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Indian Ocean Territories Aquaculture Development Plan

The Cocos (Keeling) Islands and Christmas Island

Government of **Western Australia**
Department of **Fisheries**

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Disclaimer: Note that the Aquaculture Development Plan identifies development opportunities by assessing sites, species, and production systems, based on contemporary aquaculture technology and subsequently cannot cater for future technological, economic or social developments that may occur. The projects and species it identifies should therefore be considered inclusive, not exclusive, and proposals for aquaculture development outside the scope of those identified in this document should be considered on merit and on a case by case basis.

1 Executive Summary

The Commonwealth Department of Regional Australia, Regional Development, and Local Government (Department of Regional Australia) has requested that the Department of Fisheries, Western Australia, finalise the Aquaculture Development Plan for the Indian Ocean Territories in 2010-11. The Department of Regional Australia will consider the Aquaculture Development Plan in the broader *Indian Ocean Territories Economic Development Strategy 2010-15.*

The Indian Ocean Territories possess a wide range of natural resources that offer good opportunities for sustainable aquaculture development, however, their remote location and consequential high cost commercial environment limits the types of aquaculture that can be undertaken economically. It would therefore be unrealistic to contemplate the Indian Ocean Territories playing a role in supplying any mass seafood market. Accordingly, the Aquaculture Development Plan adopts a regional focus that concentrates on food supply in local markets and on export markets only where the Indian Ocean Territories may have a sustainable competitive advantage.

The Aquaculture Development Plan for the Indian Ocean Territories identifies a range of sites, species, and production systems considered to have some capacity for industry development, based on contemporary technologies and the prevailing socio-economic environment. It recognises this is an initial step in an economic development strategy and more detailed analyses of investment feasibility are required to validate development opportunities before significant resources and funding are committed to the establishment of an aquaculture industry in the Indian Ocean Territories.

Two sites were identified as suitable for aquaculture development at the Cocos (Keeling) Islands: the Quarantine Station and the Old Farm. The Quarantine Station is considered an outstanding site that offers the best opportunities for aquaculture development at the Cocos (Keeling) Islands and, more broadly, the Indian Ocean Territories. The area is sufficiently large to support the establishment of an aquaculture precinct that provides common services, such as, sea water supply, treatment and discharge systems, and enables economies of scale not possible for individual operations.

Two sites were identified as suitable for aquaculture development at Christmas Island: the Market Garden and the Central Area Workshop. Christmas Island affords fewer opportunities than the Cocos (Keeling) Islands for aquaculture development. Due in part to the difficulty and higher cost of pumping sea water, land-based marine production systems have not been identified as an opportunity. The number of fresh water species considered suitable is also lower than for the Cocos (Keeling) Islands, because there is a higher risk finfish or shellfish that escape from aquaculture facilities could become established in the natural environment and be difficult or impossible to eradicate.

The limited availability and high price of fresh produce at the Indian Ocean Territories affords an opportunity for aquaponic systems on both islands. Aquaponics is the integration of fresh water aquaculture with the production of fresh produce in hydroponic systems. The linking of recirculating aquaculture and hydroponic production of fresh vegetables, fruit, flowers and, or, herbs, results in a bio-integrated system, which can be used for sustainable, economic food production. Aquaponic systems are best suited for the production of high quality table fish that can tolerate high stocking densities. Species such as barramundi and Murray cod are currently raised in recirculating aquaponic systems in Australia, however, most commercial aquaponic systems in North America are based on tilapia, a warm-water species that grows well in a recirculating tank environment.

Future aquaculture development at the Indian Ocean Territories also has the opportunity to exploit synergies with the tourism industry. Numerous examples around the world demonstrate the strong synergies between aquaculture and tourism, even with small-scale farms. Tourism and aquaculture businesses can generate additional revenue through innovative linkages including educational and various recreational activities.

The Aquaculture Development Plan makes the following five recommendations:

Recommendation 1: Recognise that the land and infrastructure at Quarantine Station on the Cocos (Keeling) Islands represent the best opportunity for aquaculture development at the Indian Ocean Territories and, subject to other economic development requirements, consider allocating suitable areas, buildings, plant and equipment to proponents who demonstrate the ability and capacity to establish viable aquaculture development businesses.

Recommendation 2: Commission two baseline feasibility studies (which future proponents may use to develop detailed business plans) for:

a) aquaculture at the Cocos (Keeling) Islands, using land-based, pumped-ashore systems to produce marine ornamental species for sale in export markets;

b) fresh water, recirculating aquaponic projects at the Cocos (Keeling) Islands and Christmas Island, producing fresh water finfish species and fresh produce for sale in the local market.

Recommendation 3: Undertake a project to evaluate the prospects to optimize commercial opportunities that may arise from aquaculture production at the Indian Ocean Territories, principally:

a) tourism opportunities; and
b) opportunities to add value to aquaculture products, including post-harvest processing.

Recommendation 4:	Commission a study to evaluate the feasibility of establishing a facility at Perth to enable the holding of live fish and their transfer to export markets, which may support the development of an ornamental fish aquaculture industry at the Indian Ocean Territories.

2 Introduction

The Commonwealth Department of Regional Australia, Regional Development, and Local Government (Department of Regional Australia) has requested that the Department of Fisheries, Western Australia, finalise the Aquaculture Development Plan for the Indian Ocean Territories in 2010-11. The Department of Regional Australia will consider the Aquaculture Development Plan in the broader *Indian Ocean Territories Economic Development Strategy 2010 – 2015*, which will develop an agreed set of targets and outcomes to provide direction for an unified approach to the development of actions, monitoring, and evaluation by the Indian Ocean Territories community.

Under a Service Delivery Arrangement with the Department of Regional Australia, the Department of Fisheries manages commercial, charter, recreational fisheries and aquaculture activities at the Cocos (Keeling) Islands and Christmas Island, in addition to providing fish health diagnostic services, biosecurity, fish habitat protection, pathology services and licensing services. The Federal Minister Regional Australia, Regional Development and Local Government currently holds responsibility for these excepted waters under the *Fish Resources Management Act 1994 (WA) (CI)(CKI)*.

2.1 Purpose and Objectives

Aquaculture is the business of farming aquatic animals and plants under controlled conditions, in marine, estuarine and freshwater environments.

The *Fish Resources Management Act 1994* defines aquaculture as: *the keeping, breeding, hatching or culturing of fish*. The Food and Agriculture Organisation (FAO) of the United Nations defines aquaculture as: *Farming of aquatic organism including fish, molluscs, crustaceans and plants, with some form of intervention in the rearing process to enhance production, such as regular stocking, feeding, protection from predators, etc. Farming also implies individual or corporate ownership of the stock being cultivated.*

The industry may represent an economic development opportunity for the Indian Ocean Territories that is consistent with the natural resources and socio-economic features of the islands.

The *Indian Ocean Territories Economic Development Strategy 2010 – 2015* has identified aquaculture as a target opportunity for both Cocos (Keeling) Islands and Christmas Island. To address this, the Aquaculture Development Plan seeks to identify opportunities for a sustainable aquaculture industry, however, it is anticipated that additional studies will be required to assess investment feasibility.

As the global population continues to increase, demand for seafood is projected to grow substantially.[1] The world's major wild fisheries are thought to be at, or already in excess of, their maximum sustainable yield, so the projected increase in demand for seafood can only be supplied by aquaculture.

For reasons that include their remote location and consequential high input costs, it would be unrealistic to contemplate the Indian Ocean Territories playing a role in supplying any mass seafood market. Accordingly, this Aquaculture Development Plan adopts a regional focus that concentrates on food supply in local markets and only on export markets where the Indian Ocean Territories may have a sustainable competitive advantage.

The primary objective of the Aquaculture Development Plan is to **identify the aquaculture opportunities that may exist on Cocos (Keeling) Island and Christmas Island** with two key outcomes:

1. *Supplementary supply of food for the islands, and where possible relieving existing pressure on fish stocks*

2. *Increased economic activity – in the context of the capacity to develop a competitive and sustainable export market*

To address this objective the Aquaculture Development Plan:

- identifies suitable sites where aquaculture projects may be established;
- identifies suitable species with food production value for the local market and secondly with economic potential for export market;
- identifies effective and appropriate production systems; and
- proposes a course of action consistent with the intrinsic values and uses of the area.

[1] The FAO estimates that, when the global population reaches 8.3 billion in 2030, to meet demand, an additional 30 million tonnes of seafood will have to be produced each year

3 Background Information on the Indian Ocean Territories

3.1 Location

The Cocos (Keeling) Islands (Figure 1) are located in the Indian Ocean 2,950 km north-west of Perth, Western Australia, 3,700 km West of Darwin, and 900 km south west of Christmas Island (96º 50´ East 12º 10´ South). There are 27 coral islands in the group with a total land area of approximately 14 km².

Figure 1: **The Cocos (Keeling) Islands.**

Christmas Island (Figure 2) is located in the Indian Ocean, at latitude 10º 30´ South and 105º 40´ East. It is approximately 380 km south of Java Head at the southern entrance to the Sunda Strait, approximately 1,350 km from Singapore and approximately 2,650 km from Perth, Western Australia. The nearest point of the Australian mainland is Northwest Cape, which lies approximately 1,565 km to the south east. The island has an area of 135 km².

Figure 2: **Christmas Island.**

3.2 Geography and Oceanography

The Cocos (Keeling) Islands are made up of coral atolls in a horseshoe shape formation. Coral sand beaches are to the seaward side and mudflats can be found on the lagoon side.

The northern atoll consists of North Keeling Island with the marine area extending 1.5 km around the Island form the Pulu Keeling National Park.

Christmas Island is the summit of a submarine mountain. It rises steeply to a central plateau dominated by rainforest. The plateau reaches heights of up to 360 metres above sea level and consists mainly of limestone with layers of volcanic rock.

Christmas Island's 80 kilometre coastline is an almost continuous sea cliff reaching heights of up to 20 metres. There are thirteen places where breaks in the cliff give way to shallow bays and small sand and coral beaches. The largest of these bays, Flying Fish Cove, accommodates the Island's port. The Island is surrounded by a coral reef; where there is virtually no coastal shelf and the sea plummets to a depth of about 5,000 metres within 200 metres of the shore.

3.3 Climate

The Cocos (Keeling) Islands' climate is tropical with high humidity. Temperatures range from 23°C to 30°C. The average rainfall is 2,000 mm per annum, falling mainly from January to August. The south-east trade winds blow most of the year.

Christmas Island's climate is tropical and temperatures range from 21°C to 32°C. Humidity is around 80-90% and south-east trade winds blow most of the year. During the wet season between November and April, it is common for some storm activity to occur producing a swell in seas around the Island. The average rainfall is approximately 2,000 mm per annum.

3.4 Demographics

Cocos (Keeling) Islands has a large proportion of people from a non-English speaking background. Home Island is the location of the Cocos Malay community, which has social and cultural links to both Sabah in Malaysia and to Cocos Malay communities in several centres in Western Australia. West Island has some Cocos Malay residents, but its population is largely comprised of public servants, contractors and other short term residents and their families.

On Christmas Island, the recruitment of phosphate mine workers from Asia over nearly a century has resulted in the formation of a multi-cultural community from a non-English speaking background. Approximately 65% of the population are of Chinese descent and 20% have a Malay background.

4 Legislation, Regulation and Management

4.1 Legislative Environment

4.1.1 Background on the Legislative Regime

The Indian Ocean Territories are non self-governing, with the Commonwealth fulfilling the roles of both the Federal and State Governments.

The Department of Regional Australia administers the *Christmas Island Act 1958* and the *Cocos (Keeling) Islands Act 1955* on behalf of the Minister for Regional Australia, Regional Development and Local Government, and provides the legislative basis for the administrative, legislative and judicial systems at the Indian Ocean Territories.

The Commonwealth Minister for Regional Australia currently holds responsibility under the *Fish Resources Management Act 1994 (WA)(CI)(CKI)* (*Applied Act*). This *Applied Act* is essentially an exact copy of the WA *Fish Resources Management Act 1994*, applied as Commonwealth Legislation to apply at the Indian Ocean Territories. The Department's Service Delivery Arrangement with the Commonwealth Government is under Section 8H of the *Christmas Island Act 1958* and the *Cocos (Keeling) Islands Act 1955*.

4.1.2 Aquaculture Licences

Aquaculture licences may be issued at the Indian Ocean Territories under the relevant sections of the *Applied Act.*

It is a legal requirement under the *Applied Act* that a person who keeps, breeds, hatches or cultures fish for commercial purposes must hold an Aquaculture Licence.

Aquaculture licences are issued under Section 92 of the *Applied Act*, which states that the Chief Executive Officer of the Department of Fisheries may grant aquaculture licences subject to conditions and being satisfied that, among other requirements, the activities are unlikely to affect other fish or the aquatic environment and that they have been approved by other relevant authorities. Aquaculture licences are issued subject to the conditions set out in Regulation 69 of the *Fish Resources Management Regulations 1995 (WA)(CKI)(CI) (Applied Regulations)* and other conditions that may be specified in the licence by the Chief Executive Officer.

The application and consultation procedures for an aquaculture licence are set out in Ministerial Policy Guideline No 8, *Assessment of Applications for Authorisations for Aquaculture and Pearling in Coastal Waters of Western Australia* (FWA 1997).

Aquaculture licences authorise defined fish farming activities undertaken at a specified site.

4.1.3 Land Tenure

The Department of Regional Australia is responsible for the administration of Crown land on Cocos (Keeling) Island and Christmas Island. Parks Australia is responsible for the administration of the Pulu Keeling National Park. There is also a Land Trust agreement between the Commonwealth and the Shire of Cocos (Keeling) Island, in which the Shire of the Cocos (Keeling) Islands has been granted the subject land in fee simple upon trust for the benefit, advancement and well-being of the Cocos Malays.

The Department of Regional Australia has a Service Delivery Arrangement with the Western Australian Department of Land Information (Landgate) and the Western Australian Department of Planning. Services provided include registration of titles, valuation of land and the provision of planning, legal and administrative advice on land.

4.2 Fish Health

Conditions on aquaculture licences specify that any unusually high mortalities or other signs of disease shall be reported to the Principal Fish Pathologist of the Department of Fisheries within 24 hours of the event. In such an event, a percentage of affected stock must immediately be submitted to the Fish Health Section of Department of Fisheries for examination. The Fish Health Section also provides services such as hatchery accreditation and issues health certificates when required.

4.3 Biosecurity and Translocation

Requirements for Importation of Live Fish into the Indian Ocean Territories from mainland Australia[2]

Importers seeking to import live fish into the Indian Ocean Territories need to submit an application for that purpose on a set form to the Australian Quarantine and Inspection Service (AQIS) Christmas Island office. Parks Australia is consulted when the importer supplies scientific names to ensure the application includes no species that can affect the environmental values of the National Park.

2 The Department of Fisheries is currently working with AQIS to clarify and streamline the Importation Procedure.

The importer will need to supply scientific names and numbers of the fish they wish to import, the supplier, end user, details of transport, and the address on island.

Only freshwater fish will be permitted and permits must be obtained before fish are brought to the Indian Ocean Territories. The consignment must be accompanied by a valid permit. Approximately three weeks after importation, AQIS will visit the premises to make sure the fish are still healthy and there are no fatalities. If there are fatalities within this period, importers must notify AQIS. For these three weeks imported fish must be kept in isolation to any other fish.

AQIS may seek further advice for approval for some species.

Requirements for Importation of Live Fish into the Indian Ocean Territories from Other Countries

Fish in the past have been allowed to be sourced from other countries arriving on direct flight from Asia. The same rules apply as from mainland Australia if coming direct to Christmas Island, however, if they were to transit through a mainland port they would then have to meet mainland quarantine requirements and fees as well.

4.4 Economic Factors

4.4.1 Infrastructure and Services

Generally, the Cocos (Keeling) Islands has good infrastructure.[3] There is good access by sealed roads to most areas on West Island. Electrical power is available along the main road to the north of the settlement and consequently to the sites identified as having potential for commercial aquaculture development.

As for the Cocos (Keeling) Islands, Christmas Island generally has good infrastructure. The sealed main road provides good access to the sites identified as having potential for commercial aquaculture development. Electrical power and potable mains water are available to these sites along the main road.

Cocos (Keeling) Island and Christmas Island have international airports, however, freight space is at a premium and the airline usually lacks the capacity for any significant cargo, whether for import or export. The cost of airfreight is high and, currently, may be considered prohibitive for anything other than high-value products. Any significant quantities of freight, such as building materials, tanks or general equipment, are better consigned in shipping containers by sea freight.

[3] The description and assessment of infrastructure, services and other economic factors provided in this section of the document are provided mainly in the context of aquaculture development. Other studies (see references) provide a broader, more comprehensive description of economic factors at the IOT should that be required.

4.4.2 Labour and Trades

At the scale envisaged by the Aquaculture Development Plan, aquaculture projects are unlikely to require significant numbers of employees, so labour shortages are unlikely to impede development.

Some skilled labour would be required, particularly during the early stages of development and for any transfer of technology that may be required. For any commercial development projects that may be proposed, it would be logical to assume the proponent would provide the requisite technology and specialised skills. Any community or government-funded projects that may be proposed would have to identify the level of technical and management skills required for the project and their source, whether on-island or, more likely, by way of external contractors or consultants.

High-level technical capabilities normally required for the hatchery production of marine or diadromous species, such as barramundi, would not be essential because the juveniles of these species required as seed stock would most likely be provided from mainland hatcheries. Seed stocks of fresh water species are likely to be provided from the mainland initially, however, the technology required to propagate these species is usually less complex and could be transferred to on-island facilities once the projects are under way and generating cash flow.

The trades essential for the establishment of aquaculture projects include licensed builders, electricians and plumbers. Once established, for ongoing, day-to-day operations, the availability of an electrician is generally the most critical requirement.

Labour shortages are unlikely to be of any major concern at Christmas Island, for reasons similar to those expressed for the Cocos (Keeling) Islands.

Issues in relation to the requirement for skilled labour, transfer of technology, and tradespeople that may be required for commercial development projects are similar to those discussed for the Cocos (Keeling) Islands.

4.4.3 Feed Sources

Given the dietary requirements of the species recommended for aquaculture at the Indian Ocean Territories (section 7.2), the required feeds are likely to include:

- for hatchery production, possibly wet fish diets for finfish broodstock and, for the larval rearing of ornamental and finfish species, formulated microdiets and live foods such as atremia;
- for the growout of carnivorous finfish species, manufactured, pelletised diets with formulations varying according to species; and

- for the growout of omnivorous species, manufactured pelletised diets and locally produced or available plant material.

Hatchery diets tend to be comparatively expensive and relatively low in volume, so are likely to be imported by airfreight.

Formulated growout diets would have to be imported from manufacturers in mainland Australia or countries such as Indonesia or Singapore. The cost of importing formulated diets is an important factor in determining aquaculture development opportunities for the Indian Ocean Territories. For carnivorous marine finfish species, the cost of feed generally comprises about 50% of the total cost of production and consequently is a key factor determining profitability. The added cost of freight needed to transport large quantities of manufactured diets is one key factor against the establishment of large-scale marine finfish aquaculture projects at the Indian Ocean Territories.

Smaller-scale projects either growing species less reliant on manufactured diets or those producing marine or fresh water fish species as part of an integrated polyculture or aquaponic system would be less sensitive to the cost of feed.

Aquaculture licence conditions in respect of imported, manufactured diets will require any imported feeds or feed additives, such as pre-mixed and nutrients, may be imported or used for aquaculture unless they have been manufactured in accordance with standards used and applied by AQIS in regulating the importation of the feed into Australia.

4.4.4 Equipment and Raw Materials

Aquaculture projects require a variety of buildings, structures, plant and equipment, including:

- tanks of various size, shape and material;
- pumps, controllers and pumping equipment;
- various pipelines and fittings, usually PVC or HDPE, and associated items such as valves and controllers;
- laboratory equipment;
- monitoring equipment;
- general hatchery plant including water treatment equipment; and
- plant such as emergency generators.

There are no local suppliers of the buildings, structures and equipment needed to operate an aquaculture facility: these items would all need to be imported from mainland Australia.

Raw materials mainly include ingredients for concrete and various earthworks. Sand and stone for concrete are available from a quarry at the Cocos (Keeling) Islands. The quarry could also provide the material needed for earthworks for road base and as a foundation for tanks and equipment.

The requirements for raw construction materials are unlikely to be high, given the likely scale of operations.

Christmas Island has greater capacity than the Cocos (Keeling) Islands in respect of raw materials, largely due to the larger industrial base at the island and, significantly, the presence of a mature phosphate mine.

4.4.5 Diagnostic Services

There are no diagnostic services available at the Indian Ocean Territories. The Department of Fisheries Fish Health Laboratory in Perth is considered best placed to provide what assistance may be required in the event of a disease outbreak. Any samples that need to be submitted for testing would need to be sent to the Laboratory by airfreight.

The Fish Health Laboratory is actively engaged with the Indian Ocean Territories, by way of providing fish kill kits and relevant training. This training could be extended to periodic hatchery inspections to educate operators and demonstrate procedures for preparing and submitting samples for analysis.

4.4.6 Processing and Packaging

There are no export-licensed or accredited processing and packaging facilities for aquaculture at the Indian Ocean Territories. Any facility intending to export fish for human consumption would need to have a processing licence issued under the *Applied Act* and accredited by AQIS.

4.4.7 Transportation and Markets

Transportation to and from the Indian Ocean Territories is limited to airfreight and sea freight. Cargo space for airfreight is limited so, generally, aquaculture products destined for export would likely be limited to high-value, low-volume items. The export of products such as fish for human consumption by sea freight is more likely to be economically viable in respect of freight cost for higher volumes, particularly for goods in frozen or some value-added form, such as smoked fish.

The export of large volumes of frozen or value-added fish products may be technically feasible by sea freight, however, an aquaculture project growing large volumes of fish is unlikely to be commercially viable owing to the overriding cost structures associated with marine finfish production at the Indian

Ocean Territories. Even very large-scale operations are unlikely to afford the economies of scale necessary for commercial viability.

The limited capacity and high cost of airfreight is a significant determining factor in the consideration of aquaculture development opportunities based on export markets. From a commercial perspective, for export markets, only high-value, low-volume products would be considered commercially viable.

Market factors in respect of individual species are discussed separately in section 7.3.

5 Consultation

The following stakeholders were consulted in the development of the Aquaculture Development Plan:

- Indian Ocean Territories Administrator
- Cocos (Keeling) Islands Shire Council
- Water Corporation (Cocos (Keeling) Islands)
- Cocos (Keeling) Islands Parks Australia
- Cocos (Keeling) Islands Tourism Association
- Cocos (Keeling) Islands Port
- Australian Federal Police
- Tycraft Pty Ltd
- Cocos (Keeling) Islands Community
- Christmas Island Shire Council
- Water Corporation (Christmas Islands)
- Christmas Island Parks Australia
- Christmas Island Tourism
- Christmas Islands Port Manager
- Christmas Island Australian Quarantine Inspection Service
- Phosphate Resources Pty Ltd
- Christmas Island Fresh Produce
- Christmas Island Community

Preliminary consultation was undertaken in August 2010 on-island during the initial site identification and selection process. Discussions were held with stakeholders in relation to suitable species of high value or interest and to identify any benefits or constraints that might be associated with the set up of aquaculture facilities and the development of this industry at the Indian Ocean Territories.

The Draft report formed the basis for community and stakeholder discussion and consultation via public information sessions, which were conducted on-island in February 2011.

6 Aquaculture Principles of Assessment

6.1 General Principles of Site Selection

The major site selection criteria for commercial aquaculture encompass defined physical, biological, ecological, financial, social, and legal factors.[4] These are summarised in Table 1. These principles were used for the site assessment process at the Indian Ocean Territories, but were modified as appropriate to be consistent with the characteristics of the islands.

Table 1 **Summary of Selection Criteria for Sites.**

Principal Criteria and Parameters	Factors to Evaluate
Physical Features	
Location and Size	Physical location: inland, onshore (coastal), or offshore
Topography and Hydrography	General land topography and elevation. Sea bed hydrography, depth of water and close to shore
Hydrology	Currents, wave action and tidal influences
Water Supply and Discharge	Water source (surface and subterranean) and quantity calculations. Water supply and discharge systems, open ocean or onshore wells, engineering factors
Soil and Vegetation	Nature of surface and subterranean soil characteristics
Climate	General meteorological data, particularly for storms, wind, temperature, rainfall, evaporation etc
Biological Features	
Water Quality	Comprehensive analyses of water quality including temperature, salinity, turbidity, and chemical variables
The Environment	Risks posed by the environment to aquaculture activities as well as those to the environment by t aquaculture activities
Parasites and Predators	Existing and potential threats from parasites and predators; note any previous fish kills and caus
Pollution and History	Existing or potential sources of pollutions and contamination from sewage or industrial activity, including agriculture
Finacial Features	
Infrastructure and Services	Access roads, essential services such as electrical power, transformers, potable water, sewerag communications, existing buildings
Labour and Trades	Cost and availability of skilled, semi-skilled and unskilled labour; traning, extension and research services. Proximity, availability and quality of trades persons and raw material supply
Feed Sources	Proximity and availability of specialised and other feeds for hatchery operations if required and growout
Equipment and Raw Materials	Availability of specialised and other aquaculture equipment
Diagnostic Services	Proximity of and access to competent analytical and pathological laboratories
Processing and Packaging	Proximity and availability of facilities, including consideration of using contract processing during peak times
Transportation and Markets	Proximity to targeted markets including cargo handling, availability of freight space and so on
Social and Legal Factors	
Urban Proximity	Proximity and standard of accomodation, schools, hospitals, shopping and recreational activities
Competitive Resource Use	Potential for conflict from other resource users, including recreational, mining, tourist developm and sport fishing
Land Ownership and Tenure	Naitive title of other land ownership issues that may influence the proposed enterprise
Legal and licensing requirements	Legislative and licensing requirements for any proposed aquaculture operations

4 These criteria are consistent with previous aquaculture development strategies undertaken in Western Australian and elsewhere.

6.2 General Principles of Species Selection

When choosing and evaluation candidate species for aquaculture, the main species selection criteria can be divided into four principal categories; namely, marketing, culture technology, production efficiency and commercial viability. Table 2 summarises the factors relevant to each criterion.[5] These species selection criteria are used as the basis for species selection at the Indian Ocean Territories.

Table 2 Summary of Selection Criteria for Aquaculture Species.

Main Categories and Selection Criteria	Factors to Evaluate
Marketing	
Product Features	The physical characteristics (size and texture), form (live, fresh, chilled etc.) and quality of the product.
Market Economics	Price, supply demand, volume, trends and other features of the market.
Market Place Features	Location of the market, competition and segmentation.
Culture Technology	
Broodstock	Broodstock management and husbandry. The occurrence and capture of wild broodstock, behaviour of captive fish, response to stress, disease susceptibility.
Spawning, Egg Quality	Reproductive features, fecundity, egg quality characteristics, particularly viability.
Development, Behaviour	Development and behaviour of larvae and early juveniles, larval size and ease of culture through weaning, duration of the larval period, degree of aggression and cannibalism.
Nutrition and Diet	Knowledge of nutritional requirements (hatchery growout), corresponding diet formulation for hatchery and growout feeds.
Hatchery Technology	State-of-the-art of the larviculture and nursery technology, including: suitable production system design and operation of tanks and other equipment; suitable operating procedures; and establishe dietary and feeding regimes.
Production Efficiency	
Growth Rate	Growth rate to market size and influencing factors such as temperature, dissolved oxygen etc. D and nutrition, size and age maturity.
Food Conversion Ratio	FCR for the species and how it varies according to fish size, diet, feeding regime, production syst and mortality rates.
Feeds and Feeding	Type of feed (moist, semi-moist, or dry; pellets or other), formulation, ingredients and availability. Suitable feeding methods and regime.
Environmental Tolerances	Definition of optimum and maximum ranges of environmental parameters such as temperature, salinity, turbidity and chemical variables.
Hardiness and Behaviour	Ability to withstand crowding, stress and disease, captive behaviour under high-density conditions
Commercial Viability	
Profitability	Cost-return analysis for the production species, including analysis of investment feasibility (IRR).
Other Factors	Requisite infrastructure, competitiveness, potential for intergration with other systems or speci and the amount of regulation and support.

[5] These criteria are consistent with previous aquaculture development strategies undertaken in Western Australian and elsewhere.

6.3 Production Systems

Commercial aquaculture is characterised by a wide and increasing variety of production systems, each of which can be described and defined by six principal elements. These are:

1. location and water type;
2. culture units;
3. water flow;
4. intensity;
5. production capability; and
6. scale and integration

The question that should be addressed when developing any aquaculture operation is: for the selected species, at the chosen site, which production system will deliver the maximum control over the culture environment, the maximum efficiency, the lowest cost of production, and hence the maximum profit?

Production systems should be selected according to the financial and operational requirements of the aquaculturist, the biological requirements of the cultured species, and the physical features of the proposed site. Commercial decisions about potential profitability can only be made if the respective performances of different systems can be properly evaluated.

Generally, the capital, infrastructure, and operational characteristics of the Indian Ocean Territories both define and constrain the type of aquaculture production systems that can be used. Brief descriptions of the types of production systems considered in the assessment of the Indian Ocean Territories are provided in the following sections 6.3.1 and 6.3.2.[6] The production systems considered the most suitable for the Cocos (Keeling) Islands and Christmas Island are described in sections 7.3 and 8.3, respectively.

Aquaculture production systems are logically segregated at a high level according to location; that is, whether they are located on land (land-based) or offshore. Land-based locations may be further classified as coastal or inland; and offshore locations as near shore or open ocean.

[6] It should be noted that, while it may be feasible to install and operate a production system from a purely technological perspective, the commercial viability of the system must still be considered. The identification of possible production systems comprises only one, early step in the assessment of financial feasibility for an aquaculture business.

6.3.1 Land-based

The land-based production systems that are possible from a biotechnical perspective at the Indian Ocean Territories include fresh water recirculating systems and marine flow-through systems.

Fresh Water Recirculation Systems

Figure 3: **Aquaponics System** (Source: Department of Fisheries)

Recirculating systems are those in which most of the water circulated through the culture units is continuously treated and recycled. Comparatively expensive to establish, these systems use more complex technology than other systems, so are usually employed to culture high-value species in areas where large volumes of high-quality water are not available or the temperatures unsuitable. Fresh water aquaculture at the Indian Ocean Territories would have to use recirculation systems, given the limited fresh water supply and annual rainfall variations that do occur.

For production units, these systems could use tanks, raceways, or ponds, ideally enclosed within some structure designed to limit water losses through evaporation. The systems are more likely to be intensive, but if undertaken in ponds, could be semi-intensive according to the biological requirements of the species selected for production.[7]

7 The intensity of an aquaculture production system is defined by the level of management, the stock density and the yield per unit volume or area. Intensive systems typically have a high level of management, high stock densities and use artificial feeds for the nutritional requirements of the stock. They are frequently vertically integrated to some degree and all inputs such as feeding, water quality, water-flow rates and waste-water treatment are monitored and controlled. Intensive aquaculture systems are used to cultivate species at high densities, typically in tanks, raceways and sea cages. Semi-intensive systems are used to cultivate species at intermediate densities, usually in ponds. They provide some inputs to the production system, such as supplementary feeding, aeration and water exchange.

Fresh water recirculating systems are generally established near large urban centres, where their higher capital and operating costs can be offset by proximity to markets as well as good infrastructure and services. These features are less evident at, or absent from, the Indian Ocean Territories, which have few apparent socio-economic advantages for the production of fresh water species, however, the limited availability and high price of fresh produce at the Indian Ocean Territories affords an opportunity for aquaponic systems.[8] Aquaponics is the integration of fresh water aquaculture with the production of fresh produce in hydroponic systems. The linking of recirculating aquaculture and hydroponic production of vegetables, flowers and herbs, results in a bio-integrated system, which can be used for sustainable food production based on the following principles:

- the waste products of one biological system (fish) serve as nutrients for a second biological system (plants);
- the integration of fish and plants results in a polyculture that increases diversity and yields multiple products;
- water is re-used through biological filtration and recirculation; and
- local food production provides access to healthy foods and enhances the local economy (Diver, 2006).

Fresh water recirculation systems are best suited for the production of high quality table fish that can tolerate high stocking densities. Several warm-water and cold-water fish species that are well adapted to recirculating aquaculture systems include tilapia, trout, perch, Arctic char, and bass. Species such as barramundi and Murray cod are currently raised in recirculating aquaponic systems in Australia, however, most commercial aquaponic systems in North America are based on tilapia, a warm-water species that grows well in a recirculating tank environment. Tilapia has biological characteristics that make the species ideal for intensive, low-cost production in aquaponic systems: it is a hardy species tolerant of fluctuating water conditions such as pH, temperature, oxygen, dissolved solids, and as an omnivore, consumes a varied and low-cost diet. Tilapia produces a white-fleshed meat suitable to local and wholesale markets.

The selection of plant species adapted to hydroponic culture in aquaponic greenhouses is related to the loading or stocking density of fish tanks and subsequent nutrient concentration of aquacultural effluent. Lettuce, herbs, and specialty greens (spinach, chives, basil, and watercress), which have low to medium nutritional requirements, are well adapted to aquaponic systems. Plants yielding fruit (tomatoes, bell peppers, and cucumbers) have a higher nutritional demand and perform better in a heavily stocked, well established aquaponic system. Greenhouse varieties of tomatoes are better adapted to low light, high humidity conditions in greenhouses than field varieties (Diver, 2006).

[8] In the context of this Aquaculture Development Plan, the terms *fresh produce* or just *produce* refer variously to fresh fruit, vegetables, herbs and, or, flowers.

Marine Flow Through Systems

Figure 4: **Marine Flow through Raceway** (Source: Tycraft Pty Ltd)

Invariably located close to the coast, land-based marine aquaculture systems use pumped-ashore seawater sourced from a marine intake or beach well and pass the water through the culture units continuously. In flow-through systems, also known as single-pass systems, the water enters and leaves the culture units simultaneously and at equal flow rates. The residence time of the water in the culture units varies according to the production intensity and stock density: it is usually very short (one to two hours) in high-density tanks and raceways and longer in ponds. In flow-through systems, incoming and discharged water are usually treated to some degree, according to the quality of the water, the needs of the species being cultured, and the environmental requirements in relation to discharge water quality. Tanks, raceways, and ponds are the culture units most often used in flow-through systems, which usually require the availability of very large volumes of high-quality water as well as suitable structures for water intake and discharge.

Flow-through systems have advantages that compensate for their often-higher establishment and operating costs. These mainly include better stock management and husbandry, more efficient control of water quality and better health management.

6.3.2 Offshore

The offshore production systems possible from a biotechnical perspective for aquaculture at Indian Ocean Territories are sea cages, longlines, and stock enhancement.

Sea Cages

Figure 5: **Sea Cages** (Source: Marine Produce Australia Pty Ltd)

Sea cages are offshore culture units enclosed on the bottom and sides by nets or mesh screens. A wide variety of sea cages is available for aquaculture in sheltered, near shore, and open ocean waters. The design best suited for a particular application is dependant upon several factors that include the species selected for culture, site conditions, environmental features and level of capital investment.

Advantages of sea cages include the use that can be made of offshore water bodies, which extends the areas in which marine aquaculture may be carried out. Other advantages include the often less complex management, which involves fewer variables than onshore systems, for example, they can be expanded simply by adding more cages and moved relatively easily. Capital and operating costs for sea-cage production systems can be highly variable.

Few sheltered sites are available at Indian Ocean Territories for locating sea cages and the very deep water is also a key issue. Almost invariably, sea cages deployed at the Indian Ocean Territories would have to be located in very deep water in exposed locations. Where they are used for commercial aquaculture in exposed locations, open ocean cages are generally used to grow fish in significant quantities that afford major economies of scale or close to high-value markets. These systems are unlikely to be economically viable at the Indian Ocean Territories.

Longlines

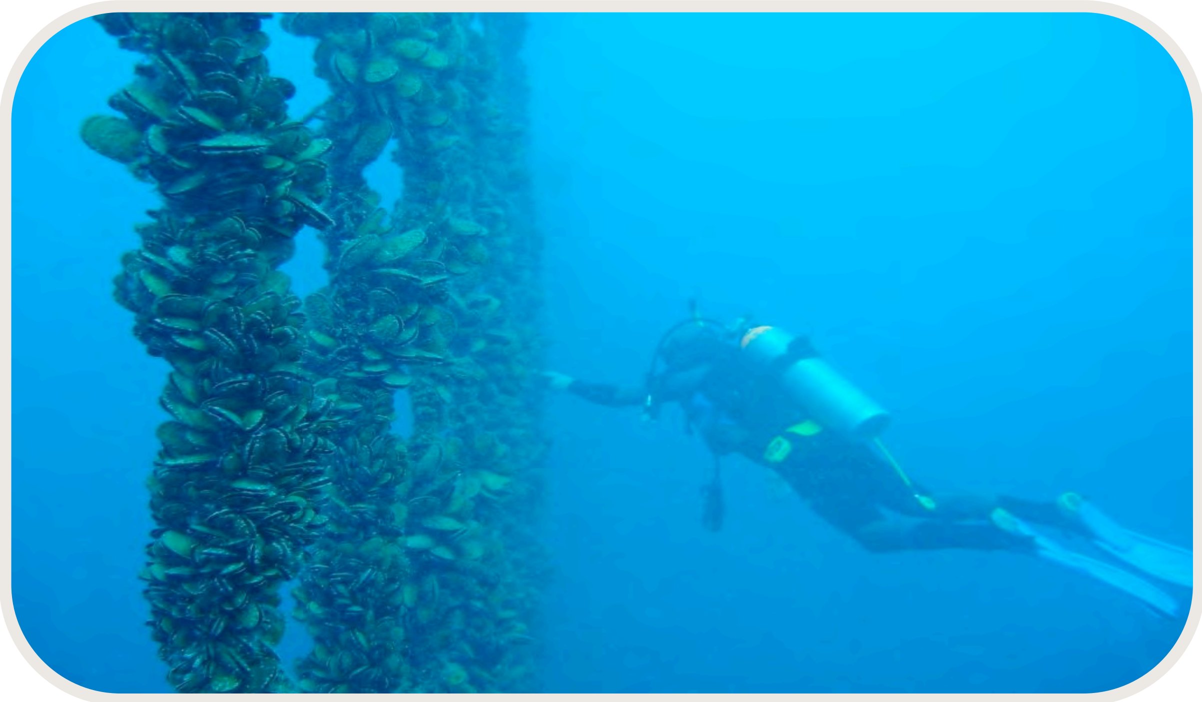

Figure 6: **Longlines** (Source: Dr Kevin Heasman, Cawthron Institute, new Zealand)

Longlines are aquaculture production systems used to culture bivalves and other shellfish in hanging culture methods, in which the shellfish are held in culture units suspended in the water column. The longlines, which usually comprise buoyant ropes suspended at the water surface or in the water column between anchors and floats, support several secondary lines, to which can be attached an array of structures such as spat collectors and pearl, lantern, and pocket nets in which shellfish are contained; or ropes, to which shellfish are attached by various means.

Typically used to culture species such as mussels, pearl oysters and scallops, longlines could be used in sheltered and unsheltered offshore areas.

Stock Enhancement and Ranching

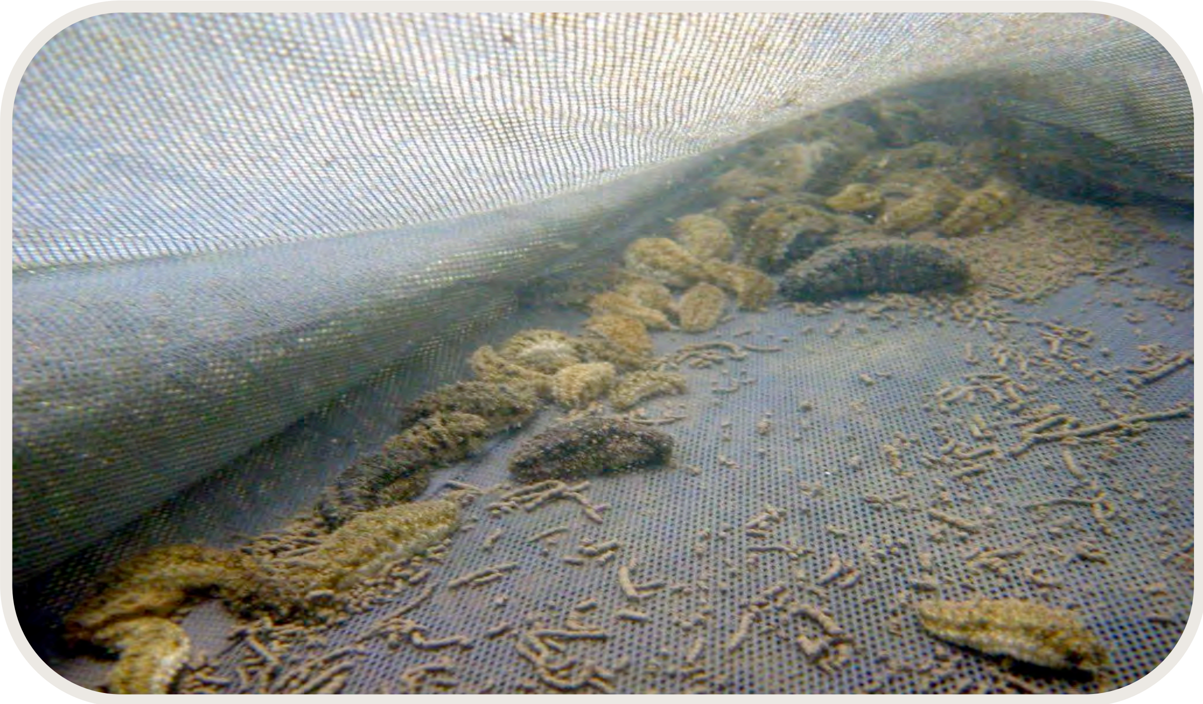

Figure 7: **Stock Enhancement** (Source: Steve Purcell)

Stock enhancement involves the release of cultured juveniles into wild populations to augment the natural supply of juveniles and optimise harvests by overcoming recruitment limitation, while ranching refers to the release of cultured juveniles into unenclosed marine environments for harvest at a larger size in “put, grow and take” operations.

While there can be benefits for stock enhancement and sea ranching, there are also associated risks. The main risks from the release of juveniles into marine environments include impacts on the genetic diversity of the wild populations, potential for the introduction of disease, and ecological impacts on the target stocks and marine environment.

7 Aquaculture Development: The Cocos (Keeling) Islands

7.1 Sites

7.1.1 Preliminary Site Identification

The aquaculture sites considered to have the features needed to support commercial aquaculture development at the Cocos (Keeling) Islands are all located on West Island. While there may be some future prospects for the establishment of aquaponic systems on Home Island, these are likely to be smaller in scale and may follow the successful development of these systems on West Island.

One land-based aquaculture operation has been established on the Cocos (Keeling) Islands. Licensed to grow ornamental marine species, the facility includes a hatchery and series of growout tanks using sea water in a flow-through system. The water is pumped ashore from a marine intake and discharged by gravity through a small settlement pond.

The sites that were identified for aquaculture development in the preliminary assessment process are the Quarantine Station, the Old Farm, the Quarry and the Lagoon. The Quarantine Station and the Old Farm (Figure 8) are considered to have the capacity to support aquaculture development. These sites are considered in further detail below.

Figure 8: **Sites Selected on the Cocos (Keeling) Islands**

The Quarry was not further considered, due mainly to it having a competing resource use and not having and competitive advantages over the two sites selected.

The Lagoon refers to the sheltered waters on the inside of the islands of the southern atoll, which was previously an approved aquaculture site for the proposed offshore production of pearl oysters (the site was never developed or used for that purpose). Within the plan, the area was not considered suitable for commercial aquaculture development for two main reasons: the sea water enclosed within the lagoon can become anoxic under certain climatic conditions, so is unsuitable for commercial development; and the reef environment is considered fragile, so any significant aquaculture development activities are unlikely to be supported.

Importantly, the Cocos (Keeling) Islands does not have any permanent surface water. This feature represents a distinct advantage when considering the species appropriate for aquaculture ventures, since there is no habitat for translocated species to establish a feral population.

7.1.2 Quarantine Station

The Quarantine Station is located at Lot 327, Sydney Highway on West Island (figure 9). Approximately 21 hectares in area, the site is located 800 m to the north of the main settlement and 1500 m from the access to the Rumah Baru jetty and off loading facility.

Figure 9: The Quarantine Station

The facility is no longer in use for quarantine purposes and the Department of Regional Australia is looking to undertake a plan of management for the site. This is in line with findings from the *Report for Cocos (Keeling) Islands Quarantine Station Outline Development Plan* (GHD, 2010), commissioned by the Commonwealth Government. The plan aims to provide a land use planning framework to guide future subdivision and development of the site taking into consideration the *Crown Land Management Plan for the Indian Ocean Territories: Cocos (Keeling) Islands* (GHD, 2009a).

The Quarantine Station exhibits flat topography an average of 1-2 m above sea level with sand and low lying grassed vegetation. Several existing buildings in the north portion of the site appear in good structural condition and may only require general internal maintenance. Two storage buildings are currently in use by the Shire of the Cocos (Keeling) Islands.

Water supply is available for either freshwater or sea water systems. Fresh water can be supplied from boreholes and these systems would have minimal discharge; and sea water through a standard marine intake pipeline and gravity discharge. The freshwater lens in the vicinity would suit recirculation systems.

GHD (2009a) recommends that future use for this area should recognise the need to reduce the islands dependency on imported food and building materials by encouraging rural development, including agriculture, horticulture and aquaculture. These recommendations are consistent with those made in this Aquaculture Development Plan.

The Quarantine Station is considered an exceptionally good site that offers the best opportunities for aquaculture development at the Cocos (Keeling) Islands. The area is sufficiently large to support the establishment of an aquaculture precinct that provides common services, such as sea water supply, treatment and discharge systems, and would enable economies of scale not possible for individual operations. The site could support the establishment of land-based marine and fresh water production systems.

7.1.3 Old Farm

Prior to its closure, the Cocos Farm (Old Farm) (Figure 10) on West Island was a 7 hectare productive horticulture system that, at its peak, was producing a range of fresh produce. It incorporated multiple green houses, cold storage facilities, irrigation and an on-site residential dwelling (Christmas Island Phosphates, 2010).

Figure 10: The Old Farm

The Old Farm is a level site well suited for aquaculture development, preferably using freshwater systems. There is a freshwater lens in the vicinity that would suit recirculation. The site may also have some potential for marine systems using a marine intake or beach wells to supply seawater. The site area has been largely cleared due to its previous operation as a farm. The previous usage may have resulted in residual pesticides in the soil and, or, groundwater. Soil residues are unlikely to affect aquaculture systems that use tanks, raceways, or other units that do not allow the water to contact the ground. The presence of pesticide residues in groundwater, and other water quality parameters, would be determined as part of a standard aquaculture project development process.

It is claimed the farm was forced to close as a result of declining returns and inefficient distribution channels (Christmas Island Phosphates, 2010). An expression of interest for the commercial rehabilitation of the farm to a functioning venture has been released, but not yet pursued. Currently there are active honey operations on the site as well as several wild growing fruit trees. The only other active use on the site is a set-down point for machinery and materials being used for the Rumah Baru Construction project (Christmas Island Phosphates, 2010).

Due to its greater distance from the coast, the Old Farm is considered less suitable for marine systems than the Quarantine Station, but the site affords good aquaculture development opportunities for fresh water aquaponic systems.

7.2 Species

The preliminary assessment identified several species that warranted further consideration and rejected those reasonably considered to have little or no prospects for commercial development (Table 3), at least in the short to medium term. For example, it is very unlikely that marine finfish species such as serranids (coral trout, various groupers), lethrinids (emperors) and lutjanids (such as mangrove jack), which may have strong commercial prospects in mainland Australia or south east Asia, could be produced profitably at the Cocos (Keeling) Islands, so these species were not considered any further.

From a purely technical perspective, many marine and fresh water species could be produced by aquaculture at the Cocos (Keeling) Islands. Those species that could be cultured were broadly considered in respect of their prospects for commercial viability, environmental impact and sustainability and, given the remote location, competitive advantage. This initial assessment included discussion with scientific, technical and industry authorities familiar with aquaculture and the economic and environmental characteristics of the Indian Ocean Territories.

Table 3 Species Identified According to Selection Criteria on the Cocos (Keeling) Islands.

Species Group	Local Market	Export
Marine Finfish		▪ Ornamentals
Marine Shellfish and Invertebrates	▪ Bêche-de-mer ▪ Gong Gong	▪ Ornamentals ▪ Pearl Oysters
Diadromous and Fresh water Species (Finfish and shellfish)	▪ Barramundi ▪ Tilapia ▪ Redfin Perch ▪ Carp ▪ Murray Cod ▪ Redclaw Crayfish ▪ Cherabin	

Species identified in Table 3 were then categorised according to their level of capacity for aquaculture development (Table 4).

Table 4 Classification of Species with Potential for Aquaculture Development on the Cocos (Keeling) Islands.

Category 1*	Category 2**
▪ Ornamentals ▪ Barramundi ▪ Tilapia ▪ Redfin Perch ▪ Carp ▪ Murray Cod ▪ Redclaw Crayfish ▪ Cherabin	▪ Bêche-de-mer ▪ Gong Gong ▪ Pearl Oysters

*Category 1: Potential for aquaculture development

**Category 2: Limited potential for aquaculture development

Note: Future feasibility studies are recommended for Category 1 species.

The more likely candidate species for aquaculture at the Cocos (Keeling) Islands were then assessed in detail according to the selection criteria and divided into the four principal categories set out below.

1. Marketing (product features, market economics and market-place features).

2. Culture technology (broodstock; spawning and egg quality; development and behaviour; nutrition and diet; and hatchery technology).

3. Production efficiency (broodstock; spawning and egg quality; development and behaviour; nutrition and diet; and hatchery technology).

4. Commercial viability (profitability, infrastructure, competitiveness, integration, regulation and support).

Category 1 Species

Ornamental Species

In the context of this report, *ornamental species* refers only to cultured organisms, not to wild-caught fish or invertebrates captured directly from the wild and held briefly in captivity before being exported. These cultured ornamental species may be either: tank-reared fish and invertebrates grown from eggs spawned in captivity from wild-caught or cultured parents; or animals grown in captivity from larval or other early life history stages collected from the wild.

Likely ornamental species that could be cultured at the Cocos (Keeling) Islands include marine finfish, corals, live rock and live sand, marine molluscs and other invertebrates. Species not previously considered ornamental may also have commercial prospects, for example, gong gong is unlikely to have commercial prospects for production as a food fish, mainly due to its low value and limited market, but may have some potential as an ornamental species (Queen conch, a relative of gong gong, is marketed to hobbyists for algae control).

In the context of this Aquaculture Development Plan, for the Cocos (Keeling) Islands, ornamental species include bivalve shellfishes cultured for the shell specimen or so-called decoration shell market. It is likely that the only viable species are the giant clams, since there is a strong demand for good quality clam shells in Australian and export markets.[9] Giant clams are not currently produced by aquaculture at any scale for the specimen or decoration shell market.

Marketing

Although they are generally more difficult and expensive to grow in a hatchery than collect from the wild, cultured finfish and corals have many important marketing and other advantages over wild-

[9] *Tridacna derasa* and *Tridacna maxima* are the giant clam species considered likely to have potential for aquaculture production. The giant clam *Tridacna gigas* is thought to be almost extinct locally and proposed for protection in the new island-specific fishing rules.

caught organisms. Because they have been reared in tanks, they are artificially selected for a closed environment, usually tolerate varying water chemistry better and, generally, thrive better during transport and in an aquarium. Cultured corals tend to be hardier and more disease resistant, which is important during transportation, when the specimen can go through several different lighting and water quality regimes.

From a marketing perspective at present, live rock, live sand, and corals are not offered by many wholesalers and so not readily available to hobbyists living some distance from coral reefs. This provides an opportunity for direct marketing that can be exploited from more remote locations such as the Cocos (Keeling) Islands. For giant clams in particular, but also for corals and other species, internet marketing affords significant opportunities for ornamental species grown at the Cocos (Keeling) Islands.

Marine ornamental species represent about 10-20% of the total ornamental trade, but that proportion is increasing as marine aquaria become more popular, particularly in the USA and Europe. Increasingly, enthusiasts want to create reef aquaria to keep finfish, invertebrates and, particularly, dynamic coral reef systems containing finfish, molluscs, crustaceans and plants. The global market for these products is experiencing significant growth, affording opportunities for aquaculture development at the Cocos (Keeling) Islands.

There is strong demand in Australian and export markets for good, gem-quality giant clam shells. Historically, very large giant clam shells exceeding 100 cm have sold for more than $1,000 per piece, however, the likely sizes that would be produced by aquaculture would be substantially smaller. Gem quality giant clam shells of approximately 20 cm would likely sell for $15-20 per piece in the wholesale market. Export restrictions would have to be taken into account in any consideration of the commercial production of these species. Gong gong shells are unlikely to be commercially viable since the Philippines currently supplies these and several other species to markets worldwide at very competitive prices of around $0.15 per piece, individually wrapped.

Culture Technology

The status of the culture technologies for ornamental species varies according to the species being grown: the culture technologies are best-developed and generally well known for tropical, fresh-water fish, which are unsuitable for production at the Cocos (Keeling) Islands because their production there is unlikely to be competitive with south-east Asian producers. The life histories of many of the marine ornamental finfish and invertebrates are complex and they are difficult to produce in economic quantities, but technology for ornamental marine finfish is improving. Aquaculture is making rare species more readily available and, because cultured marine fish are more robust than their wild-caught counterparts, they tend to survive better in aquaria and are easier to spawn than wild fish. Culturists are starting to grow new strains of wild fish as culture technology continues to improve, and with selective breeding increasing numbers will become available, as has happened with fresh water ornamental species.

The culture technologies for corals, live rock, and live sand are described in the scientific literature and more widely in hobbyist publications. Cultured corals are started using fragments of wild coral attached to synthetic substrate. In the future it is likely corals could be cultured from wild, fertilised eggs, and collected using a hand net at the time of mass coral spawnings.

Giant clams have been cultured for many years and, although good aquaculture skills are needed for their production in captivity, the techniques for their hatchery production are well known. The popularity of giant clams is increasing rapidly. Globally, *Tridacna derasa* is the cheapest and most widely available, followed by *Tridacna maxima* and *Tridacna crocea*. The most likely giant clam aquaculture candidate species at the Cocos (Keeling) Islands are *T. derasa* and *T. maxima*: the giant clam *Tridacna gigas* is likely to be extinct at the Cocos (Keeling) Islands, but could be produced there if broodstock were translocated from elsewhere. *T. crocea* has never been recorded anywhere in the Indian Ocean Territories so is not considered a candidate species.

Production Efficiency

Production efficiency varies according to the species being grown. Assuming that an appropriate site, suitable species, compatible culture technologies and production systems are selected and used, production efficiency is usually high. At present, however, marine ornamentals produced by aquaculture supply about 2% of the global trade and sources of commercial quantities have been slow to develop. This factor does not detract from the prospects of economically sustainable marine ornamental aquaculture based at the Cocos (Keeling) Islands. A marine ornamental industry at the Cocos (Keeling) Islands would need to target higher value species for niche markets due to the limitations of airspace for export markets.

If undertaken for sale as decoration shells, giant clams would have to be seeded and grown on natural reefs within the lagoon at the Cocos (Keeling) Islands.[10]

Commercial Viability

Although cultured ornamental species have advantages over wild-caught fish, they are generally more expensive to produce, as a result of higher capital costs associated with establishing a hatchery and growout tanks and the higher labour and feed costs incurred from broodstock spawning and larval rearing operations. For some species, this may mean they are not profitable to grow.

[10] The lagoon at Cocos Island is not considered suitable for aquaculture conducted under intensive or semi-intensive conditions, however, the culture of giant clams on natural reefs inside the lagoon would be carried out extensively, so these stocks would be less susceptible to environmental stresses caused by periods of low dissolved oxygen.

The business of growing ornamental species is increasing rapidly, driven by increasing market demand and diminishing supplies being available from the wild, due to habitat destruction and over-fishing. The relationship between costs and returns is such that ornamental species aquaculture is commercially viable for mainly fresh-water species with known culture technologies. Infrastructure requirements are generally small and inexpensive and there is some limited potential for diversification. There is, however, strong competition from Singapore, other South-East Asian countries, the USA, European countries and elsewhere.

For marine ornamental species, commercial viability can also be affected by problems associated with off-colouration and anomalous behaviour, such as, clown fish not forming symbiotic relationships with anemones. There is a current problem with some markets having supply problems, as a result of varying availability compared with similar wild-caught species. At present, for marine ornamental species, wild-caught fish dominate the market and relatively few cultured marine species are available. This situation is likely to change, as a result of continuing improvement in culturing techniques, decreasing production costs, and as a result of decreasing wild supplies and increasingly prohibitive restrictions on the capture of wild ornamental fish.

The aquaculture of marine ornamental species at the Cocos (Keeling) Islands would need to be undertaken as a long-term investment, due to the relatively high start-up capital costs and marketing limitations. Ideally, such a venture would be integrated with some other income source, such as tourism, to provide alternative or supplementary income sources until a reasonable cash flow business can be established.

The commercial viability of growing giant clams in extensive offshore production systems has yet to be determined, but would be governed mainly by the growth rate of the shells and their survival rate after being seeded on reefs.

Due to transportation costs and limited airfreight space, only high-value, live ornamental species produced at the Cocos (Keeling) Islands are likely to be commercially viable. There may be some capacity for specimen or decoration giant clam shells in Australian and export markets, since these can be exported by sea freight.

The difficulty of transporting commercial quantities of ornamental fish to overseas export markets as a result of current quarantine procedures represents an impediment to the development of a significant ornamental fish aquaculture industry at the Cocos (Keeling) Islands. This impediment arising from current quarantine procedures could be alleviated by establishing a facility at Perth to enable the holding of live fish and their transfer to export markets. The establishment of such a facility, which is necessary if an ornamental marine fish industry is to be developed at the Cocos (Keeling) Islands, forms the basis for one of the recommendations in the Aquaculture Development Plan,

Barramundi

Marketing

Usually sold whole, plate-size, or as fillets, barramundi have white flesh with good taste and texture. The flesh of fish grown in fresh water or recirculating systems is often considered to have a muddy taste or “taint”, a problem that may be rectified by purging the fish in sea water before harvest.

The Australian market for barramundi is supplied from the wild capture fishery, and increasingly, aquacultured product from within Australia and Southeast Asia. Due to the cost structures, likely cost of production and other economic and technical factors, barramundi produced at the Cocos (Keeling) Islands are unlikely to be competitive in mainland or other export markets.

As a stand-alone product, it is also considered unlikely barramundi could be produced and sold profitably in the local the Cocos (Keeling) Islands market, mainly due to the ready availability of marine finfish to the local population. There may be opportunities for value adding by way of developing a smoked product.

Culture Technology

The Cocos (Keeling) Islands is outside the normal distribution of barramundi, but the species has reportedly occurred at the islands. A protandrous hermaphrodite, barramundi matures first as a male before becoming a functional female. The fish are also catadromous - generally living in fresh water and migrating to estuaries to spawn. These characteristics complicate the culture technology for the species, although juveniles can now be produced reliably and in mass quantities.

The technology for the hatchery production and growout of barramundi in fresh and sea water is well known. The fish can be produced in small tanks at fairly high densities and are currently being used successfully in aquaponic systems.

The establishment and operating cost of a barramundi hatchery is relatively high and requires specific skills and experience. At least initially, the most practicable source of barramundi juveniles for growout at the Cocos (Keeling) Islands would be from hatcheries located in Australia.

Production Efficiency

Barramundi are grown out in Australia in environments ranging from marine to fresh, in land-based and offshore farms using cages, tanks, ponds, and raceways. Semi-intensive and intensive, flow-through and recirculating systems are also being used, with varying degrees of success. One operator has been transferring technology to northern Queensland Indigenous communities, who are successfully producing barramundi and fresh produce in aquaponic systems.

Aquaponic or other barramundi production systems located at the Cocos (Keeling) Islands would be dependent on the availability of disease-free stock. Several Australian hatcheries, including one in WA, are currently certified to produce and supply certified disease-free seed stocks.

Barramundi is generally a rapidly-growing, robust species well suited for commercial aquaculture. The growth rate, feed conversion efficiency, stocking density, and other production parameters for the species are well known, and under suitable conditions conducive to efficient production.

Commercial Viability

The profitability and the costs-and-returns relationship is well known for various growing systems. Infrastructure needs are high and - if barramundi aquaculture is contemplated at the Cocos (Keeling) Islands as a stand-alone venture - almost certainly prohibitive. It is highly unlikely a barramundi aquaculture project would be financially feasible if it targeted either export or local markets.

Barramundi production at the Cocos (Keeling) Islands may be economically feasible if undertaken as a key element of a larger, fresh water recirculating aquaponic system growing fresh produce for the local market. In these aquaponic systems, the fish would essentially be a by-product with the fresh produce generating a significant part of the revenue. It may be possible to supply fresh fish to the restaurants on-island, however, feasibility studies would need to be conducted to determine demand.

Commercial viability will, to a large extent, be determined by the cost of providing a manufactured diet for the fish. Fish pellets formulated for barramundi will need to be imported from mainland Australia or a south-east Asian manufacturer. Importation requirements for manufactured diets for barramundi and other species are discussed in section 4.4.3 above. The availability and cost of feed will comprise an important element of any financial feasibility study that may be done.

Tilapia

The three commercially important farmed tilapia species are Nile tilapia (*Oreochromis niloticus*), Mozambique tilapia (*Oreochromis mossambicus*) and blue tilapia (*Oreochromis aureus*). The Nile tilapia is the most popular farmed species outside Africa and Asia.

Considered a noxious species in Western Australia, tilapia have the ability to successfully invade many freshwater aquatic habitats and compete with native fishes, due to their highly efficient reproductive strategy, simple food requirements, and ability to live in a variety of conditions. The species has been identified as a candidate for aquaculture in closed, fresh water systems at the Cocos (Keeling) Islands for the reasons outlined below, but also because it is probably the most suitable fish for production in aquaponic systems. The Cocos (Keeling) Islands represents a low risk environment for the introduction of tilapia as there is no permanent fresh water on the island. Even if live fish were to escape from a production facility, they could not survive in the marine environment.

Marketing

Tilapia is a highly regarded table fish wherever it is consumed. One of the most widely cultured species in the world today, tilapia have a high quality flesh that is in increasing demand due to the ability of the product to comply with strict regulations in respect of quality, safety, traceability, labelling, environmental sustainability and product security. Currently, fresh tilapia fillets comprise a core seafood product in the supermarket and restaurant sectors in the USA and European Union. Tilapia cultured at the Cocos (Keeling) Islands would be destined for consumption in the local market as fresh table fish.

Culture Technology

The culture technology for tilapia is very well known, relatively simple, and there exists a wealth of information for their production.

Production Efficiency

Tilapia have good characteristics for farming. One of the best researched species for aquaculture, tilapia are fast-growing, able to survive in poor water conditions, eat a wide range of food types, and breed easily with no need for special hatchery technology. The fish are robust and tolerate a wide range of environmental conditions. Little environmental modification is needed, so expensive, technology-intensive aquaculture production systems are not necessary.

Worldwide, tilapia have come to be regarded as highly suitable for low cost aquaculture because they can be grown on a vegetable-based, pelletised diet. At the same time, their firm, flaky white flesh with its mild buttery taste makes them a potential substitute for wild whitefish species.

Under optimum conditions and water temperatures between 26ºC and 28ºC, these fast-growing warm-water fish can reach a market size of 500g within six to eight months. The biological features of the fish mean that it suitable for production by inexperienced aquaculturists.

Commercial Viability

Because it is a herbivorous species, the production cost of tilapia is lower than other carnivorous species such as barramundi and Murray cod, so it is more likely to be profitable. This is a key factor when considering the commercial viability of the species, particularly when produced in an integrated aquaponic system and for a market unlikely to pay a premium for cultured fish.

As for barramundi, tilapia aquaculture at the Cocos (Keeling) Islands is more likely to be successful if undertaken as a key element of larger, fresh water recirculating aquaponic system growing fresh produce for the local market. Tilapia is likely to represent greater commercial viability than barramundi and other carnivorous species due to the lower cost of feed.

Redfin Perch

An introduced species, redfin perch (*Perca fluviatilis*) is a voracious carnivore and considered a pest species due to its ability to successfully invade many freshwater aquatic habitats and compete with native fishes. It has been identified as a candidate for aquaculture in closed, fresh water systems at the Cocos (Keeling) Islands for similar reasons to those outlined for tilapia. The Cocos (Keeling) Islands represents a low risk environment for the introduction of redfin perch because escapees could not survive in the marine environment.

Marketing

Redfin perch is a highly regarded table fish in some European and Asian markets. In addition to the marketability of its high-quality flesh, redfin perch introduced from Australia and cultured in the Cocos (Keeling) Islands would have a disease-free status and an export market could possibly be developed to supply specific-pathogen-free (SPF) fertilised eggs.

Fish cultured at the Cocos (Keeling) Islands would be unlikely to be competitive in overseas markets, so would be destined for consumption in the local market only.

Culture Technology

The culture technology for redfin perch is reasonably well known and relatively simple. Initially, disease-free fertilised eggs could be imported from Australia for seed stock.

Production Efficiency

Redfin perch are well suited for aquaculture and their production is increasing. The fish grow quickly and breed easily with no need for special hatchery technology. The fish generally prefer cooler water temperatures so are less likely to thrive at the Cocos (Keeling) Islands than tilapia. In addition, they are carnivorous so would likely require a higher protein, and consequently a more expensive, diet.

Commercial Viability

The commercial viability of redfin perch aquaculture at the Cocos (Keeling) Islands is likely to be similar to, but likely lower than, that of tilapia. Although its production costs are likely to be higher, the species has some competitive advantages over tilapia, such as a source of disease-free eggs in Australia, fewer likely import restrictions (since it is not currently considered a noxious species) and a possible market for SPF eggs to export markets, however, these advantages are unlikely to be sustainable. As for other species, redfin perch aquaculture is considered more likely to be successful as an element of a fresh water recirculating aquaponic system growing fresh produce for the local market.

Carp

Carp (*Cyprinus carpio*) is the fish most widely produced by aquaculture globally. The Cocos (Keeling) Islands represents a low risk environment for the introduction of the species: there is no permanent fresh water on the island and even if live fish were to escape from a production facility, they could not survive in the marine environment.

Marketing

One of the more highly regarded table fish in many European and Asian markets, Carp is an important species where it is produced traditionally and the majority of consumption is domestic. The market usually demands live or freshly dressed fish. Carp cultured at the Cocos (Keeling) Islands would be destined for consumption in the local market only. The local demand for the product would have to be determined before any attempt is made to culture the species.

Culture Technology

The culture technology for carp is very well known, relatively simple, and there exists a wealth of information on their husbandry and culture. The fish is robust and has been demonstrated to do well in integrated agricultural systems, so would likely thrive when cultured as an element of an aquaponic system.

Production Efficiency

As for tilapia, carp have good characteristics for farming. Their production in semi-intensive systems is well known; they are able to survive in poor water conditions, eat a wide range of food types, and breed easily with no need for special hatchery technology. The fish are robust, tolerate a wide range of environmental conditions and do not require expensive, technology-intensive aquaculture production systems.

Carp are suitable for low cost aquaculture because they can be grown on a herbivorous diet and the biological features of the fish mean that it suitable for production by inexperienced aquaculturists.

Commercial Viability

The commercial viability of carp aquaculture at the Cocos (Keeling) Islands is likely to be similar to that of tilapia and redfin perch. Unlike tilapia, however, carp eggs could be obtained from Australia and would have fewer likely import restrictions. Carp aquaculture at the Cocos (Keeling) Islands is considered more likely to be successful as an element of a fresh water recirculating aquaponic system growing fresh produce for the local market.

Murray Cod

Marketing

Murray cod are highly regarded in the market place and have excellent eating qualities. The fish have firm, white flesh and are sold in a variety of product forms. Murray cod are particularly well known and generally acknowledged throughout Australia as the premium-quality native fresh-water species.

As for other finfish species, Murray cod that may be produced at the Cocos (Keeling) Islands would have limited prospects for export and would have to be marketed locally. There may be some capacity for value adding, such as smoked fish.

Culture Technology

A native fresh-water Australian species, Murray cod, is distributed naturally throughout the Murray-Darling drainage area. Although generally considered a cool water species, Murray cod will grow quite well at temperatures exceeding 30ºC provided good water quality and high dissolved oxygen levels are maintained, and so the species may be suitable for growout at the Cocos (Keeling) Islands (G. Gooley, pers. comm.). One problem normally associated with Murray cod growout at higher temperatures is the fish fail to spawn, but that is unlikely to be problematic at the Cocos (Keeling) Islands, where producers would be dependent on a supply of seed stocks from Australian hatcheries. In south-eastern Australia, about 15 hatcheries produce Murray cod juveniles for restocking and aquaculture purposes.

Traditionally grown out in extensive and semi-intensive earthen ponds, Murray cod have been successfully cultured more recently in intensive, recirculating systems. The fish are identified as suitable for use in aquaponic systems.

Production Efficiency

Under optimum growth conditions, Murray cod can reach a market size between 600g and 1.3kg within twelve to eighteen months. The growth rate, feed conversion efficiency, stocking density and other production parameters for the species are well known and under suitable conditions, conducive to efficient production.

Murray cod have proven to be tolerant of stocking densities as high as 80-150kg/m^3, but oxygen injection is required with very high stocking levels, so densities of 50-60kg/m^3 are considered more practicable. Murray cod have efficient food conversion in intensive recirculating systems with good growth rates (500-1000g within 12 months). Survival rates are high, but dependent on good fish husbandry and water quality management.

Commercial Viability

As for barramundi, Murray cod aquaculture at the Cocos (Keeling) Islands is likely to be successful only if undertaken as a key element of larger, fresh water recirculating aquaponic system growing fresh produce for the local market. In these aquaponic systems, the fish would essentially be a by-product with the fresh produce generating a significant part of the revenue. This carnivorous species is similar to barramundi as it requires a relatively high level of protein in its diet, so its culture would also necessitate the importation of manufactured pellets from the mainland.

Redclaw Crayfish

Marketing

Redclaw crayfish (*Cherax quadricarinatus*) are native to tropical Queensland and the Northern Territory. The redclaw industry in Australia is characterised by a large number of small enterprises, which have resulted in a fragmented marketing effort. Sales of redclaw in Australia at the retail level fluctuate according to the variable production levels, with most crayfish being sold to restaurants, either directly or through wholesalers. Redclaw are commonly sold in size grades, with 20g increments from 30-50g to 120g. Historically, redclaw have been sold live, although sales of cooked and frozen product are increasing.

Redclaw grown at the Cocos (Keeling) Islands would have to be sold into the local market. If required, value can be added to the product by purging in brackish water before harvest, enabling it to be marketed as a premium seafood product with a delicate flavour.

Culture Technology

Redclaw have good aquacultural attributes, such as fast growth rates, ease of reproduction, lack of any planktonic larval stages, gregariousness, and the ability to tolerate poor water quality conditions.

Biological data and information about viable farming techniques for redclaw are readily available. Current culture technology is based on research and development undertaken in Queensland that provided recommendations for cost effective, low levels of technology that produces high yields. A line of domesticated and selectively bred redclaw is now available for prospective redclaw farmers.

Redclaw are best cultured in specifically constructed, semi-intensive aquaculture ponds that provide the correct habitat for the growing animals.

Production Efficiency

Redclaw are excellent for aquaculture due to their physical, biological, and commercial attributes. They are highly adaptive omnivores that readily consume a variety of organic matter. Although the crayfish will tolerate a range of water quality conditions, optimum growth and commercial viability will only be achieved if water quality is managed and maintained within optimal ranges.

Redclaw may have good production efficiency at the Cocos (Keeling) Islands in a production system that enables their culture in semi-intensive ponds, but are considered unlikely to have good production efficiency in more intensive systems.

Commercial Viability

The commercial viability of stand-alone redclaw aquaculture at the Cocos (Keeling) Islands would be governed by the market and the ability to maintain the crayfish in static ponds with minimal or no flow-through. If a local market could be established for a quantity of product that permits its economic production, the attributes of the species are such that it could be commercially viable.

Economic modelling for redclaw aquaculture in Queensland has indicated an internal rate of return of about 29% and a discounted payback period of only four years, however, the cost of setting up a stand-alone project was estimated at $330,000, which is likely to be prohibitive for the Cocos (Keeling) Islands under the prevailing market conditions.

If undertaken in intensive systems, whether stand-alone or integrated, the commercial viability of redclaw at the Cocos (Keeling) Islands is likely to be poor.

A production system that grows redclaw in semi-intensive ponds that form part of an aquaponic system is more likely to be commercially viable and is considered to represent an option for aquaculture development at the Cocos (Keeling) Islands.

Cherabin

Marketing

Cherabin (*Macrobrachium rosenbergii*), known more widely as giant freshwater prawn, occurs naturally in tropical fresh water environments in Australia. The species is cultured in many countries, but principally in the Americas and southern Asia. At present there is no significant cherabin aquaculture in Australia, but the species has been proposed as an aquaculture candidate on several occasions.

The global annual aquaculture production exceeds 200,000 tonnes and international markets are expanding. Wild-caught cherabin have a long marketing history, but farmed shell-on freshwater prawns are now a familiar sight in the EU markets and, to a lesser extent, the USA and Japan. India, Bangladesh, Vietnam and Thailand export a significant proportion of their wild-caught and farmed prawns. Freshwater prawns are a distinct product from marine shrimp, which have their own favourable culinary characteristics. In countries outside Asia, cherabin are consumed mostly by Asians or in restaurants serving Asian food.

As for other candidate species for aquaculture at the Cocos (Keeling) Islands, the only likely market would be the local one.

Culture Technology

The culture technology for cherabin is well known and widely available. Although the prawns are grown in fresh water, they need brackish water to spawn. Stimulated by improvements in culture technology and the major expansion of world demand for this species, the farming of the freshwater prawn has developed rapidly during recent years to what is now a multi-million dollar industry.

Production Efficiency

Where they are cultured, cherabin are grown out mainly in fresh water earthen ponds at medium to low density. Production efficiency is lower at higher densities, so the species is less suited to more intensive production techniques.

Production costs vary significantly according to the site, with the more extensive pond-based systems generally being more profitable.

Commercial Viability

Aside for the efforts of some proponents, the development of cherabin aquaculture has not occurred in Australia. The commercial viability of cherabin at the Cocos (Keeling) Islands in intensive, recirculating systems is likely to be poor, even if undertaken as part of an aquaponic system.

Category 2 Species

Bêche-de-mer

As a result of there being no commercial or recreational fishery for the species locally, sea cucumbers stocks at the Cocos (Keeling) Islands are considered to be in a natural, unexploited state. Of the 18 species that occur at the Cocos (Keeling) Islands, the most common is the lolly fish (*Holothuria atra*), which comprises over 90% of the total population. The species with a high commercial value comprise a very small proportion of the total population. These include sand fish (*Holothuria scabra*) and two species of black teatfish (*Holothuria whitmaei* and *Holothuria nobilis*). Several additional species considered medium value also make up a small proportion of the sea cucumber population.

Marketing

The food product made from the treated body walls of sea cucumbers, also called “trepang”, is known commercially as “bêche-de-mer”. The international sea cucumber industry produces approximately 80,000 tonnes of raw product per year, mainly from areas in the south Pacific, Asia and Indo-Pacific, for processing into bêche-de-mer. Sand fish and black teatfish are the highest value species and those most heavily targeted. The product is marketed and consumed in a variety of ways.

In smoked, dried form, bêche-de-mer is a prized high-value food in Asian markets, where it is used in soups and reportedly as an aphrodisiac. It is also marketed in boiled, salted and dried forms.

In Japan and Korea, the body wall is eaten raw or pickled. Internal organs such as the gonad, respiratory trees and viscera are used in specialised products that are sold for prices exceeding A$1,000 per kilogram. Other product forms include dry tablets made from the treated body wall, a tonic extracted from boiled skin, food supplements said to have anti-inflammatory properties and other pharmaceutical products.

The three main markets for bêche-de-mer, Hong Kong, Singapore and Taiwan, are also the major re-exporting centres.

Culture Technology

Advances have been made over the past 10 years to develop culture technology for the more valuable sea cucumber species. A hatchery and growout project by the International Centre for Living Aquatic Resource Management (ICLARM) in the Solomon Islands, which has the objective of restocking populations of the commercially valuable species, has successfully reproduced sand fish. The culture technology is still being developed in most areas, including broodstock management and maturation, spawning, larval rearing, settlement and growout. Sand fish has proved to be the easiest of the commercial sea cucumbers to culture.

As a result of the ICLARM and other research driven by the increasing demand for the product, the basic techniques now exist to produce juvenile sand fish in large numbers at reasonable cost. The species is now reared in several countries including China, Indonesia, India, the Philippines and Ecuador.

Sea cucumber farming and ranching form a key part of the aquaculture sector in northern China, where the product is sold directly to restaurants or processed as dried edible and medicinal products. China has become the largest producer of sea cucumber worldwide.

Production Efficiency

Although they can be cultured in ponds, the most likely production system for sea cucumbers at the Cocos (Keeling) Islands is the growout of hatchery-reared seed stocks on natural reefs to enhance naturally occurring populations. Sand fish have many attributes for stock enhancement, but research is needed to develop reliable and cost-effective hatchery techniques for spawning, mass rearing of larvae, and the survival of large releases of juveniles into the wild.

If undertaken at the Cocos (Keeling) Islands, sea cucumber aquaculture would most likely be based on stocking reefs with mass quantities of hatchery-reared juveniles of the more commercially valuable species. The production efficiency of such a production system is largely unknown because, where sea cucumber stocking has occurred elsewhere, it has taken place on reefs depleted of natural populations. The stocking of large quantities of hatchery-reared juveniles on the Cocos (Keeling) Islands reefs would entail a significant intervention in the ecology of the current sea cucumber population with unknown environmental consequences.

Commercial Viability

The commercial viability of sea cucumber aquaculture at the Cocos (Keeling) Islands has not been determined, but would entail a high level of environmental risk. From a commercial perspective, given its remote location and infrastructure features, the Cocos (Keeling) Islands possesses few sustainable competitive advantages for sea cucumber aquaculture. Some locations being considered for sea cucumber aquaculture in Australia have major competitive advantages over the Cocos (Keeling) Islands, however, even these may be vulnerable as a result of comparatively high production costs and an unfavourable exchange rate.

It is beyond the scope of the Aquaculture Development Plan to argue the merit of establishing such a commercial wild fishery, however, from both a commercial and an environmental viewpoint, it would also be difficult to justify the establishment of an aquaculture industry based on stock enhancement or ranching, given the unexploited state of sea cucumbers at the Cocos (Keeling) Islands.

From a purely commercial perspective, sea cucumber aquaculture at the Cocos (Keeling) Islands is likely to be marginal at best. Unless a comprehensive business plan supported by a detailed environmental impact study provides strong commercial justification for sea cucumber aquaculture, the commercial and environmental risks are likely to significantly outweigh the potential rewards.

Access to technology for producing and releasing juveniles is not a sufficient rationale to proceed with stocking or stock enhancement to increase the yields of the more valuable species. A recent publication reasoned that the benefit of the unexploited sea cucumber population to the atoll's ecological well-being far outweighed the benefits any marginally profitable fishery (Bellchambers *et al*. 2007, cited in Hourston, 2010).

Gong Gong

Marketing

Distributed throughout the tropical regions of the western Pacific and Indian Oceans, gong gong (*Lambis lambis*) is considered a delicacy among the Cocos (Keeling) Islands Malay community, who harvest large numbers for ceremonial events.

It is unlikely an export market could be developed for gong gong as a food fish, although there may be some limited capacity for the species to be sold into the ornamental market.

Culture Technology

Technology has not been developed for culturing the species, however, it is unlikely to be difficult and if required could probably be readily adapted from the techniques developed for the aquaculture of queen conch (*Strombus gigas*), a more valuable species exploited for its shell and meat in the Caribbean. Queen conch have been successfully reared in hatcheries. Juveniles are reared in land-based pond systems before being transferred to offshore sea cages.

Production Efficiency

No information is available on the production efficiency of gong gong. Information available for queen conch indicates the cultured animals take three years to grow to market size at moderate densities in sea cages.

Commercial Viability

Semi-intensive and intensive systems used for queen conch aquaculture are unlikely to be commercially viable for the production of gong gong at the Cocos (Keeling) Islands.

For reasons that include no foreseeable demand for cultured product in the local market and lack of a high-value export market, the aquaculture production of gong gong at the Cocos (Keeling) Islands is very unlikely to be profitable and consequently the commercial viability is considered low.

Pearl Oysters

Marketing

The blacklip pearl oyster (*Pinctada margaritifera*), which is the basis of the black pearl industry in the Indo-Pacific region, occurs naturally at the Cocos (Keeling) Islands. Tahiti produces most of the black pearls sold worldwide and dominates the global market, although production is increasing in countries that include Australia, Fiji, New Zealand and Japan. In Western Australia, the production of black pearls is focused on the Abrolhos Islands.

Culture Technology

The culture technology for blacklip pearl oysters is well known and could be readily transferred to the Cocos (Keeling) Islands, however, the successful culture of pearl oysters and production of high-quality pearls requires a high level of skill and experience.

Production Efficiency

Generally, the production efficiency for blacklip pearls cultured at a suitable site that provides the biological requirements of the species is high. The filter-feeding oysters require no supplementary feeding, are reasonably tolerant and robust.

Sites suitable for pearl oyster aquaculture at the Cocos (Keeling) Islands would be located within the lagoon, however, climatic conditions periodically result in a lack of circulation and ensuing depletion of dissolved oxygen in the water. This is a major issue limiting the successful and efficient culture of pearl oysters, because these episodes would likely result in high or possibly total mortality.

Commercial Viability

The culture of blacklip pearl oysters at the Cocos (Keeling) Islands is considered to have poor commercial viability. Among other reasons, the initial establishment of a pearl farm is expensive, ongoing operating costs are high and it takes two to four years to generate any income from the sale of pearls. The cost of periodically hiring a grafting technician to work at the Cocos (Keeling) Islands may be problematic and would also be expensive. In addition, marketing and selling pearls is a very competitive undertaking and requires significant investment in time and money.

Further, from a commercial and investment perspective, a pearl farm located at the Cocos (Keeling) Islands would have no competitive advantage over one located, for example, at the Abrolhos Islands.

7.3 Production Systems

7.3.1 Land-based

Fresh Water Recirculation Systems

Fresh water, recirculating aquaponic systems growing fresh produce and fish are considered to afford good opportunities for aquaculture development at the Cocos (Keeling) Islands. Unless a local market can be developed for one or more of the identified fresh water candidate species, a stand-alone recirculating system producing table fish only would be unlikely to provide a reasonable rate of return on invested capital, so would not be financially feasible, at least under current socio-economic conditions.

Both sites identified at the Cocos (Keeling) Islands have the requisite characteristics and are considered well suited for the establishment of aquaponic systems. Water is available from a lens underlying the northern part of West Island and could be readily accessed through a relatively shallow bore. The sites are both conducive to the establishment of a variety of culture units, including tanks, raceways and ponds. Further, particularly at Quarantine Station, there is sufficient area for the planning and establishment of a dedicated aquaculture precinct that would support the development of a number of aquaculture businesses.

Marine Flow-Through Systems

At the Cocos (Keeling) Islands, land-based marine aquaculture production systems would be best suited for the production of high-value ornamental species. The production of marine species for the table fish market is unlikely to be financially viable.

Flow-through sea water systems are considered suitable for the Cocos (Keeling) Islands for the production of a wide variety ornamental marine finfish and shellfish species. These systems would ideally be located adjacent to the sea near the western boundary of Quarantine Station, to facilitate the establishment of efficient sea water intake and discharge systems.

7.3.2 Offshore

There are few viable opportunities for offshore aquaculture at the Cocos (Keeling) Islands.

The establishment of near shore sea cages or longlines inside the lagoon is considered high risk, given that the periodic anoxic conditions that occur could cause total stock mortality. Any proposal to culture species such as gong gong or sea cucumbers in stock enhancement or ranching systems would be very unlikely to receive approval due to the genetic, disease, and ecological risk that would be posed. Furthermore, the occurrence at the Cocos (Keeling) Islands of the more valuable species of sea cucumbers in very low numbers may suggest the environment is less suited to those species than the other, more prolific sea cucumbers.

The offshore environment at the Cocos (Keeling) Islands is very well suited to the production of various marine finfish species in open ocean production systems located beyond the fringing reef, however, given the depth of water and degree of exposure, the cost of installing and operating these production systems would almost certainly be prohibitive.

8 Aquaculture Development: Christmas Island

8.1 Sites

8.1.1 Preliminary Site Identification

A commercial hydroponic operation is currently present on Christmas Island. The facility is currently producing bananas in a large fruit forest plantation as well as tomatoes, cucumbers and lettuces within two greenhouses. The company is planning to expand its operation to include aquaponics and is currently in the process of obtaining AQIS approvals for importation of fish.

The sites identified for aquaculture development in the preliminary assessment process, and considered to have the capacity to support aquaculture development, at Christmas Island are the areas known as the Market Garden (adjacent to the existing hydroponic operation) and Central Area Workshop (Figure 11). These sites are considered in further detail below.

Figure 11: **Site Identified on Christmas Island.**

8.1.2 Market Garden

The Market Garden site (Figure 12) is located next to the existing hydroponics site discussed in Section 8.1.1. This flat land area is considered suitable for aquaculture operations. Groundwater is difficult to access as there is no lens and an underground stream is accessible only at certain points of the island. Water would be supplied through mains or scheme water and discharge is minimal – most practicably directly into a soak well.

Figure 12: **The Market Garden.**

The land is largely cleared with surrounding vegetation. There are no rocky outcrops and the soil is suitable for construction and location of aquaculture equipment.

The Market Garden is considered to represent the better opportunity for aquaculture development at Christmas Island, mainly due to its location adjacent to the existing related commercial activity. The current operator could use the area, if required, to expand the existing business or the site could accommodate new aquaponic businesses. Rather than being seen as competitive, a cooperative development effort between operators could increase profit margins by sharing or reducing resource costs. There are instances where aquaculture operators who form alliances reduce their production costs by leveraging volume discounts, and spreading out marketing costs and achieving other economies of scale

8.1.3 Central Area Workshop

The Central Area Workshop (Figure 13) is located on Lot 586 at the intersection of Murray Road and North West Point Road and is currently sub-leased to private contractors. The existing buildings appear structurally sound and may be suitable for re-use (GHD, 2009b).

The characteristics of this site are much the same as the Market Garden site (8.1.2)


Figure 13: **The Central Area Workshop.**

Past and current industrial uses at this site may have contributed to possible ground contamination through possible hydrocarbon spillages, however, this is unlikely to affect the proposed types of aquaculture operations, which would use above ground tanks and water not exposed to contaminated soil.

The Central Area Workshop has similar features to the Market Garden and consequently offers similar development opportunities. It may be possible for development to proceed at both sites, however, given that aquaculture development at Christmas Island is likely to be incremental, it would be more prudent to support development initiatives at a single site, at least initially

8.2 Species

Table 5 provides the species considered to have potential for aquaculture development on Christmas Island.

Table 5 **Species Identified According to Selection Criteria on Christmas Island.**

Species Group	Local Market	Export
Marine Finfish		▪ Ornamentals
Marine Shellfish		▪ Ornamentals
Fresh water Species (Finfish and shellfish)	▪ Barramundi ▪ Murray Cod	

Fewer species were identified for Christmas Island than for the Cocos (Keeling) Islands mainly because Christmas Island has permanent fresh water resources in which many of the fresh water species could establish feral populations should they escape from an aquaculture facility.

Table 6 categorises the species identified in Table 5 according to their capacity for aquaculture development.

Table 6 Classification of Species with Potential for Aquaculture Development on Christmas Island.

Category 1*	Category 2**
▪ Barramundi ▪ Murray Cod	▪ Ornamentals

*Category 1: Potential for aquaculture development

**Category 2: Limited potential for aquaculture development

The species considered as aquaculture candidates for Christmas Island are among those considered for the Cocos (Keeling) Islands. Information on the marketing, culture technology, production efficiency and commercial viability of these species is provided in section 7.3. The information provided below draws on that provided earlier, but provides additional comment specific to their potential for aquaculture development at Christmas Island.

Category 1 Species

Barramundi

The production of barramundi at Christmas Island is considered feasible if undertaken as part of an integrated aquaponic system that grows fresh produce for consumption in the local market.

Murray Cod

The production of Murray cod at Christmas Island is considered feasible if undertaken as part of an integrated aquaponic system that grows fresh produce for consumption in the local market.

Category 2 Species

Ornamental Species

No competitive advantage was identified for the production of ornamental species at Christmas Island.

The culture of marine ornamental species is likely to be less commercially viable at Christmas Island than at the Cocos (Keeling) Islands. Available sites at Christmas Island are either some distance from the ocean or would require pumping large volumes of sea water vertically to sites many metres above sea level at high cost. Any development of marine ornamental aquaculture at the Indian Ocean Territories would be best located at the Cocos (Keeling) Islands.

Species considered unsuitable for Christmas Island

Bêche-de-mer

The aquaculture of sea cucumbers is not considered commercially viable at Christmas Island, mainly because of the very limited habitat, but also due to the relevant factors identified for the Cocos (Keeling) Islands.

Gong Gong

The aquaculture of gong gong is not considered commercially viable at Christmas Island. There is virtually no export market for the species. Even if a market was identified, it would be low in value.

Pearl Oysters

The aquaculture of pearl oysters is not considered commercially viable at Christmas Island, mainly because of the limited availability of sites with suitable water depth, and due to other relevant factors identified for the species at the Cocos (Keeling) Islands.

Tilapia, Redfin Perch and Carp

The production of tilapia, redfin perch, and carp at Christmas Island would be considered feasible if undertaken as part of an integrated aquaponic system that grows fresh produce for consumption in the local market; however, for environmental reasons the translocation of the species would unlikely be approved. There exists a significant risk the fish could become established in the fresh water environment and threaten native species.

Redclaw Crayfish and Cherabin

The production of redclaw, and to a lesser extent cherabin, at Christmas Island may be feasible, particularly if undertaken as part of an integrated aquaponic system that grows fresh produce for consumption in the local market. For environmental reasons, however, the translocation of these species would unlikely be approved. There exists a significant risk they could become established in the fresh water environment and threaten native and endemic species.

8.3 Production Systems

8.3.1 Land-based

Fresh Water Recirculation Systems

Fresh water, recirculating aquaponic systems growing fresh produce and fish are considered to afford good opportunities for aquaculture development at Christmas Island. Unless a medium to high value local market can be developed for one or more of the identified fresh water candidate species, a stand-alone recirculating system producing table fish only would be unlikely to provide a reasonable rate of return on invested capital, so would not be financially feasible, at least under current socio-economic conditions.

Both the sites identified at Christmas Island are considered well suited for the establishment of aquaponic systems. Water supply would be by way of piped, scheme water, so the cost of this service would be an important factor in any assessment of financial feasibility. The sites are both conducive to the establishment of culture units such as tanks, raceways and ponds. Given the likely high cost of water, the production system would need to include structures that limit evaporative water loss, a factor that may preclude the use of ponds and semi-intensive production systems.

There is sufficient area for the planning and establishment of an aquaculture precinct that would support the development of a number of aquaponic businesses.

Marine Flow-Through Systems

Marine flow-through systems are not recommended at Christmas Island, even for the production of high-value ornamental species. The cost of pumping sea water to elevated locations some distance from the coast is likely to be prohibitive and certainly significantly more costly than similar systems located close to the coast and mean sea level at the Cocos (Keeling) Islands. Logically, from an economic perspective, marine flow-through systems growing ornamental species would be better located and supported at the Cocos (Keeling) Islands rather than Christmas Island.

8.3.2 Offshore

There are few opportunities for offshore aquaculture at Christmas Island.

Although the offshore environment at Christmas Island is very well suited to the production of various marine finfish species in open ocean production systems, realistically, the establishment of these systems would only be technically feasible close to the fringing reef before the water is too deep. In one of the few offshore locations that offers some protection from prevailing weather, the ocean depth reaches 3,000 metres within 100 metres of the shore. For environmental reasons, the cages could not be located directly adjacent to the shore due to the proximity to the pristine coral reefs.

As for the Cocos (Keeling) Islands, and particularly given the depth of water, the cost of installing and operating these production systems would be prohibitive for their use at Christmas Island.

9 Conclusions and Recommendations

Under certain conditions, aquaculture represents an opportunity for economic development and diversification at the Indian Ocean Territories.

The islands do have some competitive advantages in respect of aquaculture development, however, there are also several challenges that need to be overcome.

The Aquaculture Development Plan identifies and elaborates those features of the Indian Ocean Territories, both positive and negative, that are relevant to aquaculture development. Generally, any development initiatives should proceed sensibly and according to well considered feasibility studies and business planning process. The remote location, high-cost commercial environment, and other relevant social and economic issues are not unique to the Indian Ocean Territories: these factors are common in other areas that have successfully developed commercial aquaculture businesses on islands in areas such as the Caribbean and Pacific Ocean.

Key issues that need consideration in the development of aquaculture at the Indian Ocean Territories are marketing, infrastructure and services. Possible linkages of aquaculture with tourism and value adding to products represent good opportunities to generate supplementary revenue from commercial activities and should be considered in any business planning processes. These issues and relevant conclusions about aquaculture development at the Cocos (Keeling) Islands and Christmas Island are considered below and in sections 9.1 and 9.2.

Marketing

- Local markets at the Cocos (Keeling) Islands and Christmas Island are unlikely to pay high prices for cultured fish, because both islands have access to a ready supply of high-quality marine fish.

- There may be some niche market demand for species more traditionally consumed in Asian countries, such as carp.

- Export markets exist and are growing for a wide variety of marine ornamental finfish and shellfish, however, airfreight capacity from the Indian Ocean Territories is limited and costly. Consequently only high-value products are likely to be commercially feasible.

- Fresh produce is expensive at the Indian Ocean Territories, so the production of fish and fresh produce in recirculating aquaponic systems may be financially viable. In these systems, the fresh produce would be considered the primary product.

Infrastructure and Services

- Both islands have reasonably good general infrastructure, such as road access to, and the availability of, electrical power at identified sites. Access to fresh water is also generally good, however, the quantities available are limited and variable according to rainfall.

- Air freight services at the islands are restricted in capacity and sometimes unreliable, as freight carriage cannot be guaranteed. Export opportunities are therefore limited to high-value, low-volume products. There is a possibility that additional air freight may be provided in the future; if that is the case, air cargo capacity may increase and costs decrease, but probably not to any significant extent. For the foreseeable future, aquaculture products for export markets will be characterized by being high value and low volume.

- The commercial viability of exporting live ornamental species through Perth International Airport would be increased significantly if the fish could be unpacked and rested in a quarantine facility, before being repacked and exported to overseas markets. The establishment of such a facility would be needed to underpin growth in this sector.

- The importation of items such as plant, equipment and consumables, such as manufactured feeds, would have to be by sea freight to be economically feasible.

Aquaponics

With some variability according to where they are located, aquaponic systems generally require only half the volume of water to produce $100 worth of food in the form of fresh fish and fresh fruit and vegetables than stand-alone inorganic hydroponics (Wilson, 2006). Wilson (2005) notes that many inland Australian towns import the majority of fresh fish and vegetables from central markets in capital cities – where once they grew their own for local needs. Much the same can be said for the Indian Ocean Territories importing food from the mainland. This practice results in the produce having traveled a considerable distance at a substantial cost in transport fuel, resulting in very high retail costs for fresh produce, as well as an undesirable and unsustainable situation in respect of food security.

Aquaponic systems use fish wastes to grow fresh produce. In these systems, water use can be less than a third of that used in hydroponics alone (Wilson, 2005). For example, temperate-climate aquaponics is currently capable of using just 15 to 20 litres of water to produce food worth $100 in a barramundi and herb combination, based on market returns (Wilson, 2005).

Aquaponics Case Study: The Virgin Islands

The University of the Virgin Islands (UVI) has developed a commercial scale aquaponic system that has run continuously for the past five years in the Virgin Islands. The system produces Nile and red tilapia along with basil, lettuce, okra and other crops with substantial quality and yields.

A study conducted by the University researchers, Rakocy *et al*. (2004) on *Aquaponic Production of Tilapia and Basil: Comparing a Batch and Staggered Cropping system*, compared yields of basil and okra (a fruiting vegetable) grown in aquaponics with those grown in field production systems. The yields of basil grown in the aquaponic system were three times greater than the field grown, with aquaponic okra 18 times greater than field grown. Using the market price in the US Virgin Islands of $22 per kg for fresh basil, the researchers calculated gross income potential with aquaponics method resulting in $515 per cubic metre per year compared to $172 in field-produced basil. The yearly yield increased further when fish sales were incorporated.

UVI considers integrated water reuse systems (such as aquaponics) as a viable solution to sustainable food production in developing countries and arid regions – such as the Caribbean Islands.

These islands share similar characteristics to the Cocos (Keeling) Islands and Christmas Island, where freshwater is scarce or its supply expensive. This aquaponics case study suggests that similar aquaponic systems to those at UVI could be adapted to and be commercially viable in the Indian Ocean Territories.

Tourism Linkages

The interactions that can occur between tourism and aquaculture, both positive and negative, and their relevance to the Indian Ocean Territories are elaborated below.

- Aquaculture as a tourist attraction - There are numerous examples around the world that demonstrate strong synergies between aquaculture and tourism, even with small-scale farms. Opportunities for tourism to generate additional revenue from aquaculture projects can include tours of farms, where the aquaculturist shows and explains what is being done, followed by product tasting and purchases. If undertaken at an appropriate scale, aquaculture can also be integrated with recreational activities such as fee fishing. Small scale operations, such as those likely to be established at the Indian Ocean Territories, can often generate significant income from tourism if the necessary planning is undertaken at the outset and suitable resources provided.

- Tourism as a consumer of aquaculture products - Experience in areas such as the Mediterranean and Caribbean indicate tourists are significant consumers of seafood, much of which is produced in local aquaculture facilities. Locally cultured seafood can be served in restaurants and cafes, and relevant publicity provided by local tourism offices or associations. Farm visits can be integrated with restaurant experiences.

- Competition for land and sea - Competition and consequential negative impacts can occur between tourism and aquaculture for land and sea space where these resources are scarce. This is not an issue at the Indian Ocean Territories, where there exists little or no zoning conflict between tourism and aquaculture.

- Tourism development and environmental impact of aquaculture - Good quality water and a healthy environment are essential prerequisites for both tourism and aquaculture. There have been cases where unregulated aquaculture has led to a negative impact on the environment, leading to conflict between the industries. This would not be an issue at the Indian Ocean Territories, due in part to the legislative environment that regulates aquaculture, and in part to the likelihood that aquaculture activities are likely to remain relatively small in scale and be predominantly land based using recirculating technology.

- Tourism, aquaculture and navigation hazards - Large-scale aquaculture cage farms located offshore can impede use of marine areas and present navigation hazards, with consequential negative impacts for the relationship between tourism and aquaculture. They can also result in conflict where both industries require the use of limited land-based infrastructure such as jetties and boat ramps. Offshore farms are unlikely in the Indian Ocean Territories, so this is also unlikely to result in any negative impact.

The relationships and synergies between aquaculture and tourism at the Indian Ocean Territories are generally positive and few of the negative aspects that can arise are evident.

9.1 Conclusions: Cocos (Keeling) Islands

Two sites were identified as suitable for aquaculture development at the Cocos (Keeling) Islands: the Quarantine Station and the Old Farm. Corresponding species and production systems are provided below.

Quarantine Station is considered an outstanding site that offers the best opportunities for aquaculture development at the Cocos (Keeling) Islands and, more broadly, the Indian Ocean Territories, using marine and fresh water production systems. The area is sufficiently large to support the establishment of an aquaculture precinct that provides common services, such as sea water supply, treatment and discharge systems, and enables economies of scale not possible for individual operations.

Old Farm is less suitable for marine systems due to its greater distance from the coast, but would afford good aquaculture development opportunities for fresh water aquaponic systems.

Site	Species	Production system
Quarantine Station	▪ Ornamental marine reef fish (numerous species) ▪ Ornamental marine shellfish and invertebrates, such as clams and corals	▪ Marine: pumped-ashore flow-through, using tanks and raceways.
	▪ All fresh water finfish species identified as Category 1 for the Cocos (Keeling) Islands	▪ Fresh water: recirculating, integrated aquaponic systems using tanks, raceways and small ponds where suitable.
Old Farm	▪ All fresh water finfish species identified as Category 1 for the Cocos (Keeling) Islands	▪ Fresh water: recirculating, integrated aquaponic systems using tanks, raceways and small ponds where suitable.

9.2 Conclusions: Christmas Island

Christmas Island affords fewer opportunities than the Cocos (Keeling) Islands for aquaculture development. Due in part to the difficulty and higher cost of pumping sea water a significant vertical distance, land-based marine production systems have not been identified as an opportunity. The number of fresh water species considered suitable is also lower than for the Cocos (Keeling) Islands because there is a higher risk that finfish or shellfish that escape from aquaculture facilities could become established in, and be difficult or impossible to eradicate from, the natural environment.

A private operator, who has established a hydroponics facility on private land adjacent to the Market Garden site, is planning future expansion into aquaponics. This project could form the nucleus of a larger aquaponic industry at Christmas Island, producing fresh fish and produce for the local market.

Two sites were identified as suitable for aquaculture development at Christmas Island: the Market Garden and the Central Area Workshop. The corresponding species and production systems are listed below.

Market Garden is considered to represent the better opportunity for aquaculture development at Christmas Island, mainly due to its location adjacent to an existing commercial activity. The current operator could use the area, if required, to expand the existing business or it could accommodate new aquaponic businesses. A cooperative development effort between operators could increase profit margins by sharing or reducing resource costs. There are instances where aquaculture operators who form alliances reduce their production costs by leveraging volume discounts, and spreading out marketing costs and achieving other economies of scale.

Central Area Workshop has similar features to Market Garden and consequently offers similar development opportunities. It may be possible for development to proceed at both sites, however, given that aquaculture development at Christmas Island is likely to be incremental, it would be more prudent to support development initiatives at a single site, at least initially.

Site	Species	Production system
Market Garden	▪ Fresh water finfish species identified as Category 1 for Christmas Island (barramundi and Murray cod)	▪ Fresh water: recirculating, integrated aquaponic systems using tanks, raceways and small ponds where suitable.
Central Area Workshop	▪ Fresh water finfish species identified as Category 1 for Christmas Island (barramundi and Murray cod)	▪ Fresh water: recirculating, integrated aquaponic systems using tanks, raceways and small ponds where suitable.

9.3 Recommendations

Recommendation 1:

Recognise that the land and infrastructure at Quarantine Station on the Cocos (Keeling) Islands represent the best opportunity for aquaculture development at the Indian Ocean Territories and, subject to other economic development requirements, consider allocating suitable areas, buildings, plant and equipment to proponents who demonstrate the ability and capacity to establish viable aquaculture development businesses.

Recommendation 2:

Commission two baseline feasibility studies (which future proponents may use to develop detailed business plans) for:

a) aquaculture at the Cocos (Keeling) Islands, using land-based, pumped-ashore systems to produce marine ornamental species for sale in export markets;

b) fresh water, recirculating aquaponic projects at the Cocos (Keeling) Islands and Christmas Island, producing fresh water finfish species and fresh produce for sale in the local market.

Recommendation 3:

Undertake a project to evaluate the prospects to optimize commercial opportunities that may arise from aquaculture production at the Indian Ocean Territories, principally:

a) tourism opportunities; and

b) opportunities to add value to aquaculture products, including post-harvest processing.

Recommendation 4:

Commission a study to evaluate the feasibility of establishing a facility at Perth to enable the holding of live fish and their transfer to export markets, which may support the development of an ornamental fish aquaculture industry at the Indian Ocean Territories.

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