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# The translocation of barramundi. A discussion paper.

Makaira Pty Ltd

# THE TRANSLOCATION OF BARRAMUNDI

**A DISCUSSION PAPER**

**by**
**Makaira Pty Ltd**
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## DISCLAIMER

## OPPORTUNITY FOR PUBLIC COMMENT

This discussion paper has been prepared to provide information to assist in the assessment of the possible impact of the translocation of barramundi into and within Western Australia, for the purposes of recreational stock enhancement, aquaculture development and domestic stocking. In contemplating the translocation of any aquatic species, significant economic and social benefits must be balanced with biological and environmental risks; that is, the potential impact of the translocated species on the wider environment and native flora and fauna.

Comments about this barramundi translocation discussion paper are sought from all stakeholders, including industry members, relevant interest groups and interested members of the public. Following the receipt of comments from the aforementioned sources, consideration will be given to a policy position on the translocation of barramundi into and within Western Australia.

Your comments would be appreciated, should be marked to the attention of Mrs Jacqueline Chappell, Fish and Fish Habitat Program, and addressed to:

Executive Director
Fisheries Western Australia
3rd Floor, SGIO Atrium
168 St George's Terrace
PERTH WA 6000

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# EXECUTIVE SUMMARY

## Background

There is significant interest in the production of barramundi (*Lates calcarifer*) in Western Australia because, from biological, technical and economic perspectives, the species is an important candidate for recreational fishing stock enhancement, commercial aquaculture and domestic stocking.

Fisheries Western Australia has received numerous applications for barramundi aquaculture licences, which involve the translocation of barramundi into and within Western Australia. An assessment procedure for the translocation of live, non-endemic species for aquaculture and recreational stock enhancement has been developed; however, Fisheries WA wishes to prepare a discussion paper on the issues relevant specifically to the translocation of barramundi. These issues deal principally with the potential for translocated barramundi to:

- impact on the genetic diversity of the species;
- introduce disease; and
- impact on the natural environment and the biodiversity of native species.

This discussion paper will form the basis of consultation with stakeholders and is expected to form the basis of a management plan to guide the translocation decision making process.

An interim policy has been adopted by Fisheries WA and the Environmental Protection Authority to deal with the translocation of barramundi for growout in closed recirculating systems located outside the natural distribution of the species.

## The Biology of Barramundi

Barramundi are catadromous fish that spend most of their lives in fresh water, but return to brackish or sea water to spawn. Due to its diadromous habit, the species cannot sustain populations in fresh water. Larvae and young juveniles remain in coastal nursery areas for up to six months, when they swim upstream and repopulate the fresh-water reaches of rivers, where they undergo much of their growth. The maturing fish migrate downstream to spawn after three to four years. The species is euryhaline, so thrives and can be grown in fresh, brackish and marine water. Under culture, adult broodstock are kept in sea water, larvae and early juveniles are reared in brackish or sea water and juvenile and adult fish may be grown out or held in marine, brackish and fresh water.[1] The reproductive biology of the species influences its management and culture; as protandrous hermaphrodites, barramundi mature first as functional males and later undergo sex inversion to become functional females.

[1] Provided that they are gradually acclimatised over a period of about six hours, even small, juvenile barramundi can be transferred from salt to fresh water without losses (Rimmer, 1995).

## Stock Enhancement and Aquaculture

It has been recognised that there may be significant potential for recreational fishing stock enhancement and aquaculture of barramundi in Western Australia. Water bodies in the Kimberley and Pilbara regions likely to be suitable for stock enhancement include Lake Kununurra, Lake Argyle and the Lower Ord River in the East Kimberley; Willie Creek and Barred Creek in the West Kimberley; and the Harding River Dam in the Pilbara. The commercial aquaculture of the species in onshore and offshore production systems could make significant contributions to the economies of regional areas.

## Environmental Issues

The three main issues associated with the translocation of aquatic organisms are the potential of the translocated species to impact on the genetic diversity of native species; introduce disease; and impact on the natural environment and biodiversity.

An impact on genetic diversity may occur when an existing wild population differs genetically from the stock being introduced. There are indications that genetic heterogeneity exists between different barramundi populations. Some authorities have speculated that these differences will produce some important biological differences and contend that there is a need to preserve the natural genetic heterogeneity of the existing populations by regulating the movement of live barramundi. Other scientifically recognised authorities believe there is no direct evidence that mixing gene pools will have deleterious effects and have argued that, among barramundi stocks, genetic differences have been demonstrated only for populations, not for individual fish, and that it is the proportion of the genes present that differs between different river systems, not the actual genes. There is a concern among the former authorities that the translocation of hatchery-reared barramundi between natural stocks may result in reduced fitness.

Different year-classes of fish spawned from a single adult stock can be genetically distinct if they are exposed to different conditions during their early development. There is therefore strong potential for genetic selection during the period of larval development when the mortality rate is high and this fact may account for perceived genetic differences between stocks. Researchers have emphasised the importance of establishing genetic differences within and between areas before making deductions about stock structures.

Diseases from cultured barramundi are unlikely to threaten wild stocks: wild fish are not exposed to the stresses that can be experienced by cultured fish, so are unlikely to be affected by pathogens that may be released from aquaculture operations. The nodavirus that causes Viral Nervous Necrosis (VNN) is the only disease of significance in respect of barramundi translocation; no survey of wild stocks has yet been carried out to show whether the nodavirus exists in Western Australia. All other diseases described for the species are found in Western Australia. Most disease situations in aquaculture can be attributed to poor management practices and disease outbreaks usually only occur in barramundi aquaculture when the environmental conditions are unsuitable.

The translocation of barramundi does pose a risk, which must be managed in accordance with the precautionary principle. The precautionary principle is clearly defined as “where there are threats of serious or irreversible damage, lack of full scientific certainty should not be used as a reason for postponing measures to prevent environmental degradation" (Australia's Oceans Policy). The strict application of the precautionary principle would not permit most deliberate introductions. Therefore, in recognising that there are risks, a precautionary approach to species translocation should aim to reduce the risk of adverse impacts and establish corrective or mitigating procedures prior to any effect occurring.

## Conclusions

There is a recognisable economic benefit to the translocation of barramundi, but there is also a need to ensure the translocation will not adversely impact upon genetic diversity, introduce disease or impact on the natural environment and biodiversity.

Threats from translocation within the natural range of the species are generally considered low risk. The effects of barramundi introduced into waters in which they did not previously exist beyond their natural range are unknown.

Sound arguments have been made on both sides of the issue of the genetic heterogeneity indicated between wild barramundi stocks and the basis and importance of the perceived differences. It has been demonstrated, however, that genetic differences can arise between different year-classes, and even among a single year-class, of fish spawned from a single stock, due to selection pressures operating during critical stages of the life history of the fish. In relation to a possible decrease in fitness of wild stocks, it could also be reasonably argued that, if the fitness of wild stocks adapted to their habitats is high, introduced, less-fit stock would not be able to compete effectively, so few of their genes would enter the next generation. There are in fact no recorded instances where fish produced by aquaculture have weakened the genetic fitness of wild stocks.

Solutions proposed to overcome the issue of maintenance and protection of the genetic heterogeneity of wild populations include:

- for broodstock, using fish captured from wild stocks that inhabit the target stocking area;
- using triploid (sterile) fish; and
- preventing stock escapement.

Using wild-caught broodstock captured from stocks in the area targeted for stocking is considered best suited for growing fish for stock enhancement purposes. The use of triploid fish that cannot reproduce may have great value in the future, once the requisite technology has been developed; however, this may take some time. While good management can ensure stock escapement is low, it must be recognised that there is an associated risk. The total prevention of stock escapement is not considered a realistic proposal, but it can be minimised.

In view of the information provided in this discussion paper, there exist various options, different permutations of which may be applied to different situations, that may be considered in respect of barramundi translocation for the purpose of recreational stock enhancement, aquaculture and domestic stocking. They include:

- using large numbers of broodstock obtained from the target water body;
- obtaining seed stock ideally from broodstock captured in Western Australian waters;

- for stock enhancement purposes, prohibiting the use of selective breeding to genetically modify the stock;
- for aquaculture purposes, allowing selective breeding to improve the stock;
- taking appropriate steps to minimise escapes; and
- making efforts to redress the cause of any stock depletion that may have occurred.

## Genetics Conference

In September 1998, the Fisheries Research and Development Corporation (FRDC) and the Aquaculture Development Council supplied funding to assist the Fremantle Maritime Centre, Fisheries Western Australia, Agriculture Western Australia, Edith Cowan University and the Aquaculture Council of Western Australia to host a Conference on Genetics in the Aquaculture Industry to discuss the following issues in the aquaculture industry:

- broodstock selection and breeding programmes for the genetic improvement of important production traits; and
- genetic implications of the translocation of aquaculture stocks within and beyond their natural ranges.

Fourteen national and international speakers gave presentations at the Conference and, through their participation, it is expected that the information exchanged will be used to set strategic research priorities in the area of genetic research.

The translocation of barramundi within and into Western Australia was discussed as part of an interactive workshop. The results of these discussions will be presented in a special edition of The Journal of Aquaculture Research in 1999.

# 1 INTRODUCTION

## 1.1 Background and Objectives

Barramundi is an important species in Western Australia from three principal perspectives, *viz*.:

- for recreational fishing, for which there exist significant stock enhancement prospects;
- as a candidate for commercial aquaculture; and
- as a candidate for domestic stocking.

The biological features of barramundi make it a good candidate species for aquaculture and the requisite culture technology is well known.[2] From an economic perspective, the species is also suited for commercial production and has been grown profitably in Australia and abroad. Barramundi can be cultured using a variety of production systems in a wide range of environments throughout Western Australia. The fish may be cultured in open, flow-through and recirculating production systems, located either offshore or onshore, using marine, brackish or fresh water. Barramundi production systems can be located throughout Western Australia, from the Kimberley in the tropical north to the temperate south, where recirculating systems using heated water may be feasible.

Consequently, there is significant interest in the commercial aquaculture of barramundi and Fisheries Western Australia has received numerous applications for aquaculture licences endorsed for the species. A significant initiative by Fisheries WA involves the possibility of establishing a high-yield barramundi farming enterprise in Lake Argyle, a large body of fresh water located in the Kimberley region.

These applications and proposals may involve the intra- and interstate translocation of barramundi to be used as broodstock and seed stock and applications to gain approval to translocate stock will be submitted for assessment.

An assessment procedure to translocate non-endemic species into and within Western Australia has been established; however, due to the number and complexity of applications received for barramundi and the implications of the initiative proposed for Lake Argyle, Fisheries WA has prepared this discussion paper on the issues relevant specifically to the translocation of barramundi into and within Western Australia.

The principal objective of the paper is to identify and elaborate issues associated with the translocation of barramundi for recreational stock enhancement, aquaculture and domestic stocking purposes. The paper provides fundamental information about the biology and ecology of the species, its fishery and aquaculture and the potential for translocated barramundi to:

- impact on the genetic diversity of the species;
- introduce disease; and
- impact on the natural environment and the biodiversity of native species.

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[2] The principal biological features that make barramundi a good candidate for aquaculture include:

- reproductive attributes conducive to captive maturation and spawning and a high fecundity;
- a high captive growth rate; and
- good feed conversion efficiency (FCRs of 1.2:1 have been reported and 1.5:1 is achieved consistently).

This discussion paper will form the basis of consultation with stakeholders and is expected to form the basis of a management plan to guide the translocation decision-making process. It is not an objective of the discussion paper to make recommendations, or devise a policy in respect of barramundi translocation.

## 1.2 The Translocation of Aquatic Organisms

Translocation is the movement of fish, or distinct genetic stocks of fish, to areas outside their natural range. Including both native and introduced organisms, translocated species are those imported into a state or country as well as those moved within a state or country to regions in which they previously did not exist (Lawrence, 1993).[3]

Several fresh-water species currently found in Western Australia may be considered to have been translocated. These include yabby (*Cherax albidus* [Australian range extended]), marron (*Cherax tenuimanus* [Western Australian range extended]), trout (*Oncorhynchus mykiss* (introduced)), silver perch (*Bidyanus bidyanus* [Australian range extended]), golden perch (*Maquaria ambigua* [Australian range extended]), redfin perch (*Perca fluviatilis* [introduced]), Murray cod (*Macullochella peeli* [Australian range extended]) and tilapia (*Tilapia* spp. [introduced]).[4]

The translocation of non-endemic species into or within Western Australia requires the written approval or authority of the Executive Director of Fisheries WA, in accordance with Regulation 176 of the *Fish Resources Management Regulations 1995*.

The principal issues considered in relation to the translocation of non-endemic species include its potential to impact on genetic diversity, introduce disease and impact on the natural environment and the biodiversity of native species.

Issued pursuant to Section 246 of the *Fish Resources Management Act 1994*, Ministerial Policy Guideline No. 5, entitled '*The aquaculture and recreational fishing stock enhancement of non-endemic species in Western Australia*,' was developed to assist in the consideration of an application for the translocation of non-endemic species into and within Western Australia for aquaculture or stock enhancement purposes. The five policy guidelines may be summarised as follows.

i. Authorisation of the translocation of non-endemic species will be subject to a risk management assessment being carried out.

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[3] The terms *native* and *endemic* are not synonymous. The term *native* is correctly used to describe an indigenous species produced naturally and that belongs within a defined area, but which may also occur elsewhere. The term *endemic*, on the other hand, describes a species that only occurs naturally within a region and nowhere else. However, since the relevant regulations, Fisheries Management Papers and Ministerial Policy Guidelines refer to non-endemic species, for the sake of consistency, the latter term is used throughout this discussion paper.

[4] Morphologists have attempted to classify the numerous tilapia species according to their breeding behaviour and other features. The genera have included *Tilapia*, *Sarotherodon* and *Oreochromis* and there are several sub-genera. The various revisions of the classification of the tilapia species have not eliminated all the confusion that has arisen and many taxonomists prefer the continued use of the broad genus *Tilapia* for all species, particularly for aquaculture purposes (Pillay, 1993).

ii. The assessment will be undertaken by Fisheries WA within the context of an application and translocation synopsis provided by a proponent. Authorisation of the translocation would be conditional upon the assessment showing the translocation would present a low risk to the environment.

iii. The risk assessment must be based on the best scientific data available for the species and the environment into which it is to be introduced.

iv. The translocation application will be referred to relevant industry groups for consultation and public comment sought before any decisions are made.

v. The translocation decision should balance significant economic and social benefits with biological and environmental risks.

Species for which translocation policies have already been developed in Western Australia are redclaw crayfish (*Cherax quadricarinatus*), silver perch (*B. bidyanus*) and silver-lip pearl oyster (*Pinctada maxima*).

The procedure used to assess applications for the translocation of non-endemic species for aquaculture and stock enhancement purposes has been developed by way of a Memorandum of Understanding between Fisheries WA and the Environmental Protection Authority.

## 1.3 The Translocation of Barramundi for Culture in Recirculating Systems

Since the establishment of the Memorandum of Understanding between the Environmental Protection Authority and Fisheries WA, numerous applications were made to the latter for the translocation of juvenile barramundi for growout in closed recirculating systems, the majority of which were located within the Perth metropolitan area and outside the natural distribution of the species.[5] These and other applications received by Fisheries WA for translocating barramundi, acquired from hatcheries in Queensland and the Northern Territory, for growout in closed recirculating systems, were assessed and approved following the development of a process put into effect to deal with the issue. The development of this process was a short-term measure developed to deal with a specific type of translocation, which was considered a low risk, while Fisheries WA proceeded with its long-term approach to release a discussion paper and subsequently a management plan for the translocation of barramundi into and within Western Australia.

In respect of the translocation of barramundi for growout in closed recirculating systems, subject to the applicant satisfying specific criteria and according to several conditions, a letter of approval is issued by Fisheries WA, to allow the translocation. Some of the key criteria and conditions that need to be satisfied in this regard are paraphrased below.

- The applicant must hold or have applied for an aquaculture licence.

[5] In aquaculture, a closed system is defined as one that neither draws water from nor discharges it to the external environment (with the exception of the water used to initially fill the system). True closed systems are rare in modern aquaculture: recirculating systems invariably have some flow-through or make-up water and typically exchange a volume of up to 10 per cent of total tank volume daily. Notwithstanding this, in order to be consistent with the terminology adopted for the relevant approvals processes, this discussion paper refers to closed recirculation systems.

- The translocated stock must be certified as disease-free.

- The barramundi must be held in a closed, recirculating system; any water discharged from the system must be directed to a soak well with no provision for surface water flow.

- The barramundi must be kept outside the natural distribution of the species.

# 2 THE BIOLOGY OF BARRAMUNDI

## 2.1 Natural Biology and Ecology

### *2.1.1 Taxonomy, Description and Natural History*

Barramundi (*Lates calcarifer*, Bloch 1790) is a large centropomid perch, the suprageneric affinities of which are (ICLARM, 1997):

Class: Actinopterygii (ray-finned fishes);
Order: Perciformes (perch-like fishes);
Family: Centropomidae (snooks);
Subfamily: Latinae.

The species has an elongate body form with a large, slightly oblique mouth and an upper jaw extending behind the eye. The lower edge of the preoperculum is serrated with a strong spine at its angle; the operculum has a small spine and a serrated flap above the origin of the lateral line. The scales are ctenoid. In cross section, the fish is compressed and the dorsal head profile clearly concave. The single dorsal and ventral fins have spines and soft rays; the paired pectoral and pelvic fins have soft rays only; and the caudal fin has soft rays and is truncate and rounded.

The life cycle of barramundi is generally well known. Adult fish spawn in brackish or sea water at river mouths and estuaries; for their survival, eggs and early stage larvae require water with a salinity within the range 22-40 ‰. Because barramundi are catadromous, the species cannot support self-maintaining populations in fresh water (Rimmer and Reed, 1989). During their early development stages, larvae and juveniles take advantage of the habitat provided in coastal nursery areas, which include mangroves and low-lying coastal flats that become inundated at high tides. After three to six months, the young, juvenile fish will actively swim upriver, during the later part of the wet seasons, until the river flows cease, to repopulate the upstream, fresh-water reaches of rivers, where they undergo much of their growth. After three to four years, the then-maturing fish migrate downstream to estuaries and bays to spawn. After spawning, the adults remain in the lower and tidal reaches of the river. Thus, barramundi are diadromous and typically catadromous.[6] There are, however, indications that purely marine populations may become established in areas remote from fresh water (Pender and Griffin, 1996).

Barramundi are euryhaline, but stenothermal.[7] The former attribute allows the fish to thrive in fresh, brackish and marine water and has positive implications for stock enhancement, aquaculture and domestic stocking.

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[6] A diadromous species is one that requires both fresh and brackish or sea water to complete its life cycle. Diadromous species may be either catadromous or anadromous. Fish belonging to the former group, which includes barramundi, typically grow to maturity in fresh water and migrate to the brackish water of estuaries or to the sea to spawn. Anadromous fish include species such as Atlantic salmon (*Salmo salar*), which undergo much of their growth in the sea then return to fresh water, where they attain full sexual maturity and spawn.

[7] A euryhaline species is one that thrives within a wide salinity range; the opposite condition is stenohaline. The equivalent conditions for temperature are eurythermal and stenothermal.

### *2.1.2 Distribution*

Barramundi are widely distributed throughout the coastal and littoral waters of the Indo-West Pacific from Iran to Australia (Pillay, 1993) and their range includes China, Taiwan and Papua New Guinea. In Australia, the species occurs as far south as the Noosa River (latitude 26°30' S) on the east coast and the Ashburton River (latitude 22°30' S) on the west coast (Schipp, 1996).

The distribution of the species in Australian coastal waters is probably restricted on the east coast by temperature and the west coast by the lack of suitable habitats.

### *2.1.3 Age and Growth*

Barramundi can grow to a size of at least 150 cm total length and 50 kg weight. The species has been reported to grow to 1.5-3.0 kg within one year in ponds under optimum conditions (ICLARM, 1997), but this growth is considered exceptional and can probably only be achieved by starting with a reasonably large, wild-caught juvenile. More commonly, barramundi under culture will grow from an ex-hatchery juvenile, between 50 and 100 mm in length, to a table size of 400-600 g within 12 months and to 3.0 kg within 18 months to two years.

### *2.1.4 Development and Early Life History*

The life history of barramundi, and that of many other teleost species, encompasses five main periods of development, viz: embryonic, larval, juvenile, adult and senescent. In the context of this study, the terminology used to describe the various development periods of barramundi is consistent with that often used in finfish aquaculture. Thus, for barramundi:

- eggs refer to the embryonic period before hatching (from fertilisation to about 15 hours);
- early larvae or pre-larvae refer to pre-feeding larvae (up to about 2 days);
- larvae refer to the period between the onset of exogenous feeding and the completion of fin ray development (about 10 mm length and 20-25 days age);
- early juveniles or post-larvae refer to fish up to a size of about 25 mm (about 35 days); and
- juveniles refer to fully-weaned fish larger than about 25 mm.

Once fertilised, the buoyant, developing eggs disperse in the current and hatch after approximately 12-15 hours. The pre-feeding larvae or eleutheroembryos (pre-larvae) feed endogenously on the yolk reserves contained in their yolk sacs for the first 36-40 hours, before the onset of exogenous feeding, which is the beginning of the true larval stage of the life history of the species.

During the larval and early juvenile stages of their life history barramundi are planktivorous and piscivorous. As they grow, they consume progressively-larger prey organisms and develop a cannibalistic habit.

### *2.1.5 Maturation and Spawning*

Barramundi attain sexual maturity at an age of 2-3 years. Most are protandrous hermaphrodites (although those from Songkhla, Thailand are apparently gonochoristic (Dhert *et al*., 1992));

generally, fish smaller than 800 mm length are male and those greater than 1 m females.[8] Fish held in captivity sometimes demonstrate features atypical of fish in the wild: they change sex at a smaller size, exhibit a higher proportion of protogyny and some males do not undergo sexual inversion (Schipp, 1996).

The spawning season in Australia occurs between September and March, with two spawning peaks in November-December and February-March.

During the spawning season in the wild, mature males and females usually congregate within an estuary. Spawning occurs at night at slack water and appears linked to the lunar cycle: the greatest activity occurs on nights following the full and new moons. Fertilisation is external; during spawning, each female may release several million eggs, which are immediately fertilised by sperm released by males, which closely attend the spawning females.

### *2.1.6 Behaviour and Feeding*

Barramundi are demersal fish that inhabit coastal waters, estuaries, lagoons and rivers; they are found in clear to turbid water, usually within a temperature range of 26-30°C. The fish do not apparently undertake extensive migrations within or between river systems, a factor that has presumably influenced the establishment of genetically-distinct stocks in northern Australia.[9]

Wild barramundi are predatory carnivores. The diet of wild fish varies with age and growth; larvae and early juveniles prey on zooplankton and, as the fish continue to grow, their diet comprises macrofauna, predominantly other fishes and crustaceans.

## 2.2 Diseases, Parasites and Predators

Sections 2.2.1 to 2.2.5 briefly outline the diseases and parasites commonly found in, and the main predators of, barramundi stocks in the wild and under culture.

### *2.2.1 Protozoan Diseases*

*Marine Ich*

> Caused by the protozoan *Cryptocaryon irritans*, marine ich commonly occurs among captive fish, mainly broodstock, kept in sea water for a protracted period. It occurs when fish are stressed. The onset of the disease becomes evident when the fish exhibit “flashing” behaviour, by rubbing their sides vigorously against the tank base and sides. As the disease progresses, the fish lose their appetites, become progressively more lethargic, develop opaque eyes and white spots or ulcers on their scales. If left untreated, the fish generally die within several days. Microscopic examination shows large numbers of the protozoan on the gills and skin.

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[8] Many fish species are hermaphrodites; that is, they have gonads with a capacity to produce both ova and sperm, though usually not simultaneously. A protandrous hermaphrodite is a species that matures first as a male before undergoing sexual inversion to become a functional female (the opposite condition is called protogyny).

[9] At present, there are six genetically-distinct barramundi populations in Queensland, 10 in the Northern Territory and one in Western Australia (Keenan, 1994) (refer to section 3.2).

### 2.2.2 Bacterial, Viral and Fungal Diseases

Diseases caused by bacteria are the most common among cultured barramundi (Anderson and Norton, 1991). Outbreaks are usually associated with elevated temperatures during summer, low temperatures during winter and sudden changes in temperature or salinity, which can occur during periods of heavy rainfall.

*Vibriosis*

Vibriosis, a disease of the internal organs, is caused by bacteria commonly found in the water and on the surface and in the intestines of fish. Of the bacterial diseases that can affect cultured fish, vibriosis is considered the most common and can cause severe economic losses. The bacterial septicaemic infection, caused by *Vibrio anguillarum*, *Vibrio alginolyticus* and other *Vibrio* species, affects a diverse range of marine and estuarine fishes. *V. alginolyticus* and *Pseudomonas anguilliseptica* were identified as responsible for causing heavy mortalities in barramundi cultured in cages in a Malaysian estuary (Subasinghe and Shariff, 1992). *Vibrio vulnifcus*, *Vibrio damsela*, *Vibrio harveyi* and *V. alginolyticus* have been identified from the internal organs of barramundi affected by vibriosis (Anderson and Norton, 1991). Invariably preceded by some form of stress, vibriosis is characterised by extensive haemorrhaging and local ulceration. Wong and Leong (1989) noted that the species of vibrios isolated from the kidneys and spleens of apparently healthy fish were different from those obtained from diseased fish.

*Columnaris Disease*

The name columnaris disease covers conditions that involve skin and gill diseases caused by the long, filamentous bacteria of the Cytophaga-Flexibacter group. The disease occurs in younger juveniles when they are transported or held at high densities; older juveniles can be infected at low water temperatures (Anderson and Rodgers, 1994). Soltani *et al*. (1996) have shown that barramundi are highly susceptible to *Flexibacter columnaris*, which can affect fish cultured in fresh water within the preferred temperature range of the bacterial species (20-35°C). The clinical signs of the disease include white spots on the head, around the mouth and on the fins and tail, as well as fin and tail-rot.

*Miscellaneous Bacterial Diseases*

A mixture of bacteria are thought to cause fin and tail rot in young juvenile barramundi in fresh-water and marine environments. These diseases are invariably associated with poor water quality, nutrition and husbandry.

A bacterial skin pathogen, *Cytophaga johnsonae*, a gliding, Gram-negative rod, was found by Carson *et al*. (1993) on juvenile farmed barramundi. Clinical signs of disease on infected fish included extensive, superficial skin erosion, affecting mainly the posterior flanks but also the pectoral fins and lower jaw.

Bacterial infections of the internal organs of barramundi grown in fresh water is called *bacterial haemorrhagic septicaemia*. Possibly caused by species such as *Aeromonas hydrophila* and *Pseudomonas fluorescens*, the clinical signs displayed by infected fish are the same as for vibriosis.

*Viral Nervous Necrosis*

A picorna-like virus was believed responsible for high mortality rates experienced among hatchery-reared barramundi larvae in the late 1980s (Glazebrook *et al*., 1990). The syndrome is now known as *viral encephalopathy and retinopathy*, or *viral nervous necrosis* (VNN) (OIE, 1997). The disease affects European sea bass (*Dicentrarchus labrax*) as well as several other marine finfish species. The causative agent of VNN in barramundi and European sea bass is fish encephalitis virus (FEV) and in another marine finfish species, striped jack, is nervous necrosis virus (SJNNV); both are nodaviruses of the family Nodoviridae (OIE, 1997).

In barramundi, the clinical signs of the disease, first evident in 7-9 day larvae, include anorexia, wasting, lethargy, pale colouration and swimming with an uncoordinated, darting or corkscrew action. Mortalities were recorded within 24 hours of the onset of the disease. Studies showed the nodavirus in degenerative areas of the brains and retinas of 15 day and 18 day larvae. Later studies by Munday *et al*. (1992) showed consistent correlation between the mass mortality of hatchery-reared larval and juvenile barramundi and vacuolation or lesions in their brains and retinas, with each of which were associated large amounts of viral particles.

In affected hatcheries, vertical transmission of the disease is considered uncommon; most infection is probably transferred from older juveniles to newly-hatched larvae. Isolation, cleaning and disinfecting culture units between successive cohorts of larvae have controlled mass mortalities (Munday *et al*., 1992). An ultra-violet steriliser has been shown to inactivate model viruses similar to the nodavirus in water suspension, at flow rates comparable to those used in barramundi hatcheries and nurseries (Miocevic *et al*., 1993).

*Lymphocystis*

Lymphocystis is a common, non-lethal viral infection found in a variety of fishes, especially aquarium fish, and characterised by the development of raised, nodule-like lesions in the skin, particularly on the fins, and gills. The disease occurs in both fresh and sea water and more commonly affects younger fish. Its outbreak among barramundi has been associated with elevated temperatures, poor water quality and high stocking densities (Anderson and Norton, 1991).

*Redspot*

Redspot, also known as epizootic ulcerative syndrome or EUS, periodically infects several fish species, including barramundi. The disease may ensue from environmental conditions and is believed to be caused by a pathogenic fungus (*Aphanomyces invaderans*), though several infecting organisms, including bacteria and viruses, may also be present. EUS occurs throughout Western Australia, where it was probably introduced by imported ornamental fish.

*Fungal Diseases*

Fungal infections of the skin occur on barramundi grown in fresh and sea water. More common during cold weather, infections appear as cloudy, white foci that gradually extend and can cover the entire body of the fish. Secondary bacterial infections can develop as a consequence of fungal infections.

### *2.2.4 Nutritional Diseases*

Diseases can be caused as a result of nutritional imbalances in the diets of larval and juvenile barramundi. Fish stressed or weakened from nutritionally-inadequate diets are susceptible to, and less capable of resisting, various secondary bacterial and parasitic infections. Raw fish used as feed for barramundi can cause malnutrition as a result of essential fatty acid deficiencies and excesses of other nutrients such as tyrosine (Pechmanee, 1993).

### *2.2.4 Parasites*

Parasitic infections of cultured barramundi are uncommon in Australia (Anderson and Norton, 1991). In fresh water, the ciliated protozoans *Chilodonella* spp. and *Trichodina* spp. have been found on the gills of larvae and juveniles, but have no apparent effect; the latter have also been found on the gills of fish in sea water. The gills of barramundi growing in sea water are occasionally damaged by the gill fluke *Diplectanum* spp. The myxosporideans *Henneguya* spp. and *Kudoa* spp. are regularly found, respectively, in the gills and brain tissue of barramundi grown in sea water; their effects are unknown, but heavy infections may contribute to poor health when associated with other diseases (Anderson and Norton, 1991).

The parasite fauna of barramundi in cages off Thailand and Indonesia are more extensive and have been described, respectively, by Leong and Wong (1989) and Diani (1995).

### *2.2.5 Predators*

Under culture conditions, the major predator of larval and early juvenile barramundi are other individuals of the same species. In the wild, predators of barramundi include larger finfish, avian predators and large reptiles, such as the salt-water crocodile.

## 2.3 Barramundi Stock Variations

Genetic variations between different barramundi stocks have presumably arisen as a result of reproductive isolation due to geography or behaviour.

Electrophoretic techniques used to investigate genetic variations between barramundi stocks previously indicated a total of 14 genetically-discrete stocks (Salini and Shaklee, 1988; Shaklee *et al*., 1990; cited in Keenan and Salini, 1989). Fourteen was considered by Keenan and Salini (1989) to represent a minimum number of identifiable stocks due to the unavailability and small size of samples. The geographic locations of these 14 stocks were identified by Keenan and Salini (1989).

More recent work by Keenan (1994) identified 16 genetically-discrete stocks, in Western Australia, the Northern Territory and Queensland. The locations of these 16 stocks are identified in Table 1.

It is unknown how many genetically-distinct barramundi populations may occur in Western Australia and, at this stage, all of the barramundi populations within Western Australia may be considered to constitute a single stock.

Table 1 Population numbers and locations of Australian barramundi stocks (modified from Keenan, 1994).

| **Population number** | **Location** |
|---|---|
| 1 | Ord and Moyle rivers, WA/NT |
| 2 | Daly and Finniss rivers, NT |
| 3 | Darwin Harbour, Shoal Bay, NT |
| 4 | Mary River, NT |
| 5 | Port Hurd, NT |
| 6 | Goyder River, NT |
| 7 | Buckingham Bay, NT |
| 8 | Blue Mud Bay, NT |
| 9 | Roper River, NT |
| 10 | McArthur River, NT |
| 11 | Leichardt, Norman, Staaten and Nassau Rivers, QLD |
| 12 | Weipa, NW Cape York and Escape River, QLD |
| 13 | Orford and Shelbourne bays, Normanby River, Bathurst Heads, Friendly Point, Temple Bay, Lockhart River and Weymouth Cape, QLD |
| 14 | Bedford Bay, Cairns, Tully and Murray rivers, Hinchinbrook, Burdekin River, Townsville, QLD |
| 15 | Repulse Bay, Cape Palmerston, Broad Sound, Shoalwater Bay, QLD |
| 16 | Fitzroy River, Gladstone, Burnett, Burrum and Mary rivers, QLD |

# 3 RECREATIONAL STOCK ENHANCEMENT

## 3.1 The Barramundi Fisheries

Barramundi are widely considered the premier sport fish in the inland waters of northern Australia. The species supports an important commercial wild-capture fishery and is a major component of the recreational fishery in Queensland, the Northern Territory and Western Australia. Wild stocks of barramundi are under pressure from commercial and recreational fishing, as well as habitat alteration and destruction in parts of northern Australia (Keenan and Salini, 1989). The species is also characterised by highly variable natural recruitment, particularly near the extremes of its natural distribution (Western Australian waters, cumulatively, are considered to constitute the western extreme of the natural range of the species).

### *3.1.1 The Wild-Capture Fishery*

The quantity of barramundi caught by the wild-capture fishery in Western Australia is small compared to the commercial fisheries of the Northern Territory and Queensland. Most of the commercial Western Australian catch centres around the Ord and Fitzroy river systems. Stock abundance for barramundi is generally associated with the extent of large river systems, associated billabongs and coastal swamps and creeks for juvenile production. Continuance of river flows during winter is also associated with the abundance of juveniles in fresh water. These factors are not characteristic of the river systems of Western Australia, with the exception of the Lower Ord River, which is fed by the continual discharge from Lake Argyle.

### *3.1.2 The Recreational Fishery*

The recreational fishery in Western Australia is managed by the Recreational Fisheries Program of Fisheries WA. The Program recognises that the opportunity exists to satisfy the demand by recreational fishers to be involved in fishery enhancement through more sophisticated management of wild stocks and restocking and enhancement programmes using hatchery-reared juvenile stock.

As well as serving a commercial role as a food fish, barramundi play a significant role as a source of recreational activity. Compared to those in Queensland and the Northern Territory, the recreational fishery in Western Australia for barramundi is restricted, among other things, by a lack of access. In the Ord River system, the two main access points are below the dam wall of Lake Kununurra and at Ivanhoe Crossing. Other areas of the river can be difficult to locate and their use invariably requires a four-wheel-drive vehicle.

Barramundi are catadromous, so will not reproduce in fresh water and any barrier such as a dam wall will prevent the natural repopulation of a river. In the Ord River, for example, the dam walls that create lakes Kununurra and Argyle have restricted the upstream migration of barramundi (Doupe and Lenanton, 1998). The fish are not found in water storage impoundments across northern Australia, unless they have been deliberately stocked or have escaped from aquaculture operations. There is therefore considerable potential for the establishment of a barramundi recreational fishery in Western Australia, in permanent water bodies (section 3.2.3).[10]

The Ord River provides the basis of a high-quality recreational fishery, a draft strategy for the management of which has recently been produced (Fisheries WA and East Kimberley Recreational Fishing Advisory Committee, 1998). Barramundi is the target species for the resident population and tourists and rapid expansion and development in the region are increasing the demand upon the resource. The management strategy focuses not only on the Lower Ord, but also on Lake Kununurra, Lake Argyle, the section of the Ord River connecting the lakes and the Dunham River. Aquaculture stock enhancement programmes are cited within the document as an example of the means by which recreational fishing opportunities may be improved within these water bodies.

## 3.2 Stock Enhancement

### *3.2.1 Background*

Stock enhancement has been defined as the improvement of the productivity of fisheries by technological refinement, the cultivation of aquatic resources and, in the process, the reform of the fisheries structure (Oshima, 1984; cited in Liao, 1997). It can be viewed from two different perspectives, *viz*.:

i. direct stock enhancement, in which mass quantities of hatchery-reared juveniles are released so as to augment the natural wild stocks; and
ii. indirect stock enhancement, in which hatchery-reared stock are grown out in captivity, thereby eliminating the need for wild-caught juveniles and reducing the fishing pressure on wild stocks.[11]

Barramundi are highly regarded by recreational fishers and, due to the importance of the recreational fishing industry in Western Australia, there is increasing pressure for hatchery-reared fish to be used to enhance depleted or non-existent wild barramundi stocks in fresh-water impoundments, estuaries and coastal areas. Similar circumstances led to the Queensland Department of Primary Industries undertaking research into the production of barramundi for stocking fresh water reservoirs and aquaculture and, subsequently, to barramundi recreational fishing being targeted in the Queensland Government's strategic plan for 1989 (Rutledge, 1990).

It may be argued that, since barramundi will not spawn and their larvae not survive in fresh water, the implications of stocking estuaries and coastal waters are different from those of impoundment stockings, because the fish stocked in the former areas will become part of the breeding population and those in the latter area will not. However, this argument only applies

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[10] Currently, within Western Australia generally, a bag limit of five fish applies to barramundi, with a minimum size limit of 55 cm. Within the Lower Ord River, a bag limit of one fish applies, together with minimum and maximum size limits of 55 cm and 80 cm respectively.

[11] By definition, the growout of hatchery-reared stock is a form of stock enhancement, provided that the ensuing production reduces the quantity of fish caught in the wild-capture and recreational fisheries.

if it can be assured that the fish stocked in an impoundment cannot escape into downstream waters and enter the coastal systems.

Since adults will not spawn in fresh water, and because juveniles cannot travel upstream past the dam walls, barramundi cannot sustain a population in fresh water impoundments such as lakes Kununurra and Argyle. Any recreational fishery in these and other lakes would therefore be based on the development of a stock enhancement programme. Wild barramundi stocks that have become depleted, as a result of pressures caused by events such as habitat modification and commercial and recreational fishing, may be similarly enhanced.

Rimmer and Russell (1988) consider it widely accepted that stock enhancement can play an important role in the recovery of fish stocks that have become depleted as a result of habitat destruction or overfishing. However, while this view may be true for some situations, the role and effectiveness of stock enhancement in fisheries management is governed by the species and the situation; for example, stock enhancement may be highly effective for a freshwater species in a confined area or water body, but may be ineffective for a marine finfish that inhabits coral reefs. In appropriate situations, stock enhancement is now generally seen as an additional tool that can be used as a component of fisheries management methods that otherwise may be quite restrictive. A barramundi stock enhancement programme in fresh water impoundments has been implemented in Queensland and research is under way to determine the effects of stocking hatchery-reared fish in rivers. The Northern Territory Government already stocks barramundi in fresh water impoundments but not yet in coastal rivers (Griffin, pers. comm.; cited in Rimmer and Russell, 1988).

Stock enhancement can also be used to create new opportunities for recreational fishing. Barramundi stocking has been used to create successful fresh water impoundment fisheries in Queensland and there is a belief that similar methods could be used to enhance wild stocks (Cadwallader, 1998, unpublished manuscript). Rimmer and Russell (1998) undertook a study to determine the efficacy and cost benefits of stock enhancement of barramundi. They found that, of 69,000 juvenile fish released into the Johnstone River in North Queensland since 1993, although some fish did move within the river system, most (62%) were recaptured within 3 km of the release site.

### *3.2.2. Potential Economic Impact*

The Northern Fisheries Centre in Queensland produces between 150,000 and 250,000 juveniles each year for stocking rivers and dams (Rimmer, pers. comm.). The programme is supported by numerous, community-based stocking groups located along the Queensland coast, which request fish for stock enhancement purposes from the Department of Primary Industries (DPI) or purchase them from private hatcheries.

Rutledge *et al*. (1990) estimate that, in 1990, the barramundi recreational fishery contributed approximately $8-15 million per year to the Queensland economy; a cost-benefit analysis of the stocking of barramundi in Lake Tinaroo indicated that each $1 spent on the programme would generate a potential $31 benefit to the economy of Queensland. It should be noted, however, that the valuation of recreational fisheries is problematic unless there is some accurate means of measuring direct expenditure.

Recreational fishing in Western Australia attracts over 600,000 people over the age of sixteen, who spend approximately $400 million each year directly on the pastime (it has been estimated that over $100 million has been spent on the purchase of boats alone). Direct expenditures can be converted to estimate overall economic impact by using a multiplier that accounts for induced and indirect costs (Rutledge, 1990); that is, money spent directly on recreational fishing has multiple impacts throughout the economy.[12] If a multiplier of 2.0 is applied to Western Australia, the State's recreational fishery may be considered to have an annual overall economic impact of over $800 million.

West *et al*. (1996) estimated for the Ord River a net annual economic benefit of approximately $328,000 for resident, non-indigenous fishers; gross economic benefits of about $100,000 for the charter fishery; and gross economic benefits around $27,000 for the commercial fishery. The authors cautioned that these results do not represent a full economic assessment, which was beyond the scope of the study.

Western Australia's current barramundi recreational fishery may be considered small, particularly when compared to those of Queensland and the Northern Territory. However, there is considered to be significant potential for a recreational fishery based on stock enhancement in the Kimberley, particularly in lakes Kununurra and Argyle (Nel, 1996).

### *3.2.3 Water Bodies with Potential for Recreational Stock Enhancement*

Rimmer and Russell (1998) provide information about the suitability of preferred stocking sites and times. Fresh water, estuarine and upper tidal habitats all appear suitable for releasing hatchery-reared stock, but factors such as water quality can make some release sites unsuitable, albeit sometimes only temporarily. For example, low dissolved oxygen levels, which can follow heavy rainfall and the ensuing influx or suspension of biological material that consumes oxygen, can cause heavy mortalities. The size of the fish when they are released can also significantly influence survival.

The environmental requirements that would need to be satisfied for barramundi stock enhancement to work are outlined in Appendix One. In Western Australia, inland, estuarine and coastal waters east of the mouth of the Ashburton River, which is located near the eastern side of Exmouth Gulf, are within the natural range of the species and may be considered environmentally suitable for barramundi stock enhancement.

Taking into account accessibility, which is a major factor if the potential of the recreational fishery is to be fully realised, the principal water bodies likely to be considered for the establishment of a barramundi recreational stock enhancement programme in Western Australia include:

- in the east Kimberley: Lake Kununurra, Lake Argyle and the lower Ord River;
- in the west Kimberley: Willie Creek and Barred Creek, north of Broome; and
- in the Pilbara, in dams and reservoirs such as the Harding River Dam near Karratha.

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[12] Rutledge (1990) used a multiplier of 3.18, based on one developed specifically for sport fishing in Texas, to estimate the overall economic impact of the Australian recreational fishing industry at $10.2 billion in 1989. It is believed, however, that this multiplier is too high to be applied to Western Australia, where, based on research undertaken by the University of Western Australia, a multiplier of about 2.0 is considered more appropriate (Cribb, pers. comm.).

# 4 BARRAMUNDI AQUACULTURE AND DOMESTIC STOCKING

## 4.1 Synopsis of the Aquaculture Industry

Traditionally, barramundi have been reared in Asia, where they are commonly known as Asian seabass, in extensive culture systems, using wild-caught juveniles. The first artificial spawning of the species in Asia was achieved in 1973 in Thailand (Barnabe, 1995), where annual hatchery production now exceeds 100 million larvae. Most of the cultured fish are now grown from hatchery-reared juveniles. One of the high-value finfish species currently produced in South-East Asia, most barramundi produced by aquaculture in the region comes from seven main producers, the largest four of which are Taiwan, Thailand, Malaysia and Indonesia. The annual production of cultured barramundi is now roughly 20,000 tonnes.

In Australia, the barramundi aquaculture industry started with a research programme in Cairns in 1983 and a commercial hatchery was established in north Queensland in 1986. Production was low during the late 1980s and early 1990s, but has increased rapidly since 1992. During its early development stages, the industries in Australia and Asia were constrained mainly by a lack of juveniles and the cost and suitability of artificial feeds (Dhert *et al*., 1992; Pillay, 1993). The adoption of extensive, low-cost larval rearing methods overcame problems associated with seed stock supply and, as the industry has expanded, more efficient, lower-cost diet formulations have been developed and economic, manufactured diets have become available (Cann, 1996).

The industry in Australia is presently characterised by many, relatively small producers, mainly in Queensland, where, in 1996/97, twenty-nine farms produced a total of approximately 350 t (Lobegeiger, 1998). Industry growth has been constrained by a perceived lack of market opportunities for the small, plate-size fish, with an average total weight of 400-600 g, that have traditionally been produced. Several producers are now exploring the benefits of growing the plate-size fish to a size of 3 kg, for the fillet market. A significant sector of the barramundi aquaculture industry in Queensland involves stock enhancement of rivers and dams for the recreational fishery.

There are fewer than five licensed, commercial barramundi aquaculturists in Western Australia, where the industry sector may be considered in its infancy. While the production of cultured barramundi has doubled in 1997/98 compared to the previous year, it is still lower than 10 t.[13] Fisheries WA is currently undertaking an initiative to develop a high-yield barramundi aquaculture industry, characterised by significant economies of scale, in Lake Argyle.

## 4.2 Culture Technology

Sections 4.2.1 to 4.2.3 provide a brief account of the culture technology for barramundi, in respect of broodstock, spawning, larviculture, weaning and growout. More detailed accounts of barramundi aquaculture are provided by Rimmer (1995) and Schipp (1996).

[13] Precise data for cultured barramundi production by commercial growers in Western Australia are confidential .

### *4.2.1 Broodstock and Spawning*

Wild barramundi caught during their natural reproductive season can be used for captive spawning; alternatively, there are reliable techniques for the maintenance of broodstock held in captivity and their repetitive maturation over several successive spawning seasons. Maturation of barramundi has been achieved in Asia and Australia in onshore tanks and ponds and offshore sea cages. The main water quality parameters for captive maturation are a temperature range of 28-30°C, a salinity range of 30-32 ‰ and a pH of approximately 8.3.

In Australia, spawning generally involves the induction of mature female fish by the application of hormones. Following implantation, the female fish are placed, together with ripe males, into a tank, in which the fish then spawn (Schipp, 1996). In Singapore and other Asian countries, barramundi held in sea cages now spawn spontaneously, according to the lunar cycle, throughout the year (Chuam, pers. comm.).

To be successful, broodstock maturation and spawning call for dedicated facilities, skilled staff and significant investment in the requisite facilities.

### *4.2.2 Larval Rearing*

Larval rearing can be carried out using intensive or semi-intensive techniques and brackish or marine water. Intensive larviculture involves the use of live food organisms, which are fed to the larvae in tanks in a hatchery. Semi-intensive larviculture is usually carried out in ponds, which are fertilised to produce a bloom of zooplankton on which the larvae feed.

In Australia, barramundi larvae are cultured in semi-intensive ponds using the green water method, according to the technique developed and used in Texas, USA, for the culture of red drum (*Sciaenops ocellatus*) and described by Rimmer (1995), Vega *et al*. (1995) and Schipp (1996). Intensive larval rearing procedures are now rarely used in Australia; however, it is interesting to note that, in the USA, some producers who previously used ponds for red drum larviculture have now reverted to the more intensive, clear-water hatchery rearing techniques. Although the latter method is more expensive, it is more consistent and reliable and the additional costs are considered warranted (Sorgeloos, pers. comm.).

### *4.2.3 Weaning and Growout*

The young juvenile fish are usually weaned onto an inert diet before being stocked for growout. Weaning can begin when the fish are about 10 mm in length and, in most cases, these early juveniles are transferred to nursery tanks, cages or ponds at a length of about 20-25 mm and an approximate age of 35 days (Dhert *et al*., 1992). Brackish or marine water is generally still used through this stage; however, juvenile barramundi can be gradually accustomed to fresh water once they reach a size of about 10 mm. In Australia, manufactured pellets have been developed and are usually used for weaning. This stage of the culture process involves periodic grading, to minimise cannibalism, so is usually carried out in onshore tanks after the fish have been harvested from the larval rearing ponds.

Barramundi are now grown out on commercially-available pellets, supplied by Australian manufacturers. The use of pelletised growout diets has allowed high stocking densities, and consequently high yields, to be achieved. Floating, extruded pellets are now more typically used because they result in better food conversion efficiencies and less waste. Food conversion ratios (FCRs) vary widely between 2.0:1 and 1.3:1 according to the season, with better results being achieved during the warmer months. An FCR of 1.2:1 has been reported for intensive recirculating systems.

Barramundi are usually grown out in intensive and semi-intensive production systems, which are described in more detail in section 4.3 below.

## 4.3 Aquaculture Production Systems

An aquaculture production system can be both defined and described by six principal elements, *viz*.: location and water type; culture units; water flow; intensity; scale; and integration. Location refers mainly to whether the system is established onshore or offshore.[14] The onshore and offshore aquaculture production systems currently used for barramundi growout are considered in the following sections.

### *4.3.1 Onshore, Flow-Through Systems*

Onshore, flow-through production systems for barramundi growout use marine, brackish and fresh water. The culture units include tanks, ponds and cages.[15] Onshore systems used for growout are usually intensive to semi-intensive and, at present in Australia, small to medium scale. There is usually only limited vertical integration, with the majority of producers acquiring their seed stock from commercial hatcheries and limiting their operations to weaning and growout.[16]

Earthen or lined ponds are used in tropical areas, usually within the natural distribution of the species. The barramundi being grown out are either held in cages floating in the pond or allowed to roam freely within it. The latter procedure, commonly called *free-ranging*, reputedly gives better fish growth and appearance but makes some operations, such as harvesting, more difficult. Barramundi held in cages can be stocked at the relatively high stocking density of 40-60 kg/m$^3$; however, the optimum density is considered to be about 25 kg/m$^3$, below which negative density-dependent effects such as diminished growth are avoided. Water flows in pond systems vary according to factors such as overall stock density and are generally within the range of 5-10 per cent of pond volume per day (Rimmer, 1995).

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[14] The terms *onshore* and *offshore* are used to describe the locations of aquaculture production systems in preference to, respectively, *land-based* and *water-based*, because, by definition, all aquaculture, whether located onshore or offshore, is water-based.

[15] It may appear contradictory to classify cages within the category of onshore production systems. However, barramundi are frequently grown in cages placed in both onshore ponds and offshore, coastal locations. Within the context of this discussion paper, the distinction between cages used as culture units in onshore and offshore systems considers the scale of the water body and the design and operation of the cages. Barramundi cages located in ponds are therefore considered a component of an onshore system and those located in, for example, Lake Argyle or an offshore coastal area, part of an offshore production system.

[16] The expression *vertical integration* is used in aquaculture to describe the situation that exists when different elements of the culture process are linked to enhance overall profitability, increase efficiency or achieve some other beneficial outcome. Vertically-integrated aquaculture operations comprise several or all of the elements required for the production and sale of the species under culture. These elements can include hatchery, nursery and growout operations as well as feed production and various post-harvest activities such as processing, packaging and marketing.

Barramundi growout also takes place at onshore locations, beyond the natural distribution of the species, using intensive systems with both flow-through and recirculating water flows (the latter system is discussed below in section 4.3.2).

Flow-through systems can be used where adequate quantities of geothermal water are available. One such system, located in Victoria, grows barramundi in fresh, geothermal water, reportedly at densities up to 100 $kg/m^3$. Barramundi aquaculture has also been contemplated in inland areas of the Gascoyne region of Western Australia, using hot artesian water.

### *4.3.2 Onshore, Recirculating Systems*

Recirculating systems are used in insulated buildings, in which the water, usually fresh, is artificially heated to the requisite temperature. Several of these systems are presently used in Australia to grow barramundi outside their natural distribution, or where water supplies are limited. The used water discharged from or contained within the culture units, according to their design, is treated using a combination of physical and biological filtration before being pumped back into the tanks. Recirculating systems are typically intensive and support high stocking densities. They all have some degree of water exchange.

A significant advantage of recirculating systems is their relative independence of the local environment and limited water requirements. However, these systems are relatively expensive to establish and the technology needed for their operation at a commercial scale is still developing. Financial analyses of recirculating systems indicate that the key operating parameters are the energy input and the efficiency of the water treatment processes.

Aquaculture using recirculating water-flow systems will undoubtedly be responsible for an increasing proportion of overall production by aquaculture; however, it should be noted that, at this stage, few recirculating systems can be characterised by an established record of profitable aquaculture production on a commercial scale.

### *4.3.3 Offshore, Open Systems*

Offshore production systems almost invariably use floating cages located in a river, lake, estuary or the sea. The cages may be rectangular or circular at the surface, with the individual design and deployment varying according to the features of the site at which they are located. Features of concern include water depth, currents and the degree of shelter the site affords from waves, swells and storms.

## 4.4 Domestic Stocking

For the purpose of this discussion paper, *domestic stocking* is defined as stocking of aquatic species in water bodies for non-commercial purposes. In relation to the main issues of concern about translocation, *viz*.: genetic diversity, disease introduction and impact on the natural environment and biodiversity, domestic stocking may be considered in the same context as recreational stock enhancement and aquaculture.

# 5 NORTH-WESTERN AUSTRALIAN ENVIRONMENTAL FEATURES

The Kimberley, Pilbara and Gascoyne regions of Western Australia provide conditions under which barramundi may be cultured naturally, using flow-through production systems without any requirement for heating the culture water. Accordingly, Chapter 5 describes aspects of the environmental features of north-western areas of Western Australia. It is beyond the scope of this discussion paper to describe the environmental features of the remainder of the State.

## 5.1 Climate and Water Resources

Aquaculture using fresh and some brackish water production systems, utilising onshore ponds or offshore cages in lakes fed by seasonal flows, requires consideration of rainfall, evaporation and transpiration. Of the inhabited continents, Australia has both the lowest average rainfall and the highest proportion of rainfall lost back to the atmosphere through evaporation and transpiration. The north of Western Australia has significant, monsoonal rainfall; however, the remainder of the tropical and subtropical climatic zones are arid to semi-arid. Tropical and subtropical Western Australia comprises the Kimberley, Pilbara and Gascoyne regions.[17] Table 2 summarises some rainfall and air temperature data for selected stations in the three regions.[18]

Table 2 Rainfall and temperature data for selected stations in north-west Western Australia (source: Climate of Western Australia, Bureau of Meteorology, 1995).

| Station | Annual rainfall (mm) | | Mean daily temperature, annual range (°C) | |
|---|---|---|---|---|
| | Mean | Median | Maximum | Minimum |
| Kuri Bay (Kimberley) | 1315 | 1322 | 31.3-34.3 | 19.0-26.2 |
| Wyndham (Kimberley) | 703 | 673 | 31.1-39.5 | 17.1-27.1 |
| Kununurra (Kimberley) | 796 | 779 | 30.2-38.8 | 15.0-25.7 |
| Fitzroy Crossing (Kimberley) | 534 | 531 | 29.6-40.5 | 10.7-25.1 |
| Broome (Kimberley) | 553 | 510 | 28.7-34.3 | 13.6-26.4 |
| Derby (Kimberley) | 617 | 610 | 29.5-36.4 | 14.6-26.4 |
| Marble Bar (Pilbara) | 342 | 334 | 26.8-41.7 | 11.7-26.1 |
| Port Headland (Pilbara) | 306 | 307 | 26.9-36.8 | 12.1-25.4 |
| Learmonth (Gascoyne) | 268 | 225 | 24.0-37.8 | 11.4-24.1 |
| Carnarvon (Gascoyne) | 226 | 205 | 22.1-32.5 | 11.1-23.2 |

The Kimberley is located in the north of Western Australia, extends approximately between latitudes 14° and 20°S and comprises a land area of approximately 421,000 km$^2$. It is bounded by the Timor Sea and Indian Ocean to the north and west, the Great Sandy and Tanami Deserts to the south and the Northern Territory to the east. Although its eastern boundary is delineated by the Northern Territory border, the physiography of the region extends eastwards as far as the Victoria River.

[17] The Gascoyne Region is beyond the natural range of barramundi; however, its climate is included here because of the potential of some areas to grow the species using hot artesian water in onshore systems located some distance inland.

[18] The median rainfall figure is included because it generally provides a better guide to the rainfall experienced in a region than does the mean, which may be influenced by a few years of exceptionally high or low rainfall figures.

Located on Western Australia's north-west coast and bounded on its north, east, south and west by the Kimberley, the Northern Territory border, the Gascoyne and the Indian Ocean, the Pilbara comprises a land area of approximately 510,000 $km^2$.

The Gascoyne is located in the north-west of Western Australia. Bounded by the Mid-West region to the south and east, the Pilbara to the north and the Indian Ocean to the west, the region comprises a land area of approximately 140,000 $km^2$.

Few of the rivers in these regions are characterised by permanent flows; a notable exception is the Ord River, which feeds lakes Argyle and Kununurra. During periods of heavy rainfall the rivers form raging torrents, while during the dry season even some of the largest rivers cease flowing and main water courses are usually reduced to a series of disconnected water holes or pools.

### *5.1.1 The Kimberley*

*Climate*

The Kimberley region has a tropical monsoonal climate with two dominant seasons separated by short transitional periods. The wet season, during which the region receives about 90 per cent of its annual rainfall, usually occurs from about November to April. Monsoonal weather brings hot and humid conditions, with winds mainly from the north-west and frequent thunderstorms causing heavy rainfall. This time of year is often marked by tropical cyclones and low pressure systems that can produce intense winds, heavy rain and flooding. Dry, sunny days and cooler nights typify the dry season from May to October, as the trade winds flow from central Australia. Very little rainfall occurs during the late winter to spring months.

Annual rainfall decreases southwards, from over 1400 mm near the Mitchell Plateau to below 400 mm towards the Great Sandy Desert. Highly variable from year to year, rainfall is governed by the behaviour of the monsoon. Individual events such as tropical cyclones are often responsible for much of the annual total.

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

*Water Resources*

The principal river systems of the Kimberley include the Ord (including lakes Argyle and Kununurra), Pentecost, Drysdale, King Edward, Mitchell, Prince Regent, Isdell, Meda and Fitzroy rivers. Once the wet season begins, the river flows across the Kimberley build up quickly and discharge large volumes of water into the sea through ten drainage basins. The river systems are seasonal and all except the Ord River are dry by the end of May. Permanent and semi-permanent pools exist in the stream beds of most of the river courses.

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

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

Most streams in the Kimberley are alkaline with a pH range of 7.1-7.6, but occasionally slightly acidic water is found. Water temperatures generally range from 25 to 35°C.

### *5.1.2 The Pilbara*

*Climate*

The Pilbara is a hot, arid part of the State with very high summer temperatures. Rainfall is low, averaging 200-350 mm/yr across the region (annual rainfall can vary dramatically from year to year, subject to cyclonic activity). Evaporation is high and, in the inland parts of the region, about ten times the rainfall.

*Water Resources*

The principal Pilbara river systems include the De Grey, Fortescue and Ashburton rivers.

Water resources are scarce compared to the Kimberley, but quite plentiful. The vast majority of existing supplies come from ground water; the only significant surface water resource is provided by the Harding River Dam. Currently, two Water Supply schemes provide water to the Pilbara: the Port/South Hedland and the West Pilbara schemes. The Port/South Hedland Scheme uses water from bore fields of the Yule and De Grey Rivers; the West Pilbara Scheme uses water from the Millstream aquifer and the Harding River Dam. Other ground and surface water resources have not yet been developed.

### *5.1.3 The Gascoyne*

*Climate*

The Gascoyne region encompasses both tropical and temperate climatic features. Its northern part is arid and tropical, while the southern part tends towards a more temperate, Mediterranean climate. The Indian Ocean moderates the climate in coastal areas; inland areas experience wide temperature variations.

Climatic conditions in the Exmouth region are dominated by tropical cyclones, most of which occur during the summer months between January and March. The climate is characterised by hot temperatures and low rainfall from November to March. The majority of the rainfall occurs as a result of cyclonic activity; rainfall is highly variable but averages 278 mm per year. The mean daily maximum temperatures are highest in January and lowest in July, ranging from about 38 to 24°C. The Carnarvon region has a more even climate: its mean daily maximum temperatures are at their highest in February and lowest in July, ranging from about 32 to 22°C. In contrast to the northern part of the region, rainfall occurs mainly in winter and averages 226 mm per year. The Shark Bay area has a dry, warm Mediterranean climate characterised by hot, dry summers and mild winters; the area's mean daily maximum temperatures are similar to those of Carnarvon. The area is also influenced by south-easterly winds for much of the year. During summer, southerly winds often blow for several days at over 25 km/h.

The inland areas of the Gascoyne are arid and experience relatively extreme temperatures. Mean monthly temperatures are at a maximum during January and a minimum in July, with a range of about 41-23°C. Rainfall averages 216 mm per year at Gascoyne Junction, with the majority falling during February, May and June. Rainfall in the Gascoyne is offset by high evaporation rates, which range between 1700 and 3050 mm per year, according to seasonal conditions.

*Water Resources*

The Gascoyne is contained within the Indian Ocean drainage division. Its principal river systems include parts of the Ashburton and the Gascoyne rivers; smaller river systems include the Lyndon, Minilya and Wooramel rivers. The river systems have their catchments well inland and the catchment basins are characterised by irregular and short-lived water flows. Due to these ephemeral river flows and the high evaporation rate, the region has very little surface water. The principal river is the Gascoyne, which has a catchment area of 6.7 million hectares and extends 500 km inland. The river flows intermittently between February and August, when the aquifers in its bed are recharged. The basin contains an estimated 238 million cubic metres of ground water, most of which occurs in the rocks or unconsolidated sediments of the coastal Carnarvon Basin.

The four major towns of the Gascoyne (Carnarvon, Denham, Exmouth and Gascoyne Junction) each have their own water sources and all depend on varying degrees on ground water reserves. Bores and plant required to supply, purify and chlorinate the water are operated by the Water Corporation. Water supplies do not extend far beyond the boundaries of each town site; pastoral properties and other operations remote from the towns have their own bore holes. All bore holes and other ground water supply systems must be approved and licensed by the Water and Rivers Commission.

## 5.2 Aquatic Fauna

Section 5.2 deals principally with the fresh-water fauna of the Kimberley, Pilbara and Gascoyne, which includes invertebrates, finfishes, amphibians, reptiles, birds and mammals.

### *5.2.1 Habitat*

Almost all the factors influencing the aquatic habitats in north-western Australia are governed by the area's seasonal hydrological cycle. The rivers are generally characterised by vast amounts of water being discharged during the wet season and having negligible or no stream flow for most of the year during the dry season, when the river beds and flood plains are either dry or contain series of waterholes or billabongs. Although low overall, salinities do fluctuate and reach their maxima towards the end of the dry season. Water quality variables, usually dominated by sodium chloride and bicarbonate, fluctuate seasonally. Thermal stratification, usually absent at night, develops daily. In the northern regions, high water surface temperatures persist throughout the year, irrespective of any vertical stratification that may develop, and can range from about 22°C in July to over 40°C in November. Dissolved oxygen concentrations are generally high during the wet seasons with some stratification developing during the dry: oxygen levels can be low in the bottom waters of deep pools.

### *5.2.2 Invertebrates*

Invertebrates that inhabit the deeper parts of ponds and billabongs are relatively sparse and include species such as cherabin or freshwater shrimp (*Macrobrachium rosenbergii*) fresh water mussels, oligochaete worms and various insect (Dipteran) larvae. The diversity and abundance of invertebrates that inhabit the shallower areas vary seasonally, with the greatest diversity and abundance occurring towards the end of the wet and beginning of the dry seasons (Williams, 1983).

Knowledge of the invertebrate fauna of north-western rivers is restricted; however, that of Magela Creek, east of Darwin in the Northern Territory, is better known and may be representative of some rivers of the Kimberley, Pilbara and Gascoyne. The invertebrate fauna of this river includes various rotifer, crustacean and insect species, gastropods, oligochaete worms, triclads and hydracarines. Organic detritus is probably the food source of most of the non-predator species. The billabongs or pools in the river channels generally have a greater species diversity than those in the river flood plains. The planktonic fauna is similar to tropical plankton elsewhere and in particular to that of Indonesia (Williams, 1983).

### *5.2.3 Fishes*

Some finfish species in these regions are restricted to inland, fresh water throughout their life histories; others are basically estuarine forms or include both estuaries and fresh water habitats in their life histories. The majority of Australian freshwater fishes are considered secondary freshwater species[19]. Presumably, these were originally estuarine species that, through a natural selection process, became progressively more adapted to a fresh water environment until they were capable of completing their entire life history in fresh water. The secondary freshwater species include several highly-successful families. Australia's northern, tropical freshwater fish fauna is closely allied with that of Papua New Guinea, but is very different from the species-rich adjacent region to the north (*viz*. the Indonesian-Malaysian Archipelago and South-East Asia). The Australian freshwater fauna is characterised by being relatively impoverished (Allen, 1982).

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[19] Primary freshwater species are those derived exclusively from freshwater ancestors; secondary freshwater species are those considered to have evolved in a marine environment and moved to freshwater habitats at a later stage of their evolutionary history.

Inland Australia has been divided into several regions, based on drainage patterns and faunal distributions. Two of these, the Liechardtian and Greyian Regions, encompass the north of Western Australia. The Liechardtian region includes the Kimberley, the northern portion of the Northern Territory and the Gulf of Carpentaria drainage area of northern Queensland. In terms of species it is Australia's richest fresh water faunal region and about 20 per cent of the species found in the region also occur in Papua New Guinea. The Greyian Region extends from the De Grey River southwards to the Murchison River, so encompasses the Pilbara and Gascoyne Regions. Due to the area being largely a desert with few permanent water courses, the fresh water fauna is impoverished and characterised by a paucity of species.

There is a strong element of endemism in the Kimberley's freshwater fish fauna: 18 of its 48 fish species are endemic. The freshwater fishes of the Kimberley include barramundi, eels, freshwater herring, several species of eel-tailed and fork-tailed catfishes, garfish, longtom, several species of hardyheads, rainbowfishes, glassfishes, grunters (fresh water bream), archerfishes and gudgeons. The fauna of the Kimberley is dominated by grunters and gudgeons, which together comprise about 50 per cent of the total number of species (Allen, 1982). The semi-permanent and permanent water holes of the Gascoyne River contain fish populations that are generally flushed downstream when the River is flowing. Species reported to be surviving in these areas include mullet and perch. Like those of the Kimberley, the freshwater fish species of the Pilbara and Gascoyne are dominated by grunters and gudgeons, which collectively comprise about 50 per cent of the total species. Two exotic species, freshwater eels and tilapia, probably introduced from hobby aquaria, are reported to also live in these waters.

Most of the major river systems of the Kimberley are well separated from each other, a factor that probably contributed to the development of the high proportion of endemic species, many of which are restricted to a single system. The evolution of species in the Pilbara and Gascoyne can be explained by the isolation of the systems as a consequence of the large desert areas that separate them.

Allen (1982) identifies 12 families of freshwater fishes in Western Australia's northern fish fauna. These are:

- **Clupeidae**, or gizzard shads (one genus and a single species); found throughout the Kimberley and Pilbara, possibly Australia's most widespread inland species; habitat is slow-flowing water or large, rocky pools;
- **Ariidae,** or fork-tailed catfishes (one genus, three species); found in the Kimberley's major river systems and possibly in those of the Pilbara, widespread in northern Australia; live in estuaries and pure, fresh water;
- **Plotosidae**, or eel-tailed catfishes (three genera comprising five species); generally found in the main streams of the Pilbara and throughout the Kimberley; habitats include slow-flowing streams, billabongs, lakes and ponds; diet includes crustaceans;
- **Belonidae**, or long-toms (one genus and a single species); found throughout the Kimberley and across northern Australia in larger streams;
- **Melanotaeniidae**, or rainbowfishes (one genus comprising three species); two species are limited to the Kimberley, a third, found in northern and eastern Australia, the Kimberley and Pilbara, is probably the most abundant fish in northern waters; habitats vary from rapidly-flowing to slow-flowing streams, lakes and ponds; diet includes small crustaceans;

- **Atherinidae**, or hardyheads (two genera comprising four species); in Western Australia, three species of the genus *Craterocephalus* occur in various streams in the Kimberley, Pilbara and Gascoyne, while *Quirichthys stramineus* is found in the Kimberley's Ord River system; their diet includes small crustaceans;
- **Synbranchidae**, or blind eels (one genus and a single species); limited to a subterranean water system in the North-West Cape area of the Gascoyne;
- **Ambassidae**, or glassfishes (two genera comprising three species); nocturnal fishes found in the Kimberley and across northern Australia; habitats include slow-flowing streams, lakes and billabongs; diet includes small crustaceans;
- **Teraponidae**, or grunters (five genera comprising 11 species); the various species are generally distributed throughout northern Western Australia, where they form an integral part of the freshwater fauna, one to four species of grunter are found in virtually every stream in the Kimberley, Pilbara and Gascoyne; the sooty grunters or freshwater bream of the genus *Hephaestus* are favoured angling and table fishes; habitats range from rapidly-flowing streams to lakes, small ponds and stagnant pools; they are voracious carnivores, the diets of which include crustaceans;
- **Apogonidae**, or cardinalfishes (one genus and a single species); occurs in the Kimberley eastwards from the Fitzroy River system and across northern Australia; habitats include weedy areas of streams, billabongs and lakes;
- **Toxotidae**, or archerfishes (one genus comprising two species); both species are found in major streams north of the Fitzroy River in the Kimberley and are abundant in Lakes Argyle and Kununurra; and
- **Eleotridae**, or gudgeons (up to six genera comprising 12 species, *Hypseleotris* is the largest Australian genus); some species have a limited distribution in the Kimberley, Pilbara or Gascoyne regions, others have more widespread distributions that extend across northern Australia; habitats vary according to species from rapidly-flowing streams to slow-flowing streams, lakes, billabongs and ponds; the natural diet includes small crustaceans.

Allen (1982) also identifies a wide range of estuarine fishes frequently found in fresh water. These generally inhabit the lower reaches of major river systems; however several species are capable of inhabiting areas well inland. These species include various sharks and sawfishes, eels, milkfish, some marine pelagic and reef fishes, mullet and barramundi.

### *5.2.4 Amphibians and Reptiles*

Of the amphibians, only frogs and toads are native to Australia; others, such as salamanders and newts, do not occur here naturally. Although frogs are common in the northern areas, the amphibian fauna is much less diverse than the fish fauna; breeding may be limited by fish predation on eggs and tadpoles. Four families of frogs are native to Australia and many of the genera are widespread. Many species have adapted to the climatic conditions prevalent in the northern areas: the time when free water is needed for the tadpole stage has become reduced. Frogs are opportunistic predators; insects form a major part of their diets and they also consume a variety of other invertebrates, other frogs and fish. Little is known of the feeding habits of tadpoles. Detritus, organic matter, plant material and other tadpoles form a part of their diet; however, some ingest a large proportion of animal food. These habitual carnivores have probably adapted to life in temporary pools. The major predators of frogs are snakes and birds and they form a part of the diets of various other groups such as fish and mammals.

Reptiles include tortoises, crocodiles, lizards and snakes. Tortoises typically inhabit slow-flowing rivers, pools and swamps. Their diet comprises fish, crustaceans, molluscs and other suitably-sized invertebrates. Two crocodile species are found in northern Australia: the small fresh water or Johnston's crocodile (*Crocodylus johnstoni*) and the larger estuarine crocodile (*Crocodylus porosus*). The fresh water crocodile's diet includes fish, frogs, crustaceans, lizards and small birds and mammals. The estuarine crocodile normally consumes fish, other reptiles, water birds and some mammals. Many lizard species are found in or near water. The major part of their diets includes fish, frogs and insects. Several species of snakes are also closely associated with fresh water: several aquatic species are restricted to northern Australia and have various adaptations to a life in fresh water. Their diet is similar to that of reptiles.

### *5.2.5 Birds and Mammals*

The many different birds species associated with water are collectively termed 'waterbirds'.
The waterbirds of northern Australia are characterised by their diversity and abundance, detailed accounts of which are provided in numerous publications (Cowling, 1977; Crawford, 1979; Keast, 1981; Slater, 1970). Waterbirds use fresh water habitats to provide refuge for mating and nesting and as a major source of food. Diving waterbirds, such as darters and cormorants, habitually feed on fish and crustaceans.

The main mammals of relevance to aquaculture are water rats. The true water rat (*Hedromys chrysogaster*) is widespread. Its range includes northern Australia and as far south as northern parts of the Gascoyne. The false water rat (*Xeromys myoides*) has been found in isolated areas of the Northern Territory and northern Queensland, but its distribution may extend beyond those areas (Williams, 1983). With its water-repelling fur and webbed, paddle-like hind feet, the true water rat is well adapted to an aquatic life. The burrowing activities of large populations can cause damage to banks and dam walls. Mainly carnivorous, they feed on crustaceans, aquatic insects, mussels, fish, frogs, tortoises and small mammals and are one of the few native predators of the introduced cane toad. Its natural predators include snakes, various birds of prey and feral cats.

# 6 ENVIRONMENTAL ISSUES

The three main issues associated with the translocation of aquatic organisms are the potential of the translocated species to:

i. impact on the genetic diversity of native species;
ii. introduce disease; and
iii. impact on the natural environment and biodiversity.

Each of these factors is discussed in the following sections, with reference to the translocation of barramundi into and within Western Australia.

## 6.1 Genetic Diversity

An impact on genetic diversity may occur when an existing wild population differs genetically from the species being introduced. Genetic diversity may be decreased through inter- and intraspecific hybridisation or the mixing of genetically-discrete strains (Lawrence, 1993).

Several studies (Shaklee and Salini, 1985; Salini and Shaklee, 1988; Keenan and Salini, 1989; Shaklee *et al.*, 1993; and Keenan, 1994) indicate there is significant genetic heterogeneity between different barramundi populations across northern Australia. This genetic differentiation is considered to have important implications for the management of the commercial and recreational barramundi fishery, the aquaculture of the species and its conservation. Keenan (1994) notes that the presence of genetically-distinct stocks does not necessarily imply that significant gene exchange does not take place between stocks in the longer term.

Keenan and Salini (1989) have speculated that the observed changes in genetic variation between barramundi populations will produce some important biological differences; in relation to the impact of translocation on the genetic diversity of a separate, genetically-distinct population, they make the following arguments.

- Barramundi populations large enough to overcome occurrences of genetic drift or inbreeding depression cannot be considered already genetically compromised (and therefore not in need of protection).

- The need to preserve distinct, natural genetic lines, which in the future may constitute an important resource for selection and breeding, is fundamental to animal and plant production. Once lost, the genetic identity of isolated populations cannot be retrieved. In the future, significant genetic improvement of cultured fish is inevitable; however, this breeding may threaten wild populations if the genetically-modified fish escape and swamp the natural genetic diversity of the wild stocks.

- The best way to preserve the natural genetic heterogeneity of the existing populations of the species is to regulate the movement of live barramundi.

In relation to the importance of preserving genetic lines, Doupe (1998) and Doupe and Alder (1998) also refer to the effect that using limited numbers of broodstock, and the consequential lack of genetic diversity, may have on the selective improvement of desirable characteristics of in hatchery breeding programmes.

One of the genetics issues concerns the question of whether the different barramundi stocks have become adapted to their local environment. While there is apparently no direct scientific evidence, Keenan and Salini (1989) are of the view there is adequate indirect evidence to demonstrate that they have.[20]

Assuming the indirect evidence that wild stocks are adapted to their habitats, and so have a high fitness, is correct (Keenan and Salini, 1989), there is a perceived risk that the translocation of hatchery-reared barramundi between natural stocks may result in reduced stock fitness (Keenan, 1994).

Stoddart and Trendall (1989) contend that genetic differences between barramundi stocks have been demonstrated only for populations, not for individual fish, and it is the proportion of the genes present that differs between different river systems, not the actual genes. Work on other fish species suggests that the few differences reported in the life histories of different barramundi stocks are unlikely to have a genetic basis. Stoddart and Trendall (1989) further believe there is no direct evidence that mixing gene pools will have deleterious effects.

The maintenance of genetic diversity in wild populations is often in apparent conflict with the breeding programmes adopted in hatcheries to select for desirable characteristics in cultured fish. Doupe (1998) presents a balanced view that, as well as providing fish to markets, a diversified barramundi aquaculture industry can also provide genetic material similar to wild populations intended for enhancement, thereby promoting the conservation of the heterogeneity of wild populations.

Each year, fish in general produce very large numbers of eggs and larvae, few of which survive to maturity. There is therefore strong potential for genetic selection during the period of larval development when the mortality rate is high. It has been demonstrated that different year-classes of fish spawned from a single adult stock can be genetically distinct if they are exposed to different conditions during their early development. Snapper larvae spawned from the same adult population can have a wide genetic diversity after one or two generations.

Smith (1979) showed that, for the New Zealand snapper (*Chrysophrys auratus [= Pagrus auratus]*), different year-classes of a single fish stock can be genetically distinct from each other if they are exposed to waters of different temperature during the period of high mortality. He thus demonstrated the importance of stock-identification programmes identifying genetic variations within a single year-class at a single locality, before considering comparing genetic differences between stocks at different locations. Smith and Francis (1983) further emphasised the importance of the necessity of multiple sampling to establish genetic differences within and between areas before making deductions about stock structures. In addition to those existing between different year-classes of the same stock, genetic differences can develop within a single year class of the same stock, as the fish develop. Smith and Francis (1984) and Smith (1987) showed that genetic changes occurred, or genetic differences increased, in sand flounder (*Rhombosolea plebeia*) as the fish from a single year-class grew from juveniles to adults.

[20] The lack of direct evidence has been attributed to the difficulty of conducting the requisite experiments in an aquatic environment using fish.

## 6.2 Introduction of Diseases

The accidental spread of pathogens accompanying translocated fish can be a major concern. Since the native fauna of Western Australia are apparently free of many diseases found elsewhere in the country, adequate health testing to ensure the exclusion of diseases is a vital factor in the consideration of the translocation of any stock.

Generally, diseases from cultured organisms are unlikely to threaten wild stocks; however, information from the salmonid and marine prawn farming industries suggests that aquaculture has had some deleterious effects on wild stocks. Farmed fish may be at risk from the wild population, but there are no documented instances of cultured fish causing disease epidemics among wild fish. Evidence that diseases from farmed stocks do affect wild stocks is circumstantial (Jones, pers. comm.). Cultured fish are comparatively crowded and under stress, so more likely to be affected by disease. In their natural environment, wild fish are not exposed to the stress regularly experienced by cultured fish, so are unlikely to be affected by pathogens that may be released from aquaculture operations.

The nodavirus that causes VNN is the only disease of significance in respect of barramundi translocation, since it may affect other species. All the other diseases described for the species are found in Western Australia, but no survey of wild stocks has yet been carried out to show whether the nodavirus exists in the State.

A molecular diagnostic technique, called PCR, has been developed in Queensland for diagnostic screening, to ensure that barramundi translocated from that State are free of nodaviruses. In South Australia, a cell line has been developed to identify the presence of the virus by tissue culture. Western Australia accepts certification of the disease-free status of barramundi stocks from both Queensland and South Australia. Fish from the Northern Territory are generally screened by the Fish Health Section of Fisheries WA.

In barramundi aquaculture, problems associated with disease outbreaks usually only occur when the environmental conditions are unsuitable for the fish (Pechmanee, 1993). Most disease situations in aquaculture can be attributed to poor management practices.

## 6.3 Impact on the Environment and Native Species

The translocation of aquatic organisms to a water body can affect the ecosystem either directly, through predation or competition, or indirectly, through alterations of the environment. The alteration of an ecosystem can have significant effects since the entire aquatic community, rather than specific prey or competitor species, can be affected (Lawrence, 1993). Introduced species can affect the environment in various ways, including stirring up sediments as a result of foraging behaviour and consuming species such as macrophytes upon which other native species may depend for successful spawning. Lawrence (1993) cites several examples of introduced piscivorous species reducing and eliminating existing species.

Fish translocations have in some instances led to increased aquaculture and wild-capture fisheries production; in other cases, translocations have resulted in reduced productivity and diversity in native fish stocks (Phillips, 1995). While there have been many positive benefits from the translocation of fish, there are sufficient examples of negative impacts to justify caution. In the Philippines, the introduction of the African catfish (*Clarias gariepinus*) reportedly affected local catfish stocks and introductions of tilapia to ponds and reservoirs in India reduced yields from native fisheries (Phillips, 1995). However, in most cases where translocated fish have adversely affected the local environment and native species, the translocated fish were not native to the water bodies to which they were introduced. This would not be the case for barramundi translocated to regions of Western Australia within the natural range of the species.

It is considered unlikely that barramundi introduced into natural water bodies within their natural range as part of a stock enhancement programme, or as escapees from aquaculture operations, would have any significant impact on the environment and native species. Large numbers of barramundi released into modified habitats such as lakes Kununurra and Argyle are unlikely to have any impact on the environment, but may impact on the native species inhabiting those water bodies.

The effects of barramundi that may escape into water bodies outside their natural range is unknown; however, it is considered unlikely that these latter fish would survive or reproduce, given the unsuitable environmental conditions in these areas.

## 6.4 Conclusions

### *6.4.1 Key Translocation Issues*

Any translocation of species must balance significant economic and social benefits with biological and environmental risks. This discussion paper has been prepared to assist in the determination of an appropriate management framework for the translocation of barramundi into and within Western Australia, for the purposes of recreational stock enhancement, aquaculture and domestic stocking. The following conclusions are drawn in relation to the information provided about genetic, disease and environmental risks in previous sections.

*Genetic Diversity*

A key issue is the relationship between the demonstrated genetic differences between barramundi populations and the differences between their life histories. Genetic heterogeneity is also important for biodiversity. The translocation of barramundi does pose a risk, which must be managed in accordance with the precautionary principle. The precautionary principle is clearly defined as: "where there are threats of serious or irreversible damage, lack of full scientific certainty should not be used as a reason for postponing measures to prevent environmental degradation" (Australia's Oceans Policy). The strict application of the precautionary principle would not permit most deliberate introductions. Therefore, in recognising that there are risks, a precautionary approach to species translocation should aim to minimise any impacts on genetic diversity and establish appropriate corrective or mitigating procedures.

The genetic heterogeneity indicated between wild barramundi stocks in Australia is considered by some authorities to constitute an important resource, for future aquaculture and other purposes, and should be protected.

Other authorities are of the opinion that the differences are those between populations, not individuals; it is unlikely there is a genetic basis to the few differences between the life histories of different stocks; and there is no direct evidence to suggest that mixing gene pools would have deleterious effects.

Genetic differences can develop between different year-classes of a single fish stock and within a single year class of a single stock as the fish develop and mature. That this situation may apply for barramundi across northern Australia cannot be discounted.

In respect of the perceived risk that the translocation of hatchery-reared barramundi between natural stocks may result in reduced stock fitness, it could be argued that, if the fitness of wild stocks adapted to their habitats is high, it must be reasonable to conclude that less fit, introduced stock would not be able to compete effectively, so few of their genes would enter the next generation. There are no recorded instances where fish produced by aquaculture have weakened the genetic fitness of wild stocks.

Solutions proposed to overcome the issue of maintenance and protection of the genetic heterogeneity of wild populations include:

- using as broodstock fish captured from the wild population that inhabits the region in which the stock enhancement or aquaculture operation is proposed;
- using triploid fish, which, by definition, will be incapable of producing viable offspring with the diploid wild fish; and
- preventing stock escapement.

Using broodstock captured from stocks in the area in which the ensuing hatchery-reared juveniles would be stocked or cultured provides a practicable solution in the short to medium term. However, this option precludes the use of different stocks for breeding and selection, an argument that has been used to support the case for the protection of the genetically-distinct populations. The solution is best suited for growing fish for stock enhancement purposes. This solution would not be practicable for a commercial barramundi hatchery producing fish for growout under aquaculture conditions. For aquaculture, a genetic selection programme to improve the broodstock would invariably comprise an essential component of operations.[21] Cultured barramundi will inevitably become highly modified from a genetic perspective, by simple selection and cross-breeding for desirable traits, such as improved FCR and growth and earlier maturity, and those involving more complex biotechnologies.

The use of triploid fish to limit genetic interaction with wild stocks has merit, if it can be assured that a reasonably large proportion of the translocated fish would in fact be triploids. The use of triploid fish would significantly reduce the perceived genetic risk of translocation, even if only a proportion of cultured stocks are triploids, by reducing the number of fish that can reproduce. The requisite technology has not yet been developed for barramundi, although some preliminary experiments to induce triploidy have been carried out, and further research in this area may be warranted.

The escape of organisms translocated into culture units or other enclosures is inevitable; however, good management practices that minimise the risk of escape can be

[21] McPhee (1995) suggests significant financial returns could be achieved by selective breeding and estimates that a genetic selection programme to increase the market weight of barramundi would increase the trait by a factor of 50 per cent within five years.

implemented. Guarantees that cultured stocks will always be contained can only be applied to recirculating systems and flow-through culture units in areas unconnected to any ephemeral or permanent surface waters.

Compared to the Northern Territory and Queensland, Western Australia has limited stocks, presumably because the permanent rivers and streams required for this catadromous species to complete its life history are very limited. Consequently, fewer opportunities exist for hatchery-reared translocated fish to reproduce and influence the genetic integrity of wild populations.

*Introduction of Diseases*

In respect of the potential introduction of diseases, barramundi translocation into and within Western Australia, into areas in which the species is naturally distributed, is generally considered low risk. With the exception of VNN, there are no diseases of significance for barramundi, because all the diseases associated with the species already occur in Western Australia.

Controls are already in place in Western Australia to preclude the threat of diseases being introduced by translocated stocks.

*Impact on the Natural Environment and Biodiversity*

Barramundi are usually the top predator in the water bodies in which they naturally occur; if they are introduced into areas in which they previously occurred but have since become depleted, the natural environment and biodiversity of that system are likely to simply revert to the previous *status quo*. If they are introduced into waters in which they did not previously exist, the effects would be unknown.

In general, translocated barramundi are considered highly unlikely to have any significant, deleterious impact on the natural environment and biodiversity of water bodies in Western Australia to which they may be introduced.

### *6.4.2 Management Options under Consideration*

In relation to barramundi translocation, different situations apply, according to whether the translocation is for the purpose of recreational stock enhancement, aquaculture or domestic stocking and according to whether the location proposed for the restocking is within or beyond the natural range of the species in Western Australia. Management options that could be considered for the various situations are provided below.

*For the Purpose of Recreational Stock Enhancement*

Within the natural range of the species:

- large numbers of broodstock obtained from the target water body should be used; and
- no selective breeding should be used to genetically modify the stock.

Into areas where original stocks are now depleted:

- large numbers of broodstock obtained from the target water body should be used;
- no selective breeding should be used to genetically modify the stock; and
- efforts should be made to redress the cause of the stock depletion.

*For the Purpose of Aquaculture and Domestic Stocking*

Within the natural range of the species:

- seed stock should ideally be obtained from broodstock captured in Western Australian waters;
- selective breeding to improve the stock should be permitted; and
- steps should be taken to minimise escapes.

Outside the natural range of the species, in systems other than closed recirculation:

- seed stock should ideally be obtained from broodstock captured in Western Australian waters.

The necessity for translocated stock to be certified disease-free is implicit for all the above options.

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## APPENDIX ONE

### Environmental Requirements for Barramundi Stock Enhancement and Aquaculture

A site that may be considered suitable for the aquaculture of any species needs to satisfy certain physical, biological, economic and socio-economic requirements; a good site is almost invariably characterised by features that satisfy the more critical requirements of the species under culture and those of the aquaculturist and by having economically viable solutions for the less critical features. The environmental requirements of any aquatic species under culture constitute one of the most critical biological factors that determine the suitability of a site for aquaculture and relate simply to the quality of the water.

This section deals exclusively with the environmental or water quality requirements for successful barramundi aquaculture. In a broader context, the same environmental requirements may be applied in contemplating stock enhancement for the recreational barramundi fishery and domestic stocking. The type of water needed for barramundi aquaculture can also vary according to the stage of the culture cycle and whether it is to be used for the establishment of a hatchery, nursery or growout farm. For the purpose of this discussion document, the environmental or water quality parameters identified are those required for barramundi under growout conditions.

### Physical Parameters

Physical water quality parameters principally include temperature, salinity and turbidity.

#### *Temperature*

Water temperature, expressed as degrees Centigrade (°C), is one of the most critical environmental variables that influence aquaculture. It affects factors such as growth rate, food conversion efficiency (and hence waste production), other metabolic functions, behaviour, fish health and oxygen solubility. Each aquatic poikilothermal species is characterised by an optimum or ideal temperature range, within which the species will thrive, and a maximum range, within and towards the extremes of which it will survive, but not thrive, and beyond which it will die.

Juvenile barramundi can survive within a temperature range of 16-35°C (Schipp, 1996); however, the ideal range for good growth under commercial growout conditions is 26-30°C.[22]

#### *Salinity*

Expressed as parts per thousand ( ‰ ) or grams per litre (g/L), salinity can vary from 0 ‰ in fresh water to above 300 ‰ in hypersaline water. Aquatic environments may be classified

[22] Rimmer (1995) and Schipp (1996) consider the ideal temperature ranges to be 26-30°C and 28-32°C respectively. The former ideal range is used for this study.

according to their salinities. For the purpose of this discussion document, the terms *fresh*, *brackish*, *sea* (or *marine*) and *hypersaline* refer, respectively, to waters with salinities of <2, 2-32, 33-38 and >39 ‰.

Juvenile and adult barramundi can thrive within the relatively wide, optimum salinity range of 0-36 ‰. Broodstock are generally maintained in sea water and larvae cultured in brackish or sea water.

### *Turbidity*

Turbidity is a consequence of substances such as clay, organic compounds and phytoplankton, dissolved and suspended in water. It is usually measured as transparency using a secchi disc. Turbidity ranges for barramundi under culture conditions have not yet been quantified. Qualitatively, the fish have a high tolerance to turbidity and can be successfully grown in clear, oceanic-quality water to the very turbid water characteristic of estuaries and areas with high tidal flows.

## Chemical Parameters

Chemical water quality parameters principally include dissolved oxygen (DO), pH, nitrogenous compounds, hydrogen sulphide, heavy metals and toxins such as pesticides and herbicides.

### *Dissolved Oxygen*

Dissolved oxygen (DO) and temperature are considered the most important environmental variables that influence aquaculture. Usually expressed as milligrams per litre (mg/L), a unit equivalent to parts per million (ppm), DO may be a limiting factor if ground water, sourced from an aquifer through a well, is used, but is seldom a constraint if surface waters are used. More intensive production systems routinely use aerators or inject oxygen to maintain the requisite DO concentrations in the culture water. DO is also influenced by temperature: its solubility (and that of other dissolved gases) decreases with increasing temperature.

The ideal DO range for barramundi is 4-9 mg/L. Concentrations greater than 9 mg/L are unlikely under most conditions and the lower limit for the species is considered to be 3 mg/L.

### *pH*

The pH of a substance expresses its acidity or alkalinity and can range between 1 and 14 (pH 7 is neutral). The pH range of most surface waters is 6.5-9.5 and that of sea water 7.9-8.2. The range considered ideal for barramundi, 7.5-8.5, is within the range considered suitable for most fish species.

### *Nitrogenous Compounds*

Nitrogenous compounds of concern in aquatic systems include gaseous nitrogen ($N_2$), unionised ammonia ($NH_3$), ionised ammonia or ammonium ($NH_4^+$) nitrite ($NO_2^-$) and nitrate ($NO_3^-$). They are measured as milligrams per litre (mg/L) or parts per million. Unionised ammonia, a waste product excreted as a result of amino acid metabolism, is the main compound of concern due to its toxicity to fish. It exists in solution in equilibrium with the significantly-less-toxic ammonium; the shift between the two is governed mainly by the pH, temperature and salinity and the sum of the two is referred to as *total ammonia nitrogen*. When measuring the concentration of any nitrogen compounds, it is essential to know exactly which is being measured. Unionised ammonia ($NH_3$) is typically reported as nitrogen and written as $NH_3$-N.

For barramundi aquaculture, the concentration of unionised ammonia should be kept below 0.02 mg/L.

### *Hydrogen Sulphide*

Hydrogen sulphide ($H_2S$) is produced under anaerobic conditions in aquatic systems by certain anaerobic bacteria. It is very toxic to fish and should ideally be maintained at zero or below 0.001 mg/L for all species. The gas may be present in some ground waters or in surface water with poor circulation.

### *Heavy Metals and Toxins*

Heavy metals include iron, cadmium, copper and other elements. They are introduced to aquatic systems from natural sources and their concentrations in natural waters or soils need to be established before fish are introduced for culture or any other purpose. The concentration limits for the heavy metals of most concern for aquaculture are elaborated in table two.

Toxins such as pesticides and herbicides are frequently used to control pests in agricultural and residential areas. Typically, they are extremely toxic to aquatic organisms in very small concentrations.

## Summary of Water Quality Requirements

Table 3 provides a summary of some water quality parameters for barramundi aquaculture. In relation to water quality, Rimmer (1995) notes that the tolerances of barramundi under culture conditions are not well known and the information about the various parameters should be used only as a guide. Further, the data refer principally to pond production systems, not to offshore cages. A significant degree of control may be exerted over the quality of water in a pond, assuming proper site selection and farm design in respect of water supply, while cages located in offshore, open-water systems have little control over water quality.

Table 4 provides indicative water quality data in relation to concentrations of heavy metals. The data represent the total metals (particulate and dissolved forms).

Table 3 Recommended water quality parameters for barramundi growout (modified from Rimmer (1995) and Schipp (1996)).

| Water quality parameter | Optimum | Limit |
|---|---|---|
| Temperature (°C) | 26-30 | >20 |
| Salinity ( ‰ ) | 0-36 | |
| pH | 7.5-8.5 | |
| Dissolved oxygen | 4.0-9.0 | >3 |
| Total ammonia (TAN) (mg/L)<br>Ammonia ($NH_3$-N) (mg/L) | 0<br>0 | <1.2<br><0.02 |
| Hydrogen Sulphide ($H_2S$) | 0 | <0.3 |

Table 4 Indicative heavy metal concentrations for marine water (modified from Huguenin and Colt, 1989).

| Metal | Concentration (µg/L) |
|---|---|
| Cadmium | <3.0 |
| Chromium | <25.0 |
| Copper | <3.0 |
| Iron | <100.0 |
| Mercury | <0.1 |
| Manganese | <25.0 |
| Nickel | <5.0 |
| Lead | <4.0 |
| Zinc | <25.0 |