms and limestone ridges are dominated by seaweeds, while seagrass meadows dominate the offshore lagoons. There are no coral reefs, although coral communities are common at areas such as Rottnest Island.

Between Bunbury and Cape Naturaliste, the main feature is Geographe Bay, which has a north-facing beach exposed to moderate wave energy. The seabed in Geographe Bay is dominated by extensive seagrass meadows. Between Cape Naturaliste and Cape Leeuwin, the high-wave-energy coast features sandy beaches between rocky headlands and the area is dominated by seaweed. The leeward, eastern shores of the Capes are sheltered and more protected from wave action.

South-eastwards towards Walpole Inlet, the high-wave-energy coast is generally exposed to heavy swells. More sheltered conditions prevail in some protected bays and in the estuaries and

[27] The scientific names of these species are provided in section 5.1 of this document.

inlets. Significant features on this section of coast include Hardy, Broke, Nornalup and Walpole inlets.

6.8.2 Aquaculture Sites

6.8.2.1 Existing

There are three aquaculture zones within the boundaries of the Fremantle Port Authority, *viz.*: the Boom Defence Jetty Victoria Quay (finfish farming), Kwinana Grain Jetty and Garden Island (mussel cultivation). A site to the east of Garden Island in Buchanan Bay is proposed for the relocation of mussel farming operations, as the existing leases are due to expire and unlikely to be renewed. Three aquaculture licences, for onshore and offshore operations, have been issued for sites near Fremantle.

Aquaculture licences for mussel culture occur within Warnbro and Cockburn Sounds (three licences in the former and eight in the latter). One licence has been issued in Bunbury.

6.8.2.2 Potential

No potential aquaculture sites were identified within the planning studies that were reviewed.

6.8.2.3 Sensitive or Prohibited

The Shoalwater Islands and the Shoalwater Marine Park are sensitive areas due to their conservation and recreation significance. The management goals are for conservation, recreation, information and education, and research and monitoring. Commercial aquaculture development is unlikely to be compatible with the management objectives.

It is reported that sites have previously been identified within the Leschenault Inlet and Estuary, but proposals have been rejected by the Leschenault Inlet Management Authority on the grounds of the possible impact on the fragile marine environment. Portions of the Inlet are designated for conservation and some sections occur within the boundaries of the Bunbury Port Authority.

The Peel-Harvey Inlet is a nominated Ramsar wetland and also includes numerous sections that are within nature reserves and national park boundaries. This area is considered sensitive for aquaculture development.

Coastal conservation reserves within which aquaculture would be sensitive or prohibited include Yalgorup National Park, Leeuwin Naturaliste National Park, Gingillup Swamps Nature Reserve, Warren National Park D'Entrecasteaux National Park and the Walpole-Nornalup National Park.

Areas proposed for addition to the marine conservation reserve include:
- Five Fathom Bank, east of Garden Island and Warnbro Sound;
- sections of the Peel-Harvey Inlet system;
- sections of the Leschenault Inlet;
- the Leeuwin-Naturaliste coast (from Dunsborough to Augusta);
- Black Point;
- Warren Beach;
- Broke Inlet; and
- Walpole-Nornalup Inlet.

6.8.3 Aquaculture Species

Mussel culture already occurs within this region. No additional aquaculture species were identified within the reviewed planning studies.

6.9 The South Coast

6.9.1 General Features

The South Coast extends from Walpole Inlet to Esperance and the islands in Esperance Bay. Facing the southern ocean, the South Coast features high wave energy, strong winds and colder, usually high-quality sea water with low turbidity. The coastline comprises sandy bays, inlets, rocky headlands and cliffs with few sheltered areas. The estuaries are generally closed by sand bars across their mouths for protracted periods; the sand bars are only breached during high river flows after heavy rainfall. Limestone shores are a notable feature of this coast. The open beaches are exposed to heavy wave action and provide habitats suitable only for a few specialised plants and animals. Exposed reefs are covered by seaweeds; seagrass meadows occur in the more sheltered areas. The open, rocky shores provide a variety of habitats for marine organisms.

The western portion of the South Coast features small bays and beaches between sometimes-high headlands. The southern and south-western faces of these headlands are cliffed or steep and exposed to swell surges; the south-eastern sides are exposed to lesser wave action. The shores near the headlands usually drop off steeply into relatively deep water.

A major feature of the South Coast is the Albany Harbours area, which comprise King George Sound, Princess Royal Harbour and Oyster Harbour. King George Sound is a marine gulf, Princess Royal Harbour an enclosed marine inlet and Oyster Harbour both a marine inlet and an estuary. The habitats in these areas range from open-ocean marine and protected marine inlet to estuarine. The variety of shores, intertidal mud and sand flats, reefs and deep basins in the area supports an exceptionally rich and diverse flora and fauna. Dense seagrass beds, some of which have been depleted as a result of eutrophication, are rich in species and the extensive flats support diverse burrowing communities.

6.9.2 Aquaculture Sites

6.9.2.1 Existing

Several aquaculture licences have been issued within the Albany Harbours area, which has a history of aquaculture proposals and operations.

Within Oyster Harbour, one company owns three aquaculture sites and an onshore hatchery site. The same company also owns an onshore hatchery site near Frenchman Bay, and two additional offshore site, one in King George Sound and one in Princess Royal Harbour. One aquaculture licence has been issued to the company for all these sites.

Numerous licences exist in King George Sound for culturing mussels. An onshore abalone hatchery near Frenchman Bay has been licensed. The Albany TAFE college has also been issued with an aquaculture licence.

6.9.2.2 Potential

The Albany Harbours area has been investigated in detail for potential zones or sites that may be used for aquaculture development. The study was undertaken in order to deal with the various conflicting interests within the region, including commercial and recreational fishing, boating and shipping, coastal and marine recreation and conservation.

The Policy Area for aquaculture within the Albany harbours is divided into the five areas. These are:

- A1: 125 ha, comprises three current aquaculture leases in Oyster Harbour;
- A2: covers the eastern corner of Princess Royal Harbour, extending from Geake Point in the north to South Spit in the south (it excludes areas used by the Princess Royal Sailing Club and for harvesting algae);
- A3: approximately 75 ha, occupies the shallow, north-west marginal shelf of Princess Royal Harbour;
- A4: covers the south-west portion of King George Sound from north of Mistaken Island southwards to Frenchman's Bay (further aquaculture development would be restricted to non-obtrusive, sub-surface production systems); and
- A5: approximately 550 ha, covers one aquaculture licence currently located in the south-east corner of King George Sound from Water Bay Point to Limestone Head and includes Flat Rock.

A study into the potential for aquaculture in the Bremer Bay region investigated seven sites within Bremer and Dillon bays for onshore aquaculture purposes. The sites, their rated potential and recommended productions systems are listed below:

- Back Beach: high potential, flow-through tanks and raceways;
- Fishery Beach: medium potential, flow-through and recirculation hatchery;
- Short Beach: high potential, flow-through tanks and raceways;
- Little Boat Harbour: low potential, hatchery or land-based growout;
- Blossoms Beach: medium potential, flow-through tanks and raceways;
- Native Dog Beach: low to medium potential, flow-through tanks and raceways; and
- Dillon Bay: low potential, flow-through tanks and raceways.

6.9.2.3 Sensitive or Prohibited

There are numerous National Parks and Nature Reserves that occur on the South Coast that may inhibit onshore aquaculture development. The reserve boundaries predominantly extend to the low water mark. The National Parks include the Walpole-Nornalup National Park, West Cape Howe National Park, Torndirrup National Park, Waychinicup National Park, Fitzgerald River National Park (also an UNESCO Man (sic) & the Biosphere Program reserve), Stokes National Park and William Bay National Park.

The Nature Reserves include Two People's Bay Nature Reserve, Jerdacuttup Lakes Nature Reserve, and Lake Shaster Nature Reserve.

Ledge Bay within the Albany Harbours is a recognised anchorage on nautical charts. Interference and conflict may occur with port activities and commercial fishing operations as well as recreational and visual impacts.

Areas proposed for addition to the marine conservation reserve system include the waters of William Bay, West Cape Howe, Albany Harbours, King George Sound, Cape Vancouver to Cheyne Beach, coastal waters adjacent to Fitzgerald River National Park (including the Gordon, St Marys, Fitzgerland, Dempster and Hamersley Inlets), and the coast adjacent to Stokes National Park.

6.9.3 Aquaculture Species

Species identified by planning studies as aquaculture candidates for the Albany Harbours area include oysters, mussels, abalone and finfish.

Species identified by planning studies as aquaculture candidates in the Bremer Bay region include abalone, black bream, yellowtail kingfish, snapper, flounder, King George whiting and Westralian dhufish.

6.10 The Eucla Coast

6.10.1 General Features

The Eucla Coast extends from Esperance to the South Australian border and principally comprises the Recherche Archipelago, the dominant offshore feature, and the shores of the Great Australian Bight. These shores are characterised by high-energy wave action and comprise either high limestone cliffs or long, curved beached backed by dunes. The western part of the Eucla Coast, east of Esperance and Israelite Bay, is characterised by the Recherche Archipelago. Most of the many islands of the Recherche Archipelago are exposed to moderate to high wave action from all directions and there are few protected areas.

6.10.2 Aquaculture Sites

6.10.2.1 Existing

No existing or proposed sites have been identified in the Eucla Coast.

6.10.2.2 Potential

No sites have been identified within existing planning reports as having potential for aquaculture development.

6.10.2.3 Sensitive or Prohibited

National Parks extending to the coast in this sector include Cape Le Grand National Park, Cape Arid National Park and Eucla National Park. The Recherche Archipelago Nature Reserve includes islands of the archipelago that are incorporated into a single A-Class nature reserve. The Nuytsland Nature Reserve also occurs on the coast in this sector.

The waters of the Recherche Archipelago and islands which are State territory are recommended for inclusion into the marine conservation reserve system.

6.10.2.4 Special Significance Area: Esperance

The Recherche Archipelago east of Esperance is considered to have good potential for commercial aquaculture development. The physical, biological and other features of the area are described in additional detail in chapter 3 of *Part B: Sites and Maps*. In particular, the area is characterised by numerous islands and high-quality sea water that can be utilised for the offshore production of temperate and cold-temperate species of marine finfish and shellfish.

6.10.3 Aquaculture Species

No potential aquaculture species have been identified for the Eucla Coast in existing planning studies.

7 WA INLAND AQUACULTURE REGIONS

The major sources of water for inland aquaculture in Western Australia are surface and ground waters. The descriptions of the aquaculture-oriented resources of the Leichardtian, Greyian and Vlaminghian Regions, in sections 7.1, 7.2 and 7.3 respectively, deal with surface waters only; ground waters are dealt with as a separate category in section 7.4, the Ground Water Region. The purpose of this classification is to reflect the perceived importance of ground water resources for future aquaculture development in the State and to cater for additional, relevant information to be inserted into this document as it is developed.

Most of Western Australia has no permanent rivers and streams; however, the south-western and Kimberley areas have adequate rainfall to support both permanent and ephemeral rivers and streams. Generally, the rivers and streams of the Leichardtian, Greyian and Vlaminghian Regions are exorheic; that is, the waters drain into the sea through river systems. The few rivers in the central and Nullarbor areas of the State are arheic; little of the rainfall that does occur is carried off superficially. Endorheic systems, which drain internally to terminal lakes and the waters of which do not reach the sea, are not represented in Western Australia.

Due in part to escalating salinities in many inland areas of Western Australia, the importance of managing the State's surface and ground-water resources is becoming increasingly important. Catchments currently yielding potable water have been classified according to their potential to become more saline.[28]

7.1 The Leichardtian Region

7.1.1 General Features

The Leichardtian Region, which principally comprises the Kimberley Region of WA, has a summer wet season with thunderstorms, monsoonal rain and occasional tropical cyclones and a long winter dry season.

The major landforms of the Region vary from dune fields in the southern and eastern areas near the desert to the ranges and hills of the central and northern areas and low-lying, undulating land in the western area. Vegetation includes extensive mangrove and monsoon forests with some rain forest remnants on or near the coast; savanna woodlands in the centre; spinifex savanna in southern and eastern parts; and grasses, wattle and eucalypts in the western areas.

Pastoralism is the most extensive land use in the Region and a significant horticulture industry is developing on the irrigated, black-soil plains near Kununurra. A significant feature of the region is Lake Argyle, which provides water to Lake Kununurra and thence to the irrigated areas of the Ord River Irrigation Area. Lake Argyle constitutes a substantial aquaculture-oriented resource and is considered to have significant potential for further development.

[28] Some of the information provided in the sections that describe the general features of Western Australia's various inland regions is taken from the *State of the Environment Report*, Government of Western Australia, 1992.

The major drainage divisions and river basins of the Leichardtian Region that comprise the Timor Sea Drainage Division are the:

- Keep River;
- Ord River;
- Pentecost River;
- Drysdale River;
- King Edward River;
- Prince Regent River;
- Isdell River;
- Lennard River;
- Fitzroy River; and
- Cape Leveque Coast.

7.1.2 Aquaculture Sites

7.1.2.1 Existing

Lake Argyle supports a pilot barramundi farming operation, for which an aquaculture licence has been issued.

7.1.2.2 Potential

Lake Argyle has been identified as a site with significant potential for aquaculture development. Current impediments to commercial aquaculture development on the Lake include limited and restricted access, lack of suitable sites for onshore support facilities and a limited supply or lack of juvenile fish for growout.

Lake Kununurra, the Irrigation Area and the Lower Ord have been identified as areas with potential for fresh water aquaculture and for a put-and-take recreational fishery. Production systems could be established within the Lake, water supply channels and irrigation drains. The area presents opportunities for integrating aquaculture with the existing agricultural and horticultural industries. Compatibility of aquaculture species with pest management within the Ord River Irrigation Area is an important issue.

The Pastoral Zone of the Kimberley Region has also been nominated as having low to moderate aquaculture potential, with impediments created by limited and seasonal access, land acquisition and tenure.

7.1.2.3 Sensitive or Prohibited

This region contains numerous National Parks, within which aquaculture would be an incompatible land use and so can be considered to be Prohibited. These are the:

- Purnululu National Park;
- Drysdale River National Park;
- Hidden Valley National Park;

- Geikie Gorge National Park;
- Tunnel Creek National Park; and
- Windjana Gorge National Park.

Issues of land ownership and tenure should be investigated before feasibility studies are undertaken, due to the extent of pastoral leases and Aboriginal reserves within the region.

7.1.3 Aquaculture Species

Lake Argyle has aquaculture potential for freshwater fish including Argyle bream, barramundi, bony bream, Butler's grunter, catfish and native aquarium fish.

Lake Kununurra is rated as being suited to the cultivation of Argyle bream barramundi and fresh-water aquarium fish. The Ord River Irrigation Area has potential for the culture of Argyle bream, barramundi, native fresh water aquarium fish, redclaw crayfish, catfish, grunters and cherabin. The Lower Ord area is suited to the aquaculture of Argyle bream, barramundi, native aquarium fish, cherabin, red claw crayfish, mullet and brackish-water finfish.

The Kimberley Pastoral Zone has potential for culture of freshwater Argyle bream, barramundi, native aquarium fish, red claw and cherabin

7.2 The Greyian Region

7.2.1 General Features

The Greyian Region, which principally comprises the Pilbara, Gascoyne and Mid-West regions of WA, has a semi-arid to arid climate and, in its more northern areas, unreliable rainfall. The northern areas are influenced by cyclonic summer rainfall and less by winter rainfall. Inland areas receive sometimes-significant but patchy rainfall from thunderstorms. The more southern areas receive rainfall from the northern sections of large cold fronts in winter and some from tropical cyclones in summer.

The landforms comprise broad, low-lying river catchments and plains between irregular ranges and hills. The inland vegetation principally includes tree savanna and grasslands. The major rivers in the Region generally flood after heavy rainfall and then contract to a series of permanent pools.

Pastoralism is the most extensive land use, there is some large-scale mining and oil and gas exploration. Horticulture operations are located on the flood plains of the Gascoyne River near Carnarvon.

The major drainage divisions and river basins of the Greyian Region that comprise the Indian Ocean Drainage Division are the:

- De Grey River;
- Port Hedland Coast;
- Fortescue River;

- Onslow Coast;
- Ashburton River;
- Lyndon-Minilya River;
- Gascoyne River;
- Wooramel River;
- Murchison River; and
- Greenough River.

7.2.2 Aquaculture Sites

7.2.2.1 Existing

An aquaculture operation occurs within the Karratha town site for the production of redclaw crayfish and other freshwater tropical aquatic organisms for consumption. Two additional aquaculture licences have been issued for culturing beta-carotene; one near Karratha and one near Port Hedland.

7.2.2.2 Potential

The Carnarvon Horticulture Zone on the Gascoyne River provides surface water flow as well as fresh to brackish water in aquifers beneath the river. Potential exists in this location for the aquaculture of fresh water crustaceans from plantation water allocations, with nutrient-enriched waste water being utilised for crop irrigation. The water allocation would be used for freshwater finfish and crustaceans within tank culture systems.

7.2.2.3 Sensitive or Prohibited

The Carnarvon area may be considered sensitive for aquaculture development due to issues associated with water allocation and availability.

The Millstream-Chichester National Park, Karijini National Park, Collier Range National Park, Kennedy Range National Park and Kalbarri National Park all occur within this region and may be considered prohibited for aquaculture development.

The Barlee Range Nature Reserve, Mungaroona Range Nature Reserve, Tooloonga Nature Reserve, and Wandana Nature Reserve also occur in this region and should be considered sensitive with respect to aquaculture development.

7.2.3 Aquaculture Species

Species suited to tank and pond culture in the Carnarvon Horticulture Zone include yabbies, red claw, black bream, Spirulina and aquarium fish.

7.3 The Vlaminghian Region

7.3.1 General Features

The Vlaminghian Region principally comprises the Wheatbelt, Perth, Peel, South-West and Great Southern regions of WA.

The Wheatbelt area has a temperate to semi-arid climate dominated by rain-bearing cold fronts in winter and easterly winds in summer. The landform is slightly undulating. The main land use is agriculture, with cereal cropping and cattle and sheep grazing: much of the natural vegetation has been cleared for these purposes. Increasing problems with soil salinity and erosion are contributing to the degradation of the surface waters in the area.

The Perth and Peel areas are dominated by the passage of rain-bearing cold fronts during winter and hot easterly winds during summer. The landform is generally flat with low-lying sand dunes and numerous wetlands. Most of the area has been cleared for agricultural and urban uses. Many of the rivers in the area have their origins in the Wheatbelt, so are affected by increasing salinity and other problems such as excessive nutrients and sediments.

The south-western area generally receives high winter rainfall from rain-bearing depressions and cold fronts during winter; dry, easterly winds predominate in summer. Drainage lines are well defined and the major landforms include the Darling escarpment, prominent undulations in the Darling Range that extend from the south coast to the Wheatbelt, the Blackwood Plateau and the Scott River coastal plain, extending to the Leeuwin-Naturaliste ridge. The vegetation in the south-western area is mostly jarrah, marri and karri forest on the Darling Range, wandoo woodlands in the eastern areas and heath on the south coast. State forests dominate the area and agriculture is generally confined to some river valleys.

The temperate south coast area is dominated by cold fronts in winter and mild, dry summers. Landforms comprise extensive areas of gently-undulating land with some rocky outcrops and ranges. The vegetation varies from eucalypt forests near Albany to shrub lands and extensive heath lands in the central and eastern parts. Most of the land has been cleared for agriculture. Almost all the rivers and estuaries in the south coast areas have been affected by salinity, nutrients and sediments from the cleared land and water quality is generally deteriorating.

Rivers in the Vlaminghian Region exhibit two trends: about half arise in forested areas or areas with over 1100 mm of annual rainfall, the remainder in agricultural areas with less than 900 mm rainfall. Rivers in the latter area are characterised by increasing salinity. The major drainage divisions and river basins of the Vlaminghian Region that comprise the South-West Drainage Division are the:

- Ninghan;
- Yarra Yarra;
- Moore-Hill rivers;
- Swan Coastal;
- Avon River;
- Murray River;
- Harvey River;

- Collie River;
- Preston River;
- Busselton Coast;
- Blackwood River;
- Donnelly River;
- Warren River;
- Shannon River;
- Frankland River;
- Kent River;
- Denmark River;
- Albany Coast; and
- Esperance Coast.

7.3.2 Aquaculture Sites

7.3.2.1 Existing

Numerous (over 150) private companies and individuals operate commercial hatcheries and growout farms for marron, yabbies and various fresh water finfish.

The Pemberton trout hatchery conducts basic aquaculture research into fresh-water species and supplies juvenile rainbow and brown trout to replenish river systems for recreational fishing, stocking farm dams and other commercial needs.

Due to the perceived importance of marron as an export product for the aquaculture industry in the south-west, a proposal exists to establish a demonstration marron farm at the Wokalup Research Station near Harvey.

Curtin University and Collie TAFE are currently undertaking research into the use of disused coal-mine pits for aquaculture development using marron and native fresh-water fish. In particular, the Ewington Open Cut No. 2 Pit comprises a part of the research programme. Collie TAFE has also established the South West Aquaculture and Environment Research Centre to promote research and training in the region.

7.3.2.2 Potential

The potential for fresh water aquaculture has been assessed for the Shire of Dandaragan, which is characterised by limited and brackish surface water. The availability, quality and quantity of suitable water is therefore an issue for development. The Shire was divided into land systems for the purposes of assessing aquaculture potential, with the Yerramullah System displaying potential for development of ponds utilising streams or shallow ground water.

The Freshwater Aquaculture Taskforce identified potential for freshwater aquaculture development within the South-West Irrigation Area, which covers 34,370 ha from

Waroona in the north, down the base of the Darling Scarp, to Dardanup in the south. The proposal involves the integration of marron aquaculture with existing farming operations.

The Bremer Bay region was considered with reference to fresh water aquaculture using surface and ground water sources. The study found that the areas lakes and springs had low to medium potential for cage enclosures and pond development, with existing farm dams suitable for stocking with crayfish and fish. No specific sites were identified.

7.3.2.3 Sensitive or Prohibited

There are numerous National Parks and Nature Reserves throughout this region that constitute constraints to the development of aquaculture.

The main National Parks include the:

- Nambung National Park;
- Mount Lesueur National Park;
- Badgingarra National Park;
- Drovers Cave National Park;
- Watheroo National Park;
- Mt Frankland National Park;
- Stirling Range National Park;
- Fitzgerald River National Park;
- Frank Hann National Park;
- Stokes National Park; and
- D'Entrecasteaux National Park.

The Bremer Bay Groundwater Protection Plan nominates priority zones which regulated land use. An area adjacent to the Bremer Bay town site has been zones P1, which prohibits commercial aquaculture as a land use; however, the use of farm dams for stocking is permitted.

7.3.3 Aquaculture Species

The Dandaragan Aquaculture Plan identified species with high or moderate potential in the region, including freshwater crayfish (marron, koonac, yabbies and redclaw), table fish (cobbler, silver perch, golden perch, black bream, barramundi and mullet), sport fish (golden perch, redfin perch, Australian bass and Murray cod), bait, pond aquarium fish (minnows and pygmy perch), aquarium fish (rainbow fish and goldfish) and brackish water fish (black bream).

The South-West Irrigation Area is considered to have aquaculture potential for species that include marron, yabbies, trout, redfin perch. silver perch, cobbler or estuary catfish, Murray cod, golden perch, Australian bass and aquarium fish

The Bremer Bay region is considered to have potential for the culture of marron, yabbies and finfish.

7.4 The Ground Water Region

7.4.1 General Features

The Ground Water Region overlies the other inland regions described above and effectively comprises the Kimberley, Pilbara, Gascoyne, Mid-West, Wheatbelt, Perth, Peel, South-West, Great Southern and Goldfields-Esperance regions of the State. Its general features are therefore those described for the Leichardtian, Greyian and Vlaminghian regions above.

Many inland areas of Western Australia are characterised by having access to ground water, which is subterranean water stored or flowing in sand, sedimentary rock or fractured rock. Large volumes of ground water underlie much of Western Australia's surface. The quality of these waters can vary significantly and their salinities can range from fresh to hypersaline. Some aquifers contain fossil water; that is, they are no longer recharged. Others are recharged at rates governed by features such as soil permeability, surface drainage structures and evaporation and rainfall patterns.

The potential for aquaculture development in the Ground Water Region of Western Australia is large; however, the utilisation of large quantities of ground water for aquaculture needs to be considered with a view to the rates at which the waters are recharged and the impact their abstraction may have on the environment. This is particularly important for ground waters that are expressed as wetlands.

Aquaculture may be able to play a significant and beneficial role in reducing soil salinity problems in some of Western Australia's agricultural areas. Since it is caused by rising water tables, surface salinity can be decreased in some instances if sufficient ground water is extracted. The cost of extracting these ground waters and hence of lowering the water table can be amortised by using the water for aquaculture.

7.4.2 Aquaculture Sites

7.4.2.1 Existing

Existing sites in this region are identified in the relevant sections of the Leichardtian, Greyian and Vlaminghian regions above.

7.4.2.2 Potential

The Carnarvon town site has potential for growout and hatchery operations functioning on bore water, with excellent infrastructure available. Two sites were identified with potential, one within the existing industrial area and another at Bibawarra Bore.

The aquaculture potential of the Gascoyne Pastoral Zone has been assessed in reference to the use of ground water, as surface water is generally lacking. Lake MacLeod has been

classified as having moderate potential if the aquaculture operation could be integrated with the Dampier Salt operations. Research trials are currently under way in the Gascoyne Region using ground water to culture fresh water finfish species. The trials are at an early stage and aim, *inter alia*, to determine the commercial feasibility of the concept.

Ground water from the Birdrong Sandstone in the Gascoyne Province could be used for tank and pond enclosures of marine and estuarine species. Due to the absence of permanent surface water, this area may be suitable for quarantining or aquaculture of introduced or exotic species, as there is no threat of competition with native species.

The Dandaragan Aquaculture Development Plan included potential for the use of ground water, with two land systems considered suited for this purpose, *viz.*: the Yerramullah, Mintaja land systems using shallow and deep ground water; and the Bassendean land system utilising shallow ground water.

7.4.2.3 Sensitive or Prohibited

The use of ground water for aquaculture could be developed according to its availability and proximity to settlements and allocation of water resources for scheme use.

Aquaculture development will be a sensitive land use in or near conservation reserves and national parks throughout the State.

An additional sensitive issue is that of stygofauna occurring within karstic zones throughout the State. Alterations in ground water levels can affect aquatic stygofauna, five species of which are protected under the *Wildlife Conservation Act* 1950.

7.4.3 Aquaculture Species

Species recommended for culture in the Carnarvon Industrial Area include bream, Westralian dhufish, mullet, estuary cod, mahimahi and aquarium fish.

The potential Carnarvon/Bibawarra Bore location is considered suited to the culture of barramundi

Lake MacLeod is a naturally saline environment, which is suited to the culture of milkfish, microalgae and brine shrimp.

Water from the Gascoyne Birdrong Formation is suited to culture of barramundi, redclaw crayfish, microalgae, brine shrimp, Spirulina and aquarium fish.

Other introduced species may be well suited to some of Western Australia's inland, ground-water areas that are characterised by having no permanent surface water and that are not connected to the major drainage basins. These introduced species are likely to feature either very high market values or low production costs and could include kuruma prawns for aquaculture in brackish water and tilapia and catfish for aquaculture in fresh and brackish water.

8 INFORMATION SOURCES AND BIBLIOGRAPHY

8.1 Information Sources

An enormous amount of information exists that has some relevance to aquaculture sites and hence aquaculture planning in Western Australia. It would not be practicable to attempt to include all the information in this document; however, much of it is the type of information that may be of considerable value to prospective aquaculturists in the process of selecting or evaluating potential aquaculture sites. The following provides a limited list of some government agencies and summarises the type of information that they possess: it notes the existence of certain information rather than providing the information itself.

CSIRO - Division of Marine Research based in Marmion has five separate research programmes, four of which have the potential to provide data and findings of relevance to aquaculture development in Western Australia. This ranges from collation of water quality parameters to development of aquaculture feeds. The four programmes are:

- Aquaculture Program;
- Oceans and Climate Program;
- Maritime Industries and Environment Program;
- Tropical and Pelagic Ecosystems Program.

The Department of Transport has a dedicated Coastal Management Branch which is responsible for:

- collecting, checking and verifying survey data of the State coastline;
- hydrographic surveys of beaches and the seabed;
- producing marine boating charts; and
- collecting and analysing tide and wave data.

The Marine Geographic Information Services manages the State's marine data base and has created the Coastal Resource Atlas, which has the potential to provide detailed information relevant to aquaculture venture development.

The CALM Marine Conservation Branch is responsible for the provision of scientific advice about existing and proposed marine parks. The branch undertakes mapping of marine habitats and water monitoring programmes within existing marine parks.

The WRC includes a Groundwater Branch, which undertakes hydrogeological studies and water resource planning and management. The branch collects data on aquifers, water volumes, water quality (salinity, nitrate, phosphate, bacteria and hydrocarbons) and is responsible for allocation of ground water resources. The abstraction of ground water for commercial purposes requires issuing of a licence from the WRC.

The Western Australian Land Information Service (WALIS) maintains a Land Information Directory which provides an index to land and geographic information and aerial photography available in the State. Maps and digital information are available in a large range of areas including natural resources, land administration, socio-economic and utilities.

Regional Development Commissions in association with the Department of Commerce and Trade collate and supply environmental, economic and planning information for prospective industry developers and investors. Regional Development Commissions can assist in co-ordinating project developments and are heavily involved in aquaculture promotion.

8.2 Bibliography

This section provides bibliographies of aquaculture planning and other relevant studies carried out in Western Australia (section 8.2.1) and those currently being carried out or that are proposed (section 8.2.2). Compiled according to the alphabetical order of the titles, they include the documents referred to in chapter 2 of this document.

8.2.1 Existing Studies

The numerous existing works examined as part of this study can be broadly classified as:
- planning studies with some relevance to aquaculture;
- studies that have some relevance to aquaculture, but not to planning; and
- planning studies with no relevance to aquaculture.

The first two categories of these studies are included below.

A Bibliography of Physical Oceanography in Southwest Australian Waters. Alan Pierce, CSIRO Marine Laboratories, 1985. Report 157, 36 pp.

A Report on the Issues Affecting the Use of the Dampier Archipelago. A report to the Minister for Fisheries and Fisheries Department of Western Australia, prepared by Landvision Pty Ltd, March 1996.

A Representative Marine Reserve System for Western Australia: Report of the Marine Parks and Reserves Selection Working Group. Department of Conservation and Land Management, June 1994.

A Selected Bibliography of Marine and Estuarine Studies (other than Physical Oceanography in Western Australia). C.J. Crossland and F.E. Wells, CSIRO Marine Laboratories, 1985. Report 160, 45 pp.

Abrolhos Islands Planning Strategy. A report prepared by the Abrolhos Islands Task Force, July 1988.

Abrolhos Islands Aquatic Reserve: Final Report. Abrolhos Islands Consultative Council, May 1993.

Albany Harbours Planning Strategy. Town of Albany, June 1997. 62 pp.

Aquaculture: Development Strategies for the Industry in Western Australia. Aquaculture Development Advisory Council, Government of Western Australia, 1994. 50 pp.

Aquaculture Management Strategy for Albany Harbours: First Draft. Fisheries Department of Western Australia, August 1996, 54 pp.

Bremer Bay Coast Aquaculture Feasibility Study. A report to the Shire of Jerramungup, prepared by *ecologia* Environmental Consultants in association with Makaira Pty Ltd and O'Brien Aquaculture Research, August 1996, 80 pp.

Bremer Bay Groundwater Protection Plan. Groundwater Management and Protection Section, Water Authority of Western Australia, June 1995, 46 pp.

Coral Bay Draft Coastal Management Plan. The Coastal Management Co-Ordinating Committee and Department of Conservation and Environment, July 1984.

Coral Bay Planning Strategy. Department of Planning and Urban Development, August 1992.

Dandaragan Aquaculture Planning Strategy. A draft report prepared for the Shire of Dandaragan by O'Brien Planning Consultants, July 1995, 171 pp.

Final Report of the Review of Coastal Management in Western Australia. Western Australian Management Review Committee, State of Western Australia, May 1995, 105 pp.

Gascoyne Aquaculture Development Plan. Fisheries Department of Western Australia, November 1996, 174 pp.

Gascoyne Region Economic Development Strategy. Gascoyne Development Commission, October 1996.

Geraldton Mid-West Regional Development Study: The Way Ahead. Volume 3: Fishing. Prepared by the Geraldton Mid-West Study Team, October 1987.

Interdepartmental Submission by the Coastal Management Co-Ordinating Committee , Other Departments and Agencies to the Resource Assessment Commission Inquiry into Coastal Zone Management. State Government of Western Australia, August 1992, 98 pp.

Karratha Area Development Strategy. WA Planning Commission, April 1997.

Kimberley Aquaculture Development Plan. Fisheries Department of Western Australia, October 1996, 106 pp.

Marine Environment of Dampier Archipelago. Woodside Petroleum Development Pty Ltd North West Shelf Development Project. Meagher and Le Provost Marine Ecologists, Perth 1983.

Marine Reserve Implementation Programme: Jurien Bay and Adjacent Waters. Oceanographic Field Programme for Jurien Bay and Adjacent Waters. N. D'Adamo, Marine Conservation Branch, Department of Conservation and Land Management, December 1996.

Marine Reserve Implementation Programme: Central West Coast. Biological and Spatial Validation of the Major Benthic Habitats off the Central West Coast. J.S. Burt, Marine Conservation Branch, Department of Conservation and Land Management, December 1996.

Marine Reserve Implementation Programme: Central West Coast. Biological Survey of the Major Benthic Habitats of Jurien Bay and Surrounding Waters. J.S. Burt, Marine Conservation Branch, Department of Conservation and Land Management, March 1997.

Marine Resources Map of Western Australia; Part 1, The Resources. H.E. Jones, Fisheries Department of Western Australia, 1986. Report No. 74, 100 pp.

Marine Resources Map of Western Australia; Part 2, The Influence of Oil on Marine Resources and Associated Activities with an Emphasis on those found in Western Australia. H.E. Jones, Fisheries Department of Western Australia, 1986. Report No. 74, 33 pp.

Marmion Marine Park Management Plan 1992-2002. Department of Conservation and Land Management for the National Parks and Nature Conservation Authority, Perth, Western Australia, January 1992, 73 pp.

Monkey Mia Reserve Draft Management Plan. Department of Conservation and Land Management and the Shire of Shark Bay, 1993, 53 pp.

National Strategy on Aquaculture in Australia. Prepared by the Working Group on Aquaculture on behalf of the Standing Committee on Fisheries and Aquaculture, March 1994.

Nature Conservation Reserves in the Kimberley. A.A. Burbidge, N.L. McKenzie and K.F. Keneally, Department of Conservation and Land Management, 1991, 117 pp.

New Horizons in Marine Management. Government of Western Australia, November 1994, 10 pp.

Pearling and Aquaculture in the Dampier Archipelago: Existing and Proposed Operations. A report for public comment prepared by Ben Fraser. Fisheries Department of Western Australia, September 1996. Fisheries Management Paper no. 92, 31 pp.

Pilbara/Gascoyne Islands Ecotourism Management Strategy. Volume 1: Review of study and public responses; Implementation Recommendations, Tourism Co-ordinates 1995, 44 pp. Volume 2: Technical and Detail Papers, Higgins Wood and Associates 1995, 165 pp.

Review of Coastal Management in Western Australia. Issues and Options Paper. Western Australian Coastal Management Review Committee, September 1994.

Shark Bay Aquaculture: Community Consultation. A Draft Report to the Fisheries Department of Western Australia. Prepared by Biospherics Pty Ltd, April 1997, 17 pp.

Shark Bay Regional Strategy. A review of the 1988 Shark Bay region plan. Prepared for the Shark Bay Region Plan Review Steering Committee by the Ministry for Planning. Western Australian Planning Commission, March 1996, 71 pp.

Shark Bay Finfish Aquaculture Project. Prepared for the Department of Commerce and Trade and the Bellotti Aquaculture group by Mariculture Development Pty Ltd, August 1995, 25 pp.

Shark Bay World Heritage Area Draft Management Plan for Fish Resources. Fisheries Department of Western Australia, November 1994. Fisheries management paper No. 72, 136 pp.

Shire of Dandaragan Development Plan. Shire of Dandaragan, March 1996, 54 pp.

Shoalwater Islands Marine Park: Draft Management Plan. Department of Conservation and Land Management for the National Parks and Nature Conservation Authority, Perth, Western Australia, 1995, 72 pp.

Southern Metropolitan Coastal Waters Study (1991-1994). Department of Environment Protection, Perth WA, November 1996.

State Planning Strategy. Western Australian Planning Commission, November 1996.

Summary Report of the Freshwater Aquaculture Task Force. A report prepared by Sustainable Resource Management Pty Ltd, April 1996, 44 pp.

Technical Evaluation of Sites for Land-Based Marine Aquaculture in the Mid-West Region. Draft report prepared by Makaira Pty Ltd and *ecologia* Environmental Consultants for the Mid-West Development Commission. June 1997, 51 pp.

8.2.2 Current and Proposed Studies

The following studies are either currently being undertaken or being proposed.

Review of the Marine Farm Planning and Consultation Process for the Fisheries Department of Western Australia.

Research of WA Aquaculture Priorities.

Review of WA Coastal and Estuarine Waters Productivity Levels for Mariculture Planning Purposes.

A Review of Aquaculture Candidate Species (Fisheries Department of Western Australia).

Jurien Bay Habitat Mapping Study.

Planning for Environmental Management in the Pilbara: The North-West Shelf Marine Environmental Management Study.

Development of an Atlas of WA Ground Water Resources that may be Suitable for Aquaculture Purposes.

9 RECOMMENDATIONS

9.1 Mapping Constraints

The mapping for the purposes of this study has concentrated principally on providing information about existing and potential aquaculture sites. An additional aquaculture site category entitled *Sensitive or Prohibited* is discussed that has not incorporated all categories of constraints and has been restricted to environmentally-based sensitivities.

The sensitive or prohibited category can be increasingly refined if the database system is to be developed beyond the illustration of existing and identified potential sites. That is, the electronic database could be utilised to overlay different aspects of the physical and cultural environment, such as seagrass meadows, that provide opportunities and constraints for aquaculture development.

The mapping exercise is also constrained to some extent by the scale of the project. Because the study encompasses the entire State, the amount of detail that can be provided is limited by the accessibility and scale of electronic data available. Areas that have potential for aquaculture may therefore be presented as broad zones, or as indicative locations related to town sites. The restrictions of scale prohibit the mapping of existing marron farms at this initial stage in the compilation of the electronic database.

The presentation will initially provide general indications of the existing and potential sites throughout the regions. As additional information becomes available in electronic format the presentation can be altered to suit the needs of the user.

9.2 Additional Mapping Information

Additional mapping categories that could be overlain on the aquaculture sites base to assist in project development include:

- marine and terrestrial conservation reserves;
- land tenure;
- native title claims;
- infrastructure;
- seagrass areas and marine habitat mapping;
- ground water protection and allocation areas;
- current, tide and wave environment data; and
- significant heritage (Aboriginal and European) and recreation sites.

Data on these aspects of project development can be obtained through WALIS, or from Government agencies identified in Section 8.1.

The Environmental Protection Agency has developed a Marine Policy Structure, which incorporates the development of environmental impact assessment (EIA) policy development for aspects of the bio-physical environment, pollution prevention and the social environment. The structure is intended to include a Benthic Primary Producer Habitat Policy, which will provide separate EIA requirements for proposals affecting seagrass, coral, mangrove and algal

habitat. The EIA policies are likely to contain maps that indicate the sensitive habitats, compatible uses and indications for level of environmental assessment required. These policy documents and maps are directly relevant to aquaculture development and should be incorporated into this document where possible. This will provide the aquaculture industry with a clear indication of physical constraints and approval requirements when new proposals are investigated.

9.3 Database Maintenance

FDWA will be responsible for database updating and maintenance; accordingly, resources will need to be allocated for this purpose.

Maintenance will require:

- updating aquaculture lease information;
- adding to or altering information relating to marine and terrestrial conservation reserves; and
- acquiring and integrating additional mapping information into the database.