Biodiversity Risk and Benefit Assessment for Smooth Marron (*Cherax cainii*) and Hairy Marron (*Cherax tenuimanus*) in South Africa

Prepared in Accordance with Section 14 of the Alien and Invasive Species Regulations, 2014 (Government Notice R 598 of 01 August 2014), promulgated in terms of the National Environmental Management: Biodiversity Act (Act No. 10 of 2004).

September 2019

Document Title	Biodiversity Risk and Benefit Assessment for Smooth Marron (*Cherax cainii*) and Hairy Marron (*Cherax tenuimanus*) in South Africa.
Edition Date	September 2019
Prepared For	Directorate: Sustainable Aquaculture Management Department of Environment, Forestry and Fisheries Private Bag X2 Roggebaai, 8001 www.daff.gov.za/daffweb3/Branches/Fisheries-Management/Aquaculture-and-Economic-Development
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EXECUTIVE SUMMARY

Internationally, alien species provide a valuable food source and an economic opportunity in both the fisheries and aquaculture sectors. In South Africa, aquaculture is composed of a blend of indigenous and non-indigenous species. However, breeding and domestication of indigenous species requires time, technological and financial resources, whilst there are already alien species with proven aquaculture potential that could be utilized for food production and job creation. There is, however, an environmental risk associated with the uncontrolled introduction and use of alien species and consideration must be given to the potential benefits and risks associated with their use. Internationally, mechanisms and management practices exist to assist with the responsible use and control of alien species in aquaculture and fisheries.

This Biodiversity Risk and Benefit Assessment (BRBA) has been conducted and documented in relation to the propagation and grow out of Smooth Marron (*Cherax cainii*) and Hairy Marron (*Cherax tenuimanus*) in South Africa, albeit that only Smooth Marron is currently use in aquaculture in South Africa. These species are very similar, with some degree of taxonomic confusion and even suggestions that they should be reclassed into a single species. For this document, these species are collectively referred to as *Marron*, unless specific distinction is required.

The Department of Environment, Forestry and Fisheries (DEFF), as the lead agent for aquaculture management and development, appointed Anchor Environmental in August 2012 to conduct a Biodiversity Risk and Benefit Assessment (BRBA) for the use of Marron in South Africa. Subsequently (2017), AquaEco has been appointed to review and update these risk assessments in terms of Section 14 of the Alien and Invasive Species (AIS) Regulations (Government Notice R 598 of August 2014) and the National Environmental Management: Biodiversity Act 10 of 2004.

The aim of this assessment was to consider the appropriateness (benefit) of the use of the exotic Marron (*Cherax cainii and C. tenuimanus*) for aquaculture in South Africa, in relation to the potential effectiveness of management measures for ecologically sustainable development of the sector. This will assist the DEFF and other relevant competent authorities in taking informed decisions regarding the promotion and regulation of this alien and invasive species. The document not only serves as a broad high-level assessment to be applied in the context of new applications and regulation of the import and culture of Marron in South Africa, but also contributes to the development of environmental norms and standards for the culture of the species.

The assessment has been conducted in accordance with the risk assessment framework for such assessments contained in the Alien and Invasive Species (AIS) Regulations (Government Notice R 598 of August 2014) and the National Environmental Management: Biodiversity Act 10 of 2004. The use of Marron has also been scrutinised in terms of the restricted activities for which authorisation is required, given that this species (both *Cherax cainii and C. tenuimanus*) has been classified as a Category 2 Alien and Invasive Species in the AIS List (Government Notice R 864 of 29 July 2016).

The risk assessment investigated the taxonomy, key characteristics, dietary aspects and history of Marron culture, while considering its native environment in the south-west of Australia. It was found that Marron are particularly sensitive to water quality variation and other environmental parameters, and not prone to become invasive under South African conditions.

A detailed methodology was followed in the identification and assessment of risks, which included the scoring of each risk pathway and resulting ecological endpoint in categories of probability, severity, scope, permanence, confidence, potential for monitoring and potential for mitigation.

The identified pathways that could facilitate risks include:

- The pathway of escape, via various potential routes that include:
    - Escape during transit of stock from a supplier and transport for live sales;
    - Escape via the inflow water;
    - Escape via the outflow water;
    - Escape due to poor design, system malfunction or poor maintenance;
    - Escape through deliberate human actions such as theft or human error;
    - Escape through predation, where Marron are preyed upon and removed as live specimens to the surrounding environment; and

    - Escape caused by natural disasters such as flooding.
- The diverse pathway related to the potential transfer of disease.

The identified risk endpoints include:

- The potential for Marron to impact on prey species;
- The potential for Marron to compete for food, habitat niches and other resources;
- The potential threat of new or novel diseases carried into the environment by Marron as a vector – either directly or indirectly.

During the assessment, it was found that the overall ecological risk profile for Marron was low. The potential for monitoring and mitigation was found to be high, particularly as this related to the prevention of escape. It should however be highlighted that other freshwater crayfish species such as Australian Redclaw (*Cherax quadricarinatus*), for which invasive feral populations already exists in South Africa, can pose a high ecological risk.

Key economic and social matters were considered in a balanced manner in conjunction with the potential ecological risks. It was found that the general interest in freshwater crayfish, with no distinction between the invasive potential of each, as well as the aquarium trade could lead to unregulated spread. The establishment of a formal and lawful Marron aquaculture sector will contribute to the ecologically responsible use of this species. This will also be in alignment with government's objectives and policies around aquaculture development, apart from the fact that it will create employment, rare skills and local economic activity.

Several measures have been proposed for the monitoring and mitigation of the potential risks, and these could be included as conditions related to the issue of permits. It should however be noted that current production is limited to a single commercial farm (Smiling Valley) with a few experimental populations in different localities.

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1. INTRODUCTION

This Biodiversity Risk and Benefit Assessment (BRBA) pertain to the import, propagation and grow out of Smooth Marron (*Cherax cainii*) and Hairy Marron (*Cherax tenuimanus*) in South Africa.

The BRBA has been structured in accordance with the framework provided in the Alien and Invasive Species (AIS) Regulations (Government Notice R 598 of 01 August 2014), promulgated in terms of Section 97(1) of the National Environmental Management: Biodiversity Act 10 of 2004 (NEMBA).

2. PURPOSE OF THIS RISK ASSESSMENT

The purpose of this BRBA lies primarily in providing an information framework that can aid in determining the ecological risks and potential benefits of importing, propagating and growing Marron in South Africa. This framework sets out to provide information to assist decision making regarding the use and permitting of this species.

The BRBA aims to accurately depict the potential ecological risks associated with importing, propagating and growing Marron, and to evaluate these risks in determining possible justification through allowance by permitting.

Although this BRBA has been prepared to meet the requirements for risk assessments in terms of the AIS Regulations, promulgated in terms of NEMBA, it illustrates overarching generic information at a national level relevant to South Africa. The intension is that this framework be used as a decision support tool, for existing and future entrants into the sector, to which project- and site-specific information must be added when regulatory approval is sought for the import, propagation and grow out of Marron.

The main objectives of this BRBA are:

- To determine the primary risks associated with the import, propagation and grow out of Marron in South Africa.
- To determine the potential benefits associated with the import, propagation and grow out of Marron in South Africa.
- To provide key information related to the characteristics of Marron for risk and benefit analysis.
- To show the pathways that facilitate risks.
- To illustrate the risks in terms of probability of occurrences, degree of severity (magnitude), extent (scale or scope), longevity (permanence), confidence of the analysis and the potential for mitigation and monitoring.
- To illustrate areas of uncertainty in the determination of risk (confidence).
- To determine whether the ecological risk profile is acceptable in terms of the environment in which these risks will occur.
- To use the determined risk factors to provide guidance around decision making and mitigation.
- To use the determined risk factors to provide guidance to monitoring, research needs and ongoing risk communication.

3. THE RISK ASSESSMENT PRACTITIONER

The BRBA was originally prepared by Dr Barry Clark of Anchor Environmental. It has been reviewed, updated and recompiled by Mr. E. Hinrichsen from AquaEco (as commisioned by Nuleaf Planning and Environmental). Both authors meet the criteria for risk assessment facilitators (as per Section 15 of AIS Regulations), in that:

- They have practised as environmental assessment practitioners.
- They are independent.
- They are knowledgeable insofar as the NEMBA, the AIS Regulations and other guidelines and statutory frameworks that have relevance, are concerned.
- They are experienced in biodiversity planning in the aquaculture sector and have conducted a range of biodiversity risk assessments.

- They comply with the requirements of the Natural Scientific Professions Act 27 of 2003, and are registered as Professional Natural Scientists with the South African Council for Natural Scientific Professions (SACNASP).

4. NATURE OF THE USE OF MARRON

Marron, otherwise known as freshwater crayfish, was formally considered a single species, but is now recognised as comprising two species; the Smooth Marron (*Cherax cainii*) that was named in 2002 (Austin and Ryan, 2002) and which is known in South African aquaculture, and the critically endangered Hairy Marron (*Cherax tenuimanus*) that retained the original scientific name and which occurs in the Margaret River of south-west Australia.

Marron has been used as an aquaculture species on every continent except Antarctica (interpreted from the IUCN Red List of Threatened Species: Maps, 2017). Farming methods range widely, but these freshwater crustaceans are typically cultured in earthen ponds, albeit that culture in tanks and other artificial systems is possible. Water quality can be managed through partial exchange and through management interventions such as aeration. In the culture environment protection from predation is essential and is typically done using bird netting, solid and electric fencing.

Today, the use of Marron for aquaculture is the only distinct user group that can be identified in South Africa, albeit that an illicit aquarium trade may exist due to the novelty of the species. No confirmed invasion of this species has taken place in South Africa, albeit that other freshwater crayfish species such as Australian Redclaw (*C. quadricarinatus*) have established invasive feral populations.

5. REASONS FOR FARMING WITH MARRON

The FAO estimates that by 2030, fish farming will dominate global fish supplies. With aquaculture already providing more than half of the global seafood demand, it is now considered likely that marine harvesting and terrestrial rangeland farming has reached its capacity in many parts of the world. Aquaculture and intensified agriculture remains the only alternative to supplying a growing food need, fuelled by an increasing global population.

Although the FAO State of World Fisheries and Aquaculture Report (2016) found that Africa accounted for only 2.32 % of global aquaculture production in 2014, the FAO State of World Fisheries and Aquaculture Report (2014) highlighted that Africa showed the fastest continental growth in average annual aquaculture production (11.7 %) between 2000 and 2012. This growth will increasingly lead to the expansion of aquaculture on the African Continent, and particularly in South Africa.

The historical development of aquaculture in South Africa has been slow, and several initiatives have failed. However, South Africa is participating in this global shift that is driven by demand, market and industry globalisation, and rapidly expanding application of advanced agriculture technologies.

The National Aquaculture Policy Framework for South Africa (2013) was developed in reaction to a realization that the country is faced with rapidly diminishing marine fish stocks, an increasing demand for seafood and a developing global aquaculture sector that has become a significant agro-economic driver and food production alternative.

Marron, while alien to South Africa, is one of a range of freshwater crayfish species that are farmed worldwide, mainly for niche or high value markets. Other species such as the Australian Redclaw (*C. quadricarinatus*), the Australian Yabby (*C. destructor*) and the Danube Crayfish (*Astacus leptodactylus*) contribute to a freshwater crayfish sector that is dominated by the North American Red Swamp Crayfish (*Procambarus clarkii*), and which produced almost 800 thousand tons in 2015, worth around 3.6 billion USD (FAO Global Aquaculture Production, 2016).

Current South African production of Marron is consumed exclusively on the local market (Bursey, pers. comm.). Considering a range of challenges, some authors have raised concerns in the past as to the viability of freshwater crayfish farming in South Africa (Schoonbee 1993, Mikkola 1996 and Copeland 1999). However, despite the high set up costs and development setbacks, farms can be profitable (Burgess, 2007). Other freshwater crayfish species such as the Australian Redclaw (*C. quadricarinatus*) and the

Australian Yabby (*C. destructor*) may prove to be more viable in farming (Schoonbee, 1993), but could pose greater risks to the environment.

Although it is unlikely that Marron farming will expand rapidly in South Africa, the illicit distribution of all potentially invasive freshwater crayfish species could contribute to an increased potential for ecological risks associated with aquaculture and the aquarium trade.

6. LEGAL CONTEXT

The Department of Environmental Affairs (DEA) is the mandated authority over the National Environmental Management: Biodiversity Act 10 of 2004 (NEMBA), which sets out the framework, norms, and standards for the conservation, sustainable use, and equitable benefit-sharing of South Africa's biological resources. The AIS Regulations and the AIS List (Government Notice R 864 of 29 July 2016) have been promulgated in terms of this Act, providing enabling instruments for the Act.

These statutory frameworks recognise and categorise indigenous and alien species, some of which have the potential to become invasive when introduced into areas where they did not occur historically. A range of human activities that could potentially cause the spread and introduction of these alien species into non-native areas, are referred to as restricted activities.

6.1. CATEGORIZATION OF ALIEN AND INVASIVE SPECIES

Collectively the NEMBA, the AIS Regulations and the AIS Lists, categorise alien and invasive species, and prescribe the approach that should be taken to each category:

- **Exempted Alien Species** mean an alien species that is not regulated in terms of this statutory framework - as defined in Notice 2 of the AIS List.
- **Prohibited Alien Species** mean an alien species listed by notice by the Minister, in respect of which a permit may not be issued as contemplated in section 67(1) of the Act. These species are contained in Notice 4 of the AIS List, which is

referred to as the List of Prohibited Alien Species (with freshwater invertebrates in List 10 of Notice 4).

- **Category 1a Listed Invasive Species** mean a species listed as such by notice in terms of section 70(1)(a) of the Act, as a species which must be combatted or eradicated. These species are contained in Notice 3 of the AIS List, which is referred to as the National Lists of Invasive Species (with freshwater invertebrates in List 9 of Notice 3).
- **Category 1b Listed Invasive Species** mean species listed as such by notice in terms of section 70(1)(a) of the Act, as species which must be controlled. These species are contained in Notice 3 of the AIS List, which is referred to as the National Lists of Invasive Species (with freshwater fish in List 9 of Notice 3).
- **Category 2 Listed Invasive Species** mean species listed by notice in terms of section 70(1)(a) of the Act, as species which require a permit to carry out a restricted activity within an area specified in the Notice or an area specified in the permit, as the case may be.
- **Category 3 Listed Invasive Species** mean species listed by notice in terms of section 70(1)(a) of the Act, as species which are subject to exemptions in terms of section 71(3) and prohibitions in terms of section 71A of Act, as specified in the notice.

6.2. STATUTORY CLASSIFICATION OF MARRON

With reference to Notice 3, List 9 (National List of Invasive Fresh-water Invertebrate Species) in the AIS List (Government Notice R 864 of July 2016) and the categorization of alien and invasive species indicated in Section 5.1 above, Smooth Marron (*Cherax cainii*) and Hairy Marron (*Cherax tenuimanus*) is categorized as follows:

- Category 2 (*compulsory permitting*) for aquaculture facilities.

Further prohibitions that apply to Marron, include:

- Catch and release is prohibited.

This points to Marron as being classified in Category 2 as this relates to the general import, propagation and grow out thereof for aquaculture.

Note that the Australian Yabby (*C. destructor*) and Danube Crayfish (*Astacus leptodactylus*) is categorised as 1a (requiring combat or eradication) and the Australian Redclaw (*C. quadricarinatus*) as 1b (requiring compulsory control), while the North American Spiny Cheek Crayfish (*Orconectes limosus),* the Rusty Crayfish (*Orconectes rusticus*), the North American Signal Crayfish (*Pacifastacus leniusculus*) and the Red Swamp Crayfish (*Procambarus clarkii*) are all prohibited in South Africa.

6.3. LIST OF RESTRICTED ACTIVITIES

While Section 1 in Chapter 1 of the NEMBA defines the restricted activities in relation to alien and invasive species, these activities are expanded upon in Section 6, Chapter 3 of the AIS Regulations. These activities include:

<u>From the NEMBA:</u>

- Importing.
- Possessing (including physical control over any specimen).
- Growing, breeding or in any other way propagating or causing a specimen to multiply.
- Conveying, moving or otherwise translocating.
- Selling or otherwise trading in, buying, receiving, giving, donating or accepting as a gift, or in any way acquiring or disposing of any specimen.

<u>From the AIS Regulations:</u>

- Spreading or allowing the spread of any specimen.
- Releasing.
- Transferring or release of a specimen from one discrete catchment in which it occurs, to another discrete catchment in which it does not occur; or, from within a

part of a discrete catchment where it does occur to another part where it does not occur as a result of a natural or artificial barrier.

- Discharging of or disposing into any waterway or the ocean, water from an aquarium, tank or other receptacle that has been used to keep a specimen or a listed invasive freshwater species.
- Catch and release of a specimen of an invasive freshwater fish or an invasive freshwater invertebrate species.
- Releasing of a specimen of an invasive freshwater fish species, or of an invasive freshwater invertebrate species into a discrete catchment system in which it already occurs.

All the restricted activities above could potentially apply to the import, propagation and grow out of Marron in South Africa. However, import will be excluded where stock is obtained locally (i.e. from local producers), while intentional release generally does not apply to the use of Marron for aquaculture.

7. TARGET SPECIES: MARRON

7.1. TAXONOMY

Common Name: Marron

Kingdom:	*Animalia*
Subkingdom:	*Bilateria*
Infrakingdom:	*Deuterostomia*
Phylum:	*Arthropoda*
Subphylum:	*Crustacea*
Infraphylum:	*Crustaceomorpha*
Superclass:	*Multicrustacea*
Class:	*Malacostraca*
Subclass:	*Eumalacostraca*
Superorder:	*Eucarida*
Order:	*Decapoda*

Suborder:	*Pleocyemata*
Infraorder:	*Astacidae*
Superfamily:	*Parastacoidea*
Family:	*Parastacidae*
Genus:	*Cherax*
Species:	Smooth Marron: *C. cainii* (Austin and Ryan, 2002) Hairy Marron: *C. tenuimanus* (Smith, 1912)
Other Names:	Freshwater Crayfish, Marron Crayfish
Synonyms:	*Chaeraps tenuimanus (*Smith, 1912)

Since Marron was first described in 1912, the taxonomy of the species has been in dispute, but genetic studies have demonstrated that the species is not homogenous and consists of two distinct forms (Austin & Ryan 2002). However, the dispute remains, with some proposals to re-combine these species, for functional clarity but not for taxonomic similarity (Molony et al. 2006).

7.2. ORIGINATING ENVIRONMENT

Marron is endemic to south-western Australia, where they live in deep pools of clear, flowing rivers (Merrick and Lambert 1991, Mosig 1998, Wingfield 1998). They prefer a sandy substrate with adequate shelter from predators and access to accumulated organic matter, but can survive in a variety of habitats (TSSC 2005). They are generally found in well oxygenated waters between 17.5°C and 24.5°C (Bryant and Papas 2007).
The Smooth Marron (*C. cainii*) has been widely redistributed in Australia and established feral populations in several areas (Austin and Ryan 2002). In addition, this species has been translocated to North America (Merrick and Lambert 1991), New Zealand (McDowall 1988), South Africa, Japan, Zimbabwe, China, Chile and the Caribbean (Lawrence and Morrissy 2000), and most likely to a range of other countries. It has a status of *Least Concern* in the IUCN Red List of Threatened Species (2017).

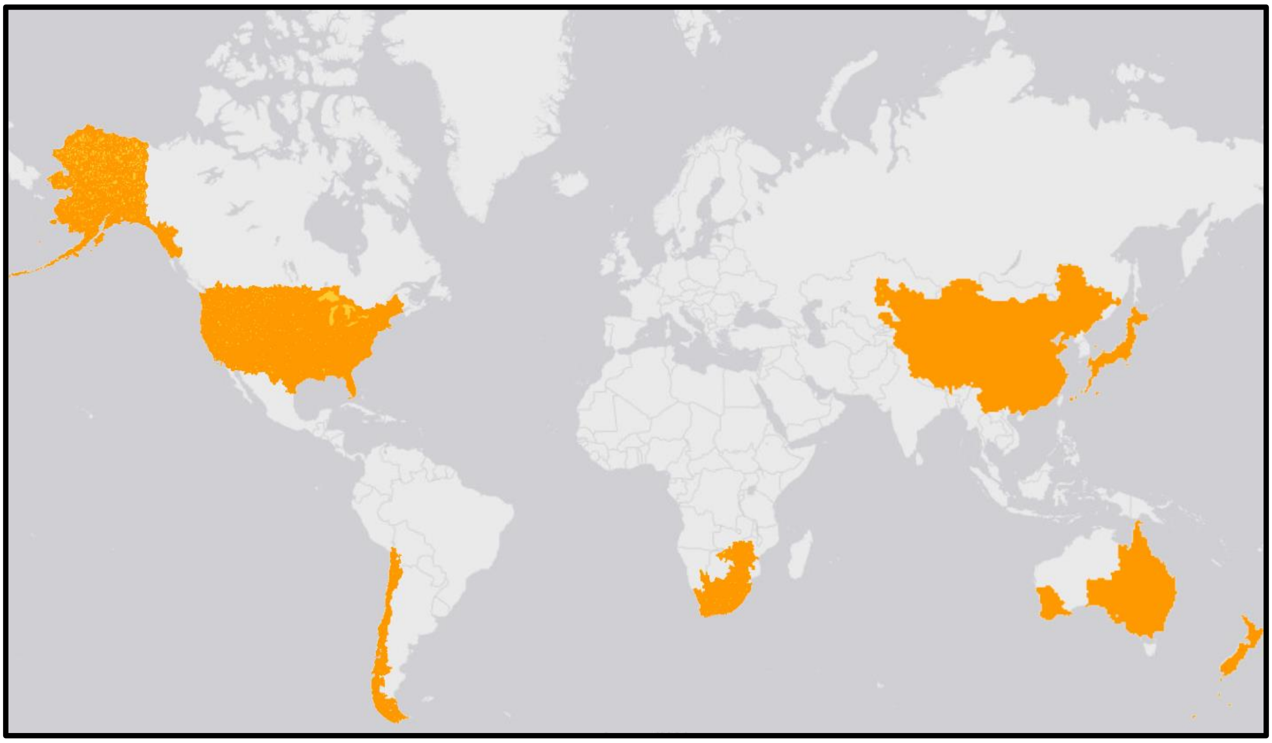

Figure 1: Global map showing the occurrence of Marron (Cherax caini). The native range is located in south-west Australia (IUCN).

The Hairy Marron (*C. tenuimanus*) has a status of *Critically Endangered* in the IUCN Red List of Threatened Species (2017) and is restricted to the upper reaches of the Margaret River (Morgan and Beatty 2005, Bunn 2004). This population is in decline and is suffering from genetic introgression through hybridization with the Smooth Marron (*C. cainii*), which could lead to its ultimate extinction.

7.3. KEY PHYSIOLOGICAL CHARACTERISTICS

Marron is the third largest freshwater crayfish species in the world (Riek 1967; Austin and Knott 1996), and has a robust carapace that is divided into a head, thorax and segmented abdomen that end in a tail fan. The head has two protruding eyes, two sets of smaller compound feelers, a pair of long feelers and a subterminal mount. A large prominent pair of pinchers is attached anterolaterally to the thorax, followed by 2 smaller pairs of pinchers and two pairs of legs.

Marron have a distinct prominence running back from the postorbital spine. The rostrum is characterised by lateral serrations present on both sides, that ends in a sharp spine

(Picker & Griffiths 2011). They have two raised longitudinal ridges extending backwards from behind the eyes; two raised ridges extending backwards from each edge of the rostrum; and one raised ridge in the middle of the two raised rostral ridges (five ridges in total). These crustaceans can grow to approximately 40 cm and weigh up to 2.5 kg (Picker & Griffiths 2011).

Marrons are commonly black, olive or brown in colour, but can range naturally from brick red to electric blue.

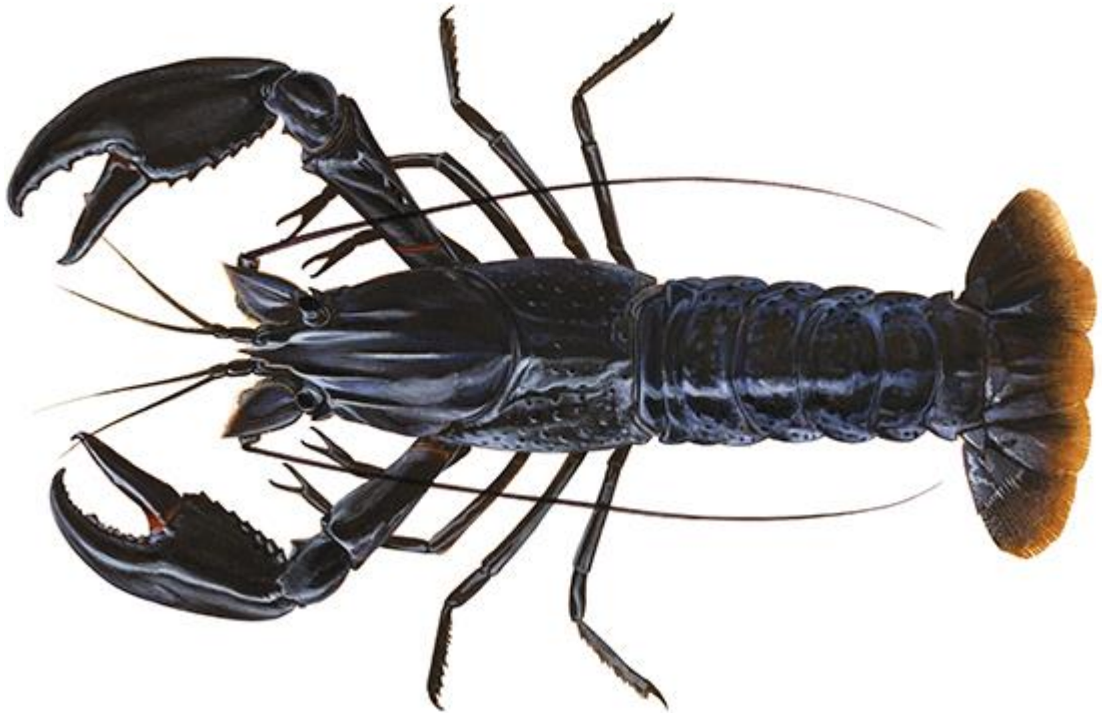

Figure 2: Freshwater Marron (Cherax cainii).

7.4. REPRODUCTION

Records indicate that Marron can breed annually in spring from their second or third year (Safriel & Bruton 1984, de Moor & Bruton 1988). Unlike other *Cherax* species, Marron does not spawn more than once in a season (Beatty *et al.* 2005).

The number of eggs produced per individual ranges from 90 to 900 and depends on the size of the female (Coetzee 1985). Eggs are carried by the female beneath its tails (pleopods) for a period of twelve to sixteen weeks, where after they hatch and undergo two development stages (de Moor & Bruton 1988), while remaining attached to the female. The entire life cycle is completed within freshwater (Cubitt 1985).

The life history characteristics (e.g. body size, life span, time to sexual maturity and reproductive frequency) of Marron classifies it as a K-selected species (de Moor 2002 and Beatty *et al.* 2005).

7.5. DIETARY ASPECTS

Juvenile Marron feed mainly on zooplankton, while adults are primarily benthic detritovores, scavenging on dead plants and other forms of organic detritus (Read 1985). However, they will consume living aquatic plants (Coetzee 1985). In their natural habitat, their main sources of nutrition are the microbes (including bacteria and fungi) that break down plant matter. As opportunistic omnivores they will eat small invertebrates, aquatic insects, fish eggs and fish larvae if they get hold of these. Large Marron will cannibalise on juveniles.

Through stable isotope analysis, Marron has been shown to be a keystone species in the Hutt River, playing a key role in nutrient cycling and the aquatic food web (Beatty 2006).

Marrons are crepuscular, meaning they are most active just after sunset.

7.6. ENVIRONMENTAL TOLERANCES

Marron require good quality water, with minimal environmental disturbance (TSSC 2005), while sudden fluctuations in pH, low dissolved oxygen levels (< 5 ppm) or low concentrations of pollutants such as pesticides and herbicides can lead to mass mortalities (Bursey, pers. comm.).

Marron is a temperate water species, growing best at 17 - 24 °C (Read 1985 and Morrissy 1990), but will tolerate temperatures as high 30°C and as low as 8°C, with outer lethal limits at 6 °C and 32°C respectively. Adults are more resilient to low water temperatures (Cubitt 1985), while tolerance to higher and lower temperatures diminish during moulting.

Marron can tolerate salinities of up to 20 ppm under laboratory conditions, but field results suggest that they can tolerate up to 12 ppm, (full strength seawater is 35 to 38 ppm) (ACS Distance Education 2017).

Marron prefer slightly acidic waters and the target range for ideal culture conditions range from a pH of 5.0 to 6.5 (Safriel & Bruton 1984). Water hardness below 50 mg/l can cause the carapace to become soft, increasing their vulnerability.

Similar to other crayfish species, Marron can survive out of water for several days (Ackefors & Lindqvist 1994).

7.7. NATURAL ENEMIES, PREDATORS AND COMPETITORS

In Australia an extensive range of freshwater crayfish species share a common life history strategy, although many were historically separated. Many of these species have been translocated and although each occupies a slightly different ecological niche, the level of competition is high; leading to certain species becoming endangered. Marron and the Yabby (*C. destructor*) were found to have a similar diet and trophic position (Beatty 2006), while Marron can outcompete several other crayfish species (Bryant and Papas 2007). Smooth Marron (*C. cainii*) successfully outcompetes the Hairy Marron (*C. tenuimanus*) for resources and through generic introgression and hybridization in much of the Margaret River.

Marron are prone to high levels of predation, especially where waters are clear and shelter from predators is scarce. They are eaten by a variety of water birds, predatory mammals that associate with water, turtles and fish (Tay *et al*. 2007). On the Smiling Valley Marron farm near East London (South Africa) predation is reported from frogs and crabs (Bursey, pers. comm.), while it is likely that they will be prone to predation by otters, crocodiles and monitor lizards.

7.8. POTENTIAL TO HYBRIDISE

Smooth Marron (*C. cainii*) hybridises readily with Hairy Marron (*C. tenuimanus*) in the Margaret River in Australia. There are however no records of Marron hybridising with other freshwater crayfish species, albeit that hybridisation within the *Cherax* genus may be possible.

The genus *Cherax* is not native to African waters, and thus there are no indigenous species in the environment that could provide the basis for reproductively compatible populations through hybridisation (de Moor 2002).

7.9. PERSISTENCE AND INVASIVENESS

The major factors limiting the distribution of Marron in South Africa are water quality and predation. Where these crayfish are introduced into a suitable habitat with less predatory pressures, they may become established. However, no invasion has been reported in the areas where Marron have historically been farmed and kept in South Africa, even though some escape would most likely have occurred. Although freshwater crayfish (across all species) have been reported as high-impact invaders that can cause serious negative environmental impacts, no detailed information exists on freshwater crayfish distribution, abundance and impacts in South Africa (Nunes *et.al.* 2016).

In the compilation of this risk assessment, it was found that the invasive potential of all alien freshwater crayfish in South Africa is often considered to be similar across species, which is not the case. Species such as the Red Swamp Crayfish (*P. clarkii*) and the Australian Redclaw Crayfish (*C. quadricarinatus*) are highly invasive.

Although this assessment has been compiled for the import, propagation and grow out of Marron, it is noteworthy that some alien freshwater crayfish species that occur in South Africa can disrupt aquatic plant growth, decimate smaller aquatic invertebrates and cause structural damage by burrowing. The Red Swamp Crayfish (*P. clarkii*) was introduced into Kenya's Lake Naivasha in 1970, causing the destruction of aquatic vegetation, decimation of habitat for fish and a reduction in native snails and freshwater crabs, while affecting the livelihoods of fishermen through feeding off fish in gill nets and disturbing the breeding of some fish species (Nunes 2016).

Globalisation has contributed to the spread of many aquaculture species, with introduced species being marketed worldwide, and modern transport options allowing for the relocation of species across physical barriers (Cambray 2003). Although Marron can move downstream by flow, and although they can walk upstream and even across short distances on land, the primary dispersal mechanisms is through human actions when they are moved for aquaculture and the aquarium trade.

Marron is not known to be a burrowing crayfish (Beatty *et al.* 2005). This, together with the fact that the species has failed to become established outside of artificial systems in South Africa, renders its invasive potential and risk to the environment relatively low.

7.10. HISTORY OF TRANSLOCATION AND CULTIVATION

Marrons were first grown in Australia in farm dams in the 1960's, before more serious efforts were made to improve their culture methods. This accumulation of practical knowledge represented the beginning of the freshwater crayfish industry. In 1976 legislation was passed to allow the farming of marron and by 1995 total production stood at approximately 18 tons per annum, between 31 licensed growers. In the 1990's changes to legislation and ongoing improvements to farming techniques made commercial farming more efficient and saw production increase to approximately 42 tons per annum at the turn of the century from around 250 license holders in Western Australia (ACWA 2012).

Under culture conditions Marron can yield 2 to 3 tons/ha/annum (Read 1985) but under natural conditions in Australia they attain densities of 400 - 600 kg/ha/annum (de Moor & Bruton 1988). Marron is generally market ready when it reaches a weight of 75-125 g (de Moor 2002).

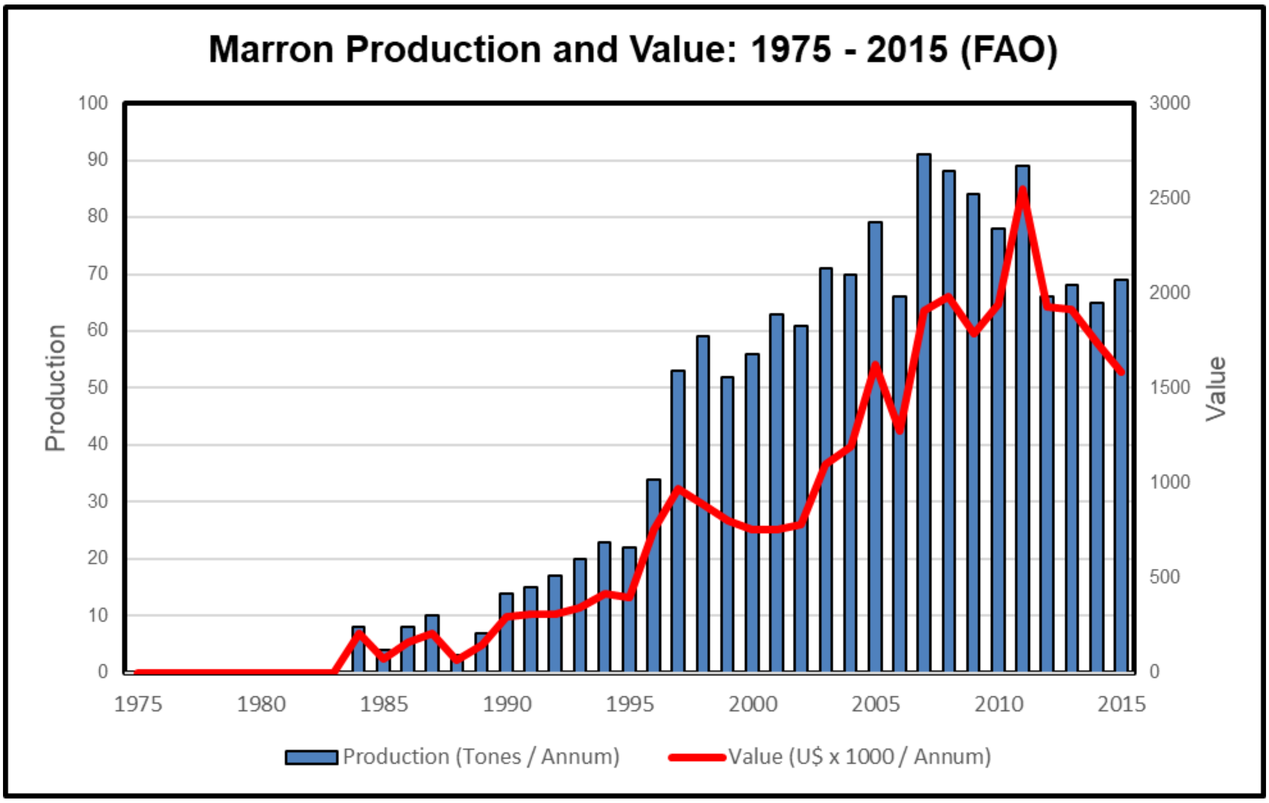

Figure 3: International production of Marron in tonnage and value between 1975 and 2015 (FAO - Fisheries and Aquaculture Information and Statistics Service).

Marron was first introduced into the then Natal Province of South Africa in 1976 by a private fish farmer (Borquin *et al*., 1984). In 1982, the first successful farm was established in George (de Moor & Bruton, 1988). They were also kept at the Pirie Hatchery in King Williamstown, where they managed to escape into the Buffalo River. However, this population did not become established (Picker & Griffiths, 2011). There are anecdotal reports of it being found in small streams at Nieu-Bethesda near Graaff-Reinet during the mid-1990's (R. Scott, pers. Comm.), and at Madam Dam, near Stutterheim (de Moor & Bruton, 1988), but it is unclear whether these were viably reproducing populations.

Subsequently, a commercial farm was established in Hoekwil near Knysna and Paarl in the Western Cape, both of which have since closed. By 2010 the total Marron production in South Africa was reported as being 0.8 tons per annum (DAFF 2012a), reaching 5 tons per annum by 2013 (DAFF 2014), and remaining at 5 tons per annum into 2015 (FAO Global Aquaculture Production 2016). This production was ascribed to a single commercial farm at Smiling Valley near East London in the Eastern Cape. Other than this farm, a research population is currently maintained in Roodeplaat near Pretoria, and it is possible that other isolated populations exist.

7.11. ABILITY TO CREATE ECOSYSTEM CHANGE

Escapees from aquaculture facilities are inevitable and occur worldwide, unless appropriate mitigatory methods are applied. Yet, the escape of Marron into South African waters has not led to the survival of a viable feral population (Nunes pers. comm.)

Although Marrons are benthic detritovores (Read 1985) they can feed on living aquatic plants and may feed opportunistically on small aquatic invertebrates as well as larvae and fish eggs. This can lead to alterations in the ecology, which can potentially affect fish recruitment and growth (Charlebois & Lamberti 1996). Marrons are also known to carry a range of parasites, which may affect indigenous crustaceans (see also Section 10.3.6 on Disease). Marron is not known to be a burrowing crayfish (Beatty *et al.* 2005).

Through an ecological knock-on effect these aspects could lead to extended ecosystem changes, yet the fact that Marron has not established viable populations in South African waters renders these changes of low risk. In the event of feral establishment, the impact on the physical or abiotic characteristics of any habitat is likely to be limited and complete ecosystem dysfunction is highly unlikely.

7.12. PROBABILITY OF NATURALISATION

The use of Marron for aquaculture may lead to the escape of the species into the wild. As indicated above, Marron has historically escaped from aquaculture facilities in the Eastern Cape, but no feral populations have been found downstream in the Buffalo River (de Moor & Bruton 1988). Nevertheless, there are areas of the country that have water bodies with parameters within the tolerance thresholds of Marron. Coetzee (1985) concluded that the species would be able to survive in the Western Cape should it escape.

It is probable that viable feral populations of Marron could become established if released into the upper and mid reaches of many perennial rivers where temperatures are moderate and dissolved oxygen levels sufficient. However, it is unlikely that they would become a significant invasive threat as they are susceptible to predation from otters, water mongoose and cormorants (Coetzee 1985, de Moor & Bruton 1988).

7.13. POSSIBLE IMPACTS ON BIODIVERSITY AND NATURAL RESOURCES

The possible impacts of Marron on biodiversity depend on the habitat type. These potential impacts include:

- Marron can outcompete certain freshwater crayfish species for food and habitat and it is therefore conceivable that they would be able to compete with certain indigenous detritus feeding crabs in South African waters. This is only possible in suitable habitat types, in which susceptible native species occur.
- Although Marron are benthic detritivores (Read 1985), they can feed opportunistically on aquatic invertebrates such as insects and snails, as well as eggs and larvae of fish.
- Marron may affect the growth and abundance of aquatic macrophytes through feeding and disturbance.
- Marron is known to carry a range of parasites, which may affect indigenous crustaceans (see also Section 10.3.6 on Disease).

Although the impacts of Marron in South African may be limited, the risk assessment process considers the potential general impacts on biodiversity, through related ecological consequences and extended tropic disturbances.

The possible impacts of Marron on other natural resources is restricted as they are unlikely to impact on any fisheries resources in the unlikely event of a feral population becoming established in South African waters.

7.14. MARRON AS A VECTOR OF OTHER ALIEN SPECIES

The uncontrolled movement of Marron from one area to another may result in the introduction of other species and parasites, if care is not taken with regards to ensuring that other similar looking crayfish species are excluded. This is unlikely to happen under controlled hatchery conditions where Marron are handled as a specific species. However, given the presence of invasive populations of Red Swamp Crayfish (*P. clarkii*) and the Australian Redclaw Crayfish (*C. quadricarinatus*) in South Africa, the reckless and negligent movement of these species for aquaculture or for the aquarium trade may occur, perhaps even under pretention of being the less invasive Marron.

8. THE RECEIVING ENVIRONMENT

As a national framework document, this risk assessment cannot report on the receiving environment for specific areas, and on specific Marron projects or restricted activities. Nationally, the entire South Africa is seasonally within the lethal temperature tolerance range for Marron, meaning that this species would be able to survive in any waterway in South Africa during certain seasons, if not year-round. Other factors such as dissolved oxygen levels and predation however also a significant role play in the potential for this species to survive.

8.1. CLIMATE AND HABITAT MATCH

In South Africa, several habitat types are potentially suited to the naturalisation of Marron. As water temperature, oxygen levels and predation are primary determinants for the survival of Marron it is impossible to accurately determine all areas in which this species could establish viable populations.

The compatibility of this species to local environmental conditions was evaluated by comparing the ambient annual temperature ranges of the 31 terrestrial ecoregions of South Africa (Kleynhans *et al.* 2005) to the temperature tolerance ranges for Marron, to determine the areas that could potentially be suitable to naturalisation from a temperature perspective. In this coarse analysis, it was found that Marron could seasonally survive in all the ecoregions, but that the minimum mean annual temperature in the Eastern Escarpment Mountains would severely limit survival. The probability of establishment however ranges and is not evenly distributed, even within an ecoregion.

In this BRBA is it important to recognise that aquaculture with Marron can be practised in systems in which temperatures can be regulated. This means that Marron farming can be practised successfully in areas outside of the environmental range in which they would be able to survive in open waterbodies.

The invasive potential of Marron has been assessed in accordance with the European Non-Native Species Risk Analysis Scheme (ENSARS) (Copp *et al.* 2008) developed by the CEFAS (UK Centre for Environment, Fisheries & Aquaculture Science). ENSARS provides a structured framework (Crown Copyright 2007 - 2008) for evaluating the risks of escape, introduction to and establishment in open waters, of any non-native aquatic organism being used in aquaculture. For each species, 49 questions are answered, providing a confidence level and justification (with source listed) for each answer. The outcome of the scoring was that Marron should be further evaluated before introductions are made. This risk assessment and the assessments that are required for permitting of specific projects is therefore justified.

The questions and results of the assessment are attached in Appendix A.

Table 1: Altitude and Ambient Temperature in the Ecoregions of South Africa (Kleynhans et al. 2005).

Ecoregion	Altitude (m.a.s.l)	Temperature range (°C)	Mean annual temp (°C)
1. Limpopo Plain	300-1100 1100-1300 limited	2 to 32	18 to >22
2. Soutpansberg	300-1700	4 to 32	16 to >22
3. Lowveld	0-700 700-1300 limited	4 to 32	16 to >22
4. North Eastern Highlands	300-1300 1300-1500 limited	2 to 32	16 to 22
5. Northern Plateau	900-1500 1500-1700 limited	2 to 30	16 to 20
6. Waterberg	700-900 limited 900-1700	2 to 32	14 to 22
7. Western Bankenveld	900-1700	0 to 32	14 to 22
8. Bushveld Basin	700-1700 1700-1900 very limited	0 to 32	14 to 22
9. Eastern Bankenveld	500-2300	0 to 30	10 to 22
10. Northern Escarpment Mountains	500-900 limited 900-2300	0 to 30	10 to 22
11. Highveld	1100-2100 2100-2300 very limited	-2 to 32	12 to 20
12. Lebombo Uplands	0-500	6 to 32	18 to >22
13. Natal Coastal Plain	0-300	8 to 32	20 to >22
14. North Eastern Uplands	0-100 limited 100-1500	0 to 30	14 to >22
15. Eastern Escarpment Mountains	1100-3100 3100-3500 limited	<-2 to 28	<8 to 18
16. South Eastern Uplands	300-500 limited 500-1700 1700-2300 limited	0 to 30	10 to 22
17. North Eastern Coastal Belt	0-700	4 to 30	16 to 22
18. Drought Corridor	100-300 limited 300-1900 1900-2100 limited	-2 to 30	10 to 20
19. Southern Folded Mountains	0-300 limited 300-1900 1900-2100 limited	0 to 32	10 to 20
20. South Eastern Coastal Belt	0-500 500-1300 limited	2 to 30	12 to 20
21. Great Karoo	100-300 limited 300-1700 1700-1900 limited	0 to >32	10 to 20
22. Southern Coastal Belt	0-700 700-1500 limited	4 to 30	10 to 20
23. Western Folded Mountains	100-300 limited 300-1700 1700-2500 limited	0 to >32	10 to 20
24. South Western Coastal Belt	0-300 300-900 limited	4 to 32	10 to 20
25. Western Coastal Belt	0-700 700-1100 limited	2 to >32	16 to 20
26. Nama Karoo	300-1700 1700-1900 limited	0 to >32	12 to 20
27. Namaqua Highlands	100-1300 1300-1500 limited	2 to 32	12 to 20
28. Orange River Gorge	0-1100	2 to >32	16 to 22
29. Southern Kalahari	500-1700 1700-1900 limited	-2 to >32	14 to 22
30. Ghaap Plateau	900-1700	0 to 32	16 to 20
31. Eastern Coastal Belt	0-500 500-900 limited	4 to 28	16 to 20

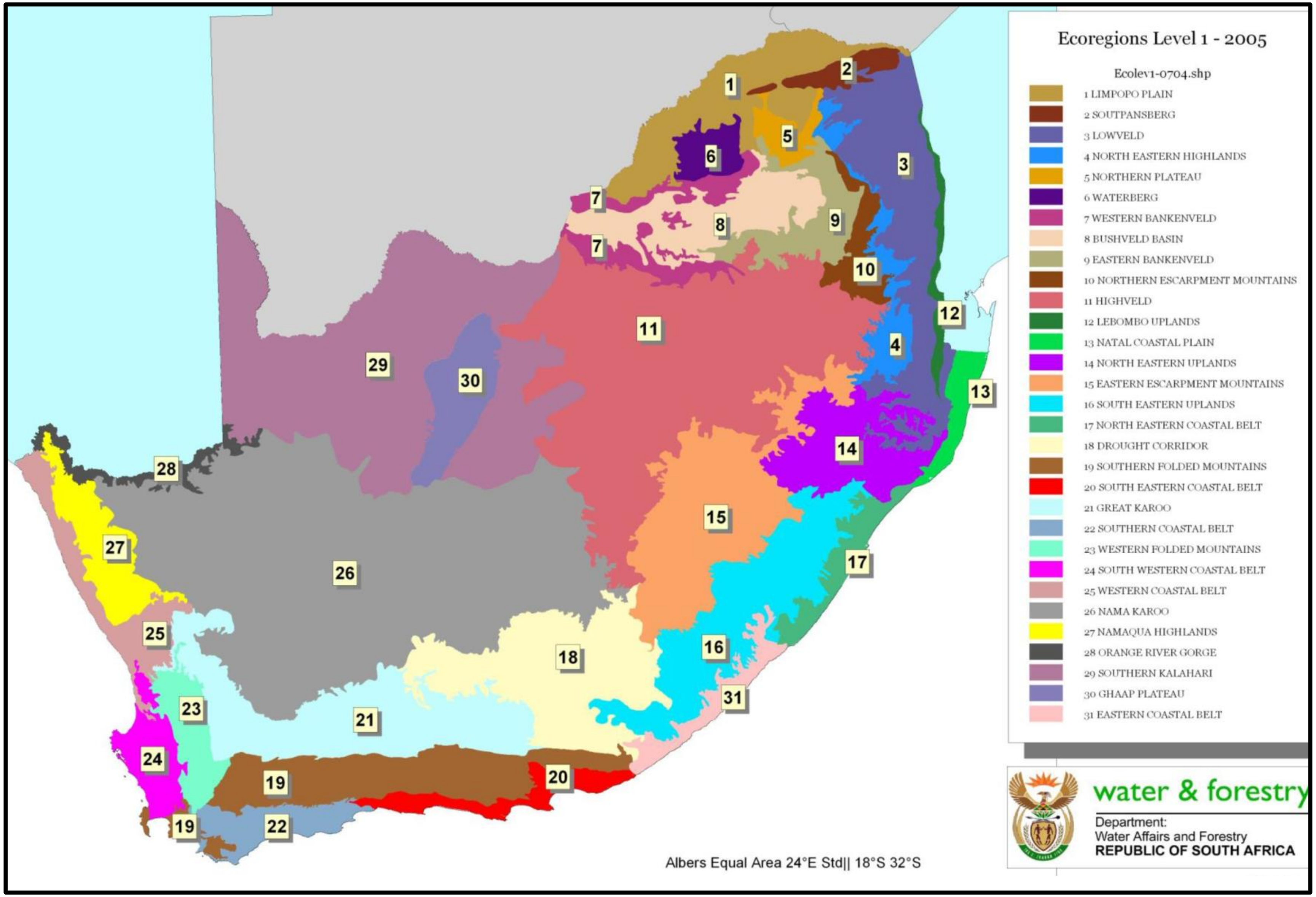

Figure 4: *Ecoregions of South Africa*

8.2. TOOLS TO IDENTIFY SENSITIVE AREAS

Many national and provincial conservation plans, biodiversity frameworks and mapped sensitive areas can be used to determine sensitive areas in which Marron may pose a biodiversity impact. These include, but are not limited to:

- The National Freshwater Ecosystem Priority Areas (NFEPA), which geographically identifies sensitive freshwater environments, including environments in which certain fish species are identified as sensitive.
- A range of geographic mapping tools are published by the South African National Biodiversity Institute (SANBI), through which proclaimed conservation areas, critical biodiversity areas and other sensitive habitats can be identified.
- Apart from general information that can be accessed from the National Department of Environmental Affairs (DEA), local and provision conservation authorities, and mandated provincial biodiversity authorities can provide local information of relevance.

9. THEORY BEHIND ECOLOGICAL RISK ASSESSMENT

Ecological Risk Assessment provides an effective tool for assessing environmental effects or actions, and aids in resource based and environmental decision making. The risk assessment approach is widely recognized and much of this document is based on internationally researched risk assessment principals. To this end, the process is well suited to the establishment of the BRBA framework for the import, propagation and grow out of Marron, in that it provides a platform from which decisions can be made and from which risks can be identified for management and monitoring.

The European Union (2000) defines risk as the probability and severity of an adverse effect or event occurring to man or the environment from a risk source. The assessment methods for such risks are widely used in many environments and for many diverse purposes. Through determining the interplay between uncertainty and variability, a risk assessment evaluates the likelihood that adverse ecological effects may occur as a result of one or more stressors. This likelihood of occurrence can be further defined in terms of temporal structure (longevity or permanence), severity, scope (scale), uncertainty and the respective potential for mitigation and monitoring.

McVicar (2004) describes risk analysis as "*a structured approach used to identify and evaluate the likelihood and degree of risk associated with a known hazard*". This is done with due cognizance of information or outcome uncertainties, so that it is generally accepted that higher levels of uncertainty correspond to higher levels of risk. It is, however, important to realise that uncertainty and probability are different elements in risk assessment, and that these in themselves stand distinguished from factors such as extent (scope and scale), significance (severity) and permanence.

The risk analysis process is built around the concept that some aspects of the activity under consideration can lead to the release of a hazard, which in turn could lead to a change in the environment. In the case of importing, propagating and growing Marron, an example would be the escape and survival of an alien species (the hazard) into the environment, potentially leading to impacts on indigenous biodiversity (the result or endpoint).

9.1. THE PRECAUTIONARY AND OTHER PRINCIPALS

The precautionary principle has emerged as a fundamental driver in risk assessment and has become a popular approach to deal with uncertainty in decision making. The United Nations 1992 Conference on Environment and Development referred to the precautionary principal as an approach in which "*the lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation*".

The precautionary principle was re-stated and internationally agreed in Principle 15 of the Rio Declaration of the UN Conference on Environment and Development (UNCED):

> "*In order to protect the environment, the precautionary approach shall be widely applied by States according to their capabilities. Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as*

a reason for postponing cost-effective measures to prevent environmental degradation".

The precautionary principal is often wrongly used as a "*trump card*" to legitimize arguments against development and environmental change. The precautionary principal is, however, a principal that removes the need for concrete scientific proof of cause and effect, and rather shifts the emphasis to responsible precaution based on logical analysis of risk and implementation of cost-effective mitigation measures.

The wide application of risk assessment also incorporates other principals, the most important of which are:

- Optimal management of risk can only occur where there is an open, transparent and inclusive process that integrates effective risk communication with hazard identification, risk assessment and risk management.
- Risk assessment is most valuable if considered together with social and economic impacts (positive and negative).
- The nature of a risk depends largely on the acceptable endpoint (acceptable level of change), which can be highly subjective.
- For risk management to be effective, acceptable endpoints should be measurable.
- Zero tolerance to environmental change is not practical in risk management.
- Specific risks should not be seen in isolation to risks associated with other activities in a common environment (risk proportionality).
- Risk assessment depends on effective and understandable communication of risk.
- Risk assessment must be consistent in the manner in which risks are determined and scaled.
- A risk does not exist if a causal pathway between the hazard and the endpoint is absent. The level of risk is however influenced by the nature of such a pathway.
- Risk assessment should lead to monitoring to improve understanding of the mechanisms leading to environmental change and the level of risk (increased or decreased).

- Risks should be identified along with the environmental change they may cause.
- Uncertainly is not a failing of risk assessment, but a characteristic which should be used in risk management.
- Cost benefit analysis should be used in risk management to logically determine the practicality, need and nature of risk mitigation measures.

9.2. METHODOLOGY IN THE RISK ASSESSMENT

In aquaculture, several risk assessment methodologies are used, each of which depict different levels of complexity and subjectivity (Burgman, 2005; Kapuscinski et al. 2007; Vose 2008; FAO, 2015). However, the interplay between likelihood and consequence to determine acceptability and management remains at the core of most methods.

Many risk assessment methods suffer from bias and these shortcomings must be managed (Burgman, 2001). Hayes *et al*. (2007) outline several ways to help maintain the scientific credibility of risk assessment (FAO, 2015).

Risk assessment is primarily made up of three phases, consisting of problem formulation, problem analysis and risk characterisation. The problem analysis phase can be further sub-divided into two distinct sections: characterisation of exposure and characterisation of effect.

Risk analysis provides an objective, repeatable, and documented assessment of risks posed by a particular course of actions or hazards. This BRBA framework depicts two methods to assess risk:

1. A step-by-step process expanded and modified from the aquaculture risk assessment work by Fletcher et al. (2002 and 2003), in which an inventory of potential risks is characterized and scored for probability, severity, scope, permanence, confidence, monitoring and mitigation; and
2. The European Non-Native Species Risk Analysis Scheme (ENSARS) (Copp *et al.,* 2008) developed by CEFAS (UK Centre for Environment, Fisheries & Aquaculture Science). ENSARS provides a structured framework (Crown

Copyright 2007-2008) for evaluating the risks of escape and introduction to, and establishment in open waters, of any non-native aquatic organism. For each species, 49 questions are answered, providing a confidence level and justification (with source listed) for each answer. The questions and results of the assessment on Marron can be found in Appendix A.

The following steps constitute the method that has been expanded and modified from the work by Fletcher et al. (2002 and 2003):

- Identification of risks and determination of endpoints (consequences). This is also referred to as problem formulation in risk assessment and determines what is at risk.
- Determination of the endpoints and the acceptability in endpoint levels (the level of acceptable change if a risk or stressor were to occur).
- Modelling of the risk pathway from hazard to endpoint (also called logical modeling).
- Assessing the risk by means of any information resources and experience. This can be divided into two distinct sections: the exposure assessment (nature of the risk / stressor) and effects assessment (nature of the endpoint or effect on the environment).
- Determination whether the risk has the potential to increase the probability of the endpoint occurring. If there is no such potential, such a risk can be eliminated from analysis.
- Describing the probability, intensity (severity) and scale (scope) of the risk to the environment (also called risk characterisation).
- Determining the level of uncertainty (confidence) in risk characterisation.
- Tabulating the findings according to intensity (severity or degree) of change, the geographical extent of the change (scope), and the duration or permanence of the change.
- Approximating the probability and the uncertainty.
- Addressing areas of weakness where the collated information appears incomplete or inadequate.

- Assessing the acceptability of the proposed activity through reference to the tabled analysis.
- Assessing the opportunity for risk mitigation and monitoring, and the need for additional research to reduce uncertainty.
- Effectively communicating risk in an on-going manner to all relevant stakeholders.

9.3. THE RISK PATHWAY

Before any risk can be characterised, the link between the hazard and the endpoint must be established. For any specific ecological risk to come to fruition and create an impact, a risk pathway is required. For example, in the case Marron, the ecological risk or hazard that these crustaceans could pose to the environment through competition with other species (example of an endpoint or impact) is directly linked to the pathway of escape from the facilities in which it is used or kept, into the surrounding water resources. The ecological endpoint is therefore facilitated and dependent on the physical pathway of escape. For this reason, each identified risk must be evaluated from its potential occurrence (the hazard), through the pathway and the resultant effects (the endpoint) thereof, as well as the mitigation measures that can be implemented to reduce the risk from occurring, or minimising any negative effects.

In aquaculture of Marron, only two pathways exist through which a risk can influence or impact on an endpoint. These are the pathway of escape and the pathway that facilitates the introduction or spread of a potential disease or parasite. It is therefore logical that the potential manifestation of species related ecological impacts or endpoints of the identified risk is eliminated if the potential for escape is eliminated (apart from disease).

Some confusion is caused by the fact that both the pathway (escape in the case of aquaculture with Marron) and the endpoint can be characterised and scored for probability, severity, scope, permanence, confidence, monitoring and mitigation. It is important that characterisation of the pathway be determined and presented separately, with due regard that a zero risk in occurrence of a pathway will render the risk of an endpoint invalid. However, a low risk in the pathway does not necessarily correlate with a low risk in the endpoint.

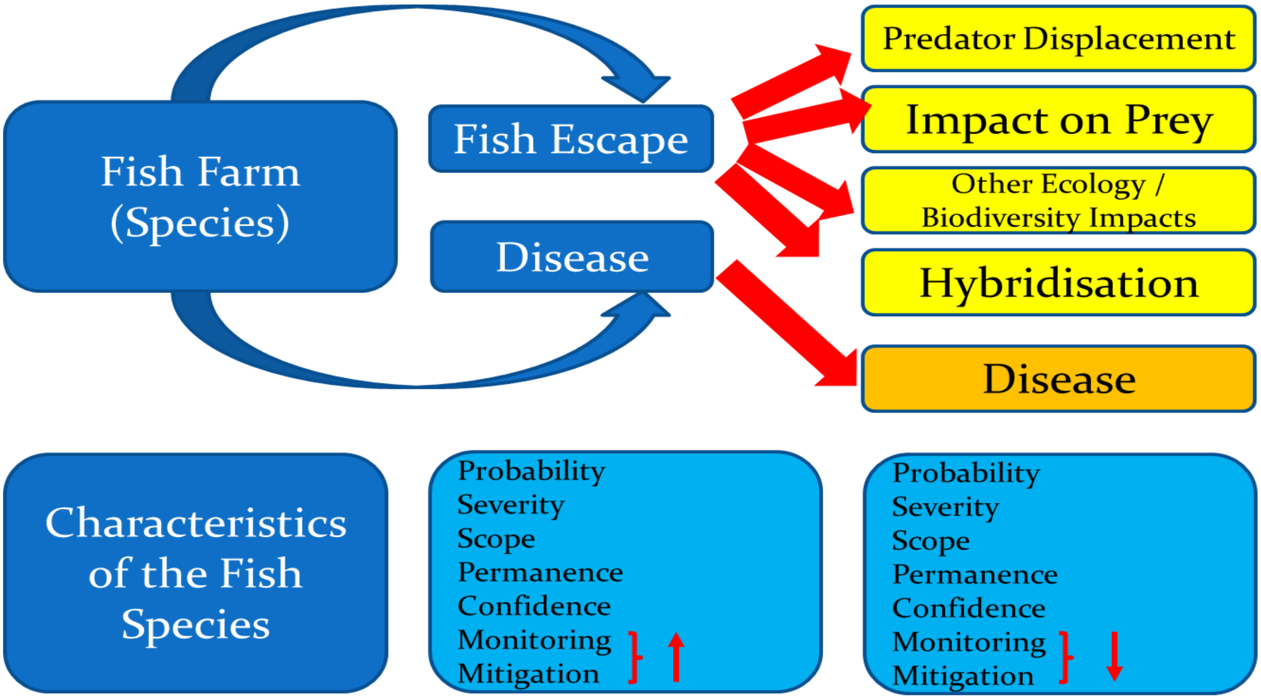

Figure 5: Schematic illustration of the risk assessment process and the dependency of endpoint risk on the pathway.

9.4. SCALES AND CATEGORISATION OF RISK

Several scaling methods are used to determine risk and the factors that contribute to risk. These scales are largely subjective, but depend on professional judgement where technical experts determine a suitable scaling, bootstrapping where previous or historical examples are used, and formal analyses where theory-based procedures for modeling are used to set scales. For this risk assessment, the following scaling or categorization has been determined by using a combination of professional judgement and referencing to several international methodologies.

Table 2: Categories of risk probability: Probability of a risk or stressor occurring.

Scale	Explanation and Comments
High	The risk is very likely to occur.
Moderate	The risk is quite likely to be expressed.
Low	In most cases, the risk will not be expressed.
Extremely Low	The risk is likely to be expressed only rarely.
Negligible	The probability of the risk being expressed is so small that it can be ignored in

	practical terms.

Table 3: Categories of risk severity: Severity of the effects of the stressor on the endpoint.

Scale	Explanation and Comments
Catastrophic	Irreversible change to ecosystem performance or the extinction of a species or rare habitat.
High	High mortality or depletion of an affected species, or significant changes in the function of an ecosystem, to the extent that changes would not be amenable to mitigation.
Moderate	Changes in ecosystem performance or species performance at a subpopulation level, but they would not be expected to affect whole ecosystems and changes would be reversible and responsive to high levels of mitigation.
Low	Changes are expected to have a negligible effect at the regional or ecosystem level and changes would be amenable to some mitigation.
Negligible	Effects would leave all ecosystem functions in tacked without the need for mitigation.

Table 4: Categories of risk scope or scale: Scope or scale of the effects of the stressor on the endpoint (i.e. geographic extent).

Scale	Explanation and Comments
Extensive	Effects are far reaching over multiple ecosystems (or biomes) incorporating various habitat types.
Regional	The effects are manifested over a measurable distance, usually limited to one or two ecosystems.
Local	The effects are limited to a distance covering a portion of an ecosystem, such as a single water body or coastal bay.
Project Based	The effects are limited to the boundaries of the project or within a distance that can be influenced directly by remediation, without affecting other users of a common resource.
Negligible	Effects are so limited in scale that the scope is insignificant.

Table 5: Categories of permanence or longevity: Permanence or longevity of the effects of the stressor on the endpoint.

Scale	Explanation and Comments
Permanent	Change to the endpoint caused by the stressor will last for more than one century, regardless of the mitigation measures.
Long lasting	Change to the endpoint caused by the stressor will outlast the expected lifespan of the activity or project.
Moderate	Effects can be measured in years, but it is within the expected lifespan of the activity or project and where effects are measured on organisms, it is usually within the organism's expected lifespan.

Temporary	Effects are usually inside of one year in duration.
Short term	Effects can usually be measured in days.
Periodic	Effects occur more than once within the temporary or short-term classification of permanence.

Table 6: Categories of uncertainty (or certainty and confidence): Uncertainty in the analysis of risks, stressors and endpoints and the interrelationships between these.

Scale	Explanation and Comments
Doubtful	When confidence in the analysis is so low that the outcome can be near random.
Low	When confidence in the analysis is such that an alternative outcome will occur regularly, but that such an alternative in probability, severity, scope and permanence will regularly constitute a change by more than one position in the respective scales.
Moderate	When confidence in the analysis is such that an alternative outcome will occur regularly, but that such an alternative in probability, severity, scope and permanence will rarely constitute a change by more than one position in the respective scales.
High	When variability in an analysis is accurately predictable and an alternative outcome occurs only occasionally.
Very High	When confidence in the analysis is at a level at which an alternative outcome is virtually impossible, and occurs rarely.

Table 7: Categories of monitoring: Monitoring of the effects of the stressor on the endpoint within reasonable time and cost.

Scale	Explanation and Comments
Zero	Where no monitoring is possible.
Low	Where limited indicators can be collected and reported about either severity, scope or the temporal nature of the effect or impact of a stressor, and where inferred changes in ecosystem functionally, habitat and species loss is mostly used.
Moderate	Where only certain indicators can be collected and reported about the severity, scope and temporal nature of the effect or impact of a stressor, and where inferred changes in ecosystem functionally, habitat and species loss is used.
High	Where sufficient information (key indicators) can be collected and reported about the severity, scope and temporal nature of the effect or impact of a stressor, to identify major changes in ecosystem functionally, habitat and species loss.
Very High	Where the full severity, scope and temporal nature of the effect or impact of a stressor may be monitored with confidence and reported within the resources of a project.

Table 8: Categories of mitigation: Mitigation of the effects of the stressor on the endpoint within reasonable time and cost.

Scale	Explanation and Comments

Irreversible	When no degree of mitigation can prevent the alteration of ecosystem functionally, habitat or species loss.
Low	When the effects of a stressor or risk can be mitigated, but where such mitigation requires additional resources and where the outcome of mitigation is doubtful, and where some ecosystem functionally, habitat or species loss may occur.
Moderate	When the effects of a stressor or risk can be mitigated, but where such mitigation requires additional resources and where the outcome of mitigation may lead to altered ecosystem functionally but not ecosystem, habitat or species loss.
High	When the effects of a stressor or risk can be mitigated within the resources of a project and when the outcome of mitigation can return the environment to a condition in which ecosystem changes and functions do not cause multi-tropic disturbances.
Very High	When the effects of a stressor or risk can be mitigated within the resources of a project and when the outcome of mitigation can return the environment to a condition near to that prior to the establishment of the activity, within a reasonable timeframe.

Using the scales above the following example of an assessment matrix for a risk and endpoint can be illustrated. This matrix has been used as the format for this risk assessment of the import, propagation and grow out of Marron in South Africa.

Table 9: Example of a matrix indicating all categories and scales of risk.

Risk / Stressor	As example: the escape of Marron				
Endpoint	As example: competition with indigenous species				
Probability	High	Moderate	Low	Extremely low	Negligible
Severity	Catastrophic	High	Moderate	Low	Negligible
Scope	Extensive	Regional	Local	Project based	Negligible
Permanence	Permanent	Long-lasting	Moderate	Temporary (Periodic)*	Short term (Periodic)*
Confidence	Doubtful	Low	Moderate	High	Very high
Monitoring	Zero	Low	Moderate	High	Very high
Mitigation	Irreversible	Low	Moderate	High	Very high

* *The addition (or submission) of "periodic" under permanence can be used to add additional information with regards to the temporal nature of the effects on the endpoints.*

One important aspect, which is not directly addressed in this multi-criteria scaling is the nature of the receiving environment. The severity of the effect is scaled, but this is only indirectly related to the nature of the receiving environment. As an example, if an activity was proposed or developed in a degraded environment, it will be necessary to adjust the severity of the impact, as opposed to the severity when the same activity was to be undertaken in a pristine environment.

It is important to continuously be mindful of the fact that the analysis, and particularly the management of risk, depends on financial, human, intellectual and other resources. The scaling of risk, and particularly the potential for monitoring and mitigation, should therefore take cognisance of the availability and practical application of financial and human resources.

The identified risks and the scaling of probability, severity, scope, permanence, confidence, mitigation and monitoring must be considered collectively, to arrive at a risk profile. As an example, if an effect on the environment has a "*high*" probability, but with "*low*" severity and "*temporary*" permanence, then the resultant risk can be seen to be acceptable.

9.5. PERCEPTION OF RISK

The nature and perception of risk differs significantly from environment to environment for the same stressors. This difference is caused by factors such as the nature of the endpoint and the surrounding environment, but also significantly by the different manner in which people perceive risk. Risk perception involves people's beliefs, education, attitudes, judgements and feelings, as well as the wider social or cultural values that people adopt towards different risks and their consequences. Factors such as income level, ethnic background, political outlook, public values, historical land use, zoning, life style and psychological condition, inevitably drive the acceptance and perception of varying levels of risk, and the manner in which risk is managed.

In this case, it is important that the perception of risk remains in context to the use of Marron, the environment in which the use will occur, the use or development scale, the potential for mitigation and other factors.

9.6. RISK COMMUNICATION

A comprehensive an accurate assessment of risk is worthless if risk is not correctly communicated to planners, managers, industry experts, environmental agencies and stakeholders. In this framework assessment, the communication of risk is not being fully investigated. Yet, the following notes on communication of risk are important:

- Risk assessment is the first step in an on-going process in which risks must be monitored, mitigated and correctly communicated through tools such as assessments, plans, audits, meetings and more.
- The communication of risk must take cognisance of the nature of the parties to which information is given. This should incorporate consideration of factors such as education, manner in which they are being affected by the risk, socio and economic character and more.
- Risk communication must be used to improve the understanding and confidence of initial risk assessment.
- Risk communication must always be clear, transparent, timely and unbiased.
- The communication of risk is the means through which information can be provided to decision making authorities to evaluate the granting of rights (authorisations, permits, concessions etc.) in terms of statutory provisions.

10. SPECIFIC FRAMEWORK ASSESSMENT FOR MARRON

The methodology above meets the requirements for risk assessment as per Section 14 of the AIS Regulations (GN R 598 of August 2014). However, this BRBA is a framework document that users need to pullulate with specific and detailed information pertaining to the receiving environment and the nature of their own proposed import, propagation and grow out of Marron.

10.1. INVENTORY OF POTENTIAL PATHWAYS AND RISKS

The ecological risks associated with the import, propagation and grow out of Marron, have been determined and generically evaluated for the entire South Africa. This information should be used as a starting point towards compiling a project specific risk assessment.

The following pathways between risks or stressors and the endpoint (i.e. the environment) have been identified:

- Escape, which could take on many forms (discussed below).
- The diverse pathway related to the movement of disease and parasites.

The following risk endpoints have been identified and make up the risk inventory for assessment:

- The potential for physical (abiotic) damage to the environment
- The potential for predator displacement
- The potential for competition - for food, habitat niches and other resources
- The potential for hybridisation and displacement
- The potential for impacts on prey species
- The potential threat of new or novel diseases and parasites

As indicated, the primary ecological risks in the inventory above are linked to the pathway of escape, and further, with the ability of Marron to establish a feral and self-propagating population, were it to escape. This ability is determined by the nature of the facilities in which they are kept, and the life history characterises of Marron as described in Section 7.

10.2. DISCUSSION OF RISK PATHWAYS

Using the risk inventory above, further information is provided for the respective risks in the sections below. It should be noted that the manifestation of any risk is directly related to the degree of mitigation, and that the severity of all risks is directly dependant on the level of mitigation.

10.2.1. THE PATHWAY OF ESCAPE

The potential for escape of all life stages must be evaluated from the proposed holding or production facilities. In this regard, consideration must be given to the following potential pathways of escape, which are discussed hereafter:

- Escape during transportation / shipment to an aquaculture facility, or from an aquaculture facility in the case of live sales
- Escape through the incoming water resources
- Escape by means of outflow water
- Escape caused by poor design, system malfunction or poor maintenance
- Escape by means of deliberate or accidental human actions such as theft or human error, including inadvertent actions that cause escape during grading, handling or harvesting.
- Escape through predation, where fish are preyed upon and removed as live specimens to the surrounding environment in the process
- Escape due to natural disasters such as flooding

Escape during transportation / shipment

During this process, there is a risk that the containers or packaging materials could be breached, and that crayfish could be released to the environment. It is generally concluded that although a low probability of escape exists, the chances of any such event leading to the establishment of a feral population is negligible, given that escape during transport is not likely to lead to the crayfish landing in an aquatic environment in which they will survive. The risk of an escape event occurring during the shipment process is thus negligibly low, with a high potential for monitoring and mitigation.

As Marron is often sold live, the risk of escape during transport to market must also be brought into consideration. Here also, the risk is negligibly low, with a high potential for monitoring and mitigation.

Escape through the incoming water resources

In general, escape of Marron through incoming water resource is improbable, given that water is typically supplied to aquaculture facilities through directional flow in a pipeline (often from a borehole or via a high velocity pump). From this perspective, the risk of escape through the incoming water can be ignored.

The exception to the above would be in cases where water is supplied to an aquaculture facility through passive flow with a low velocity and no other barrier to prevent crayfish from migrating out of a production facility and into a suitable habitat.

Escape through outflow water

Marron will move with water from a production facility and colonise the surrounding environment if:

- The physical (e.g. velocity, pressure, temperature) and chemical properties of the water through which the crayfish move is suitable.
- There are no physical barriers such as screens, filters, soakaway systems etc.
- There are no biological barriers such as predation dams.
- The receiving environment can support survival.

In fully recirculating systems, the outflow volume can generally be controlled, and water can be released via a range of barriers, which could include the release of water into an environment that is not likely to support survival. However, in flow through systems it is probable that a pathway for escape exists.

It is important that containment for all life stages (eggs, larvae, growers and brood stock) be investigated, and the potential for escape established. In certain instances, the potential for escape for adult crayfish may be absent, while smaller individuals may be transferred freely to the surrounding environment.

Escape through poor design, system malfunction or poor maintenance

A pathway for escape (and disease) can be facilitated by poor design, system malfunction and poor maintenance. The design of any system (even fully recirculating systems) should pay attention to the prevention of pathways that could lead to the escape of crayfish. Likewise, regular maintenance is required to prevent malfunction and the development of situations that could lead to escape.

The most common design and maintenance issues relate to the failure of key components such as tanks, pipes, filters etc. It is important that these critical points be identified and that the consequences of failure are anticipated through predicting a pathway of escape in the event of system failure or malfunction. Doing this will allow an opportunity for the creation of a contingency barrier against the escape of crayfish (such as an overflow sump or soakaway trench along the anticipated pathway of flow).

Escape by means of deliberate human actions such as theft or human error, including inadvertent actions that cause escape during grading, handling or harvesting.

Theft is a human characteristic that depends on a combination of socio and economic factors. Escape through theft of live crayfish is generally improbable, given that the incentive for theft is mostly around a means to a meal. However, measures such as security systems and access controls should be implemented to prevent theft.

Illegitimately giving or selling crayfish to third parties, potentially creates a greater risk than theft.

Human error is an unavoidable characteristic of all human endeavours and can be directly linked to factors such as level of training, experience, awareness, employment conditions and the nature of the production facility. As with design and maintenance aspects, it is important that critical points and causes of human errors be identified and that the consequences thereof be anticipated through predicting a pathway of escape. Doing this will allow an opportunity for the creation of a contingency barrier against the escape of crayfish (such as an overflow sump or soakaway trench along the anticipated pathway caused by the human error).

Escape through predation

For crayfish to escape through predation, a predator must gain access to the crayfish and prey in such a manner that allows for specimens to be transferred to an escape pathway or into the surrounding environment in a viable state. This is generally uncommon in closed or contained production systems, but can be common in open ponds, where predatory animals such as birds have access.

Escape due to natural disasters such as flooding

Natural disasters such as flooding and storms can lead to inundation or structural damage that facilitates the escape of crayfish. This risk is a function of the sighting of facilities, the design of such facilities and the prevalence of natural disasters. Aquaculture facilities should not be sighted in low lying areas that are prone to flooding.

As with the matters above, it is important that potential weaknesses or risk prone aspects, insofar as natural disasters are concerned, be identified and that the consequences thereof be anticipated through predicting a pathway of escape. Doing this will allow an opportunity for the creation of a contingency barrier against the escape of crayfish (such as an overflow sump or soakaway trench along the anticipated pathway caused by the natural disaster).

10.2.2. THE PATHWAY OF DISEASE

Concomitant with all species introductions, there is potential for the introduction of novel diseases (bacterial, viral pathogens and parasites) into the recipient environment, and these could affect indigenous species and the ecology. These diseases can either originate from the introduced crayfish, or as a result of contaminated transport water or packaging materials.

The introduction of disease does not necessarily depend on the pathways that may exist for the escape of crayfish. Disease causing organisms can move from a crayfish farm into the surrounding environment through the transfer of water (with or without crayfish), but also through the disposal of dead crayfish, through the moving of crayfish farming equipment, on the hands and shoes of people that move through a crayfish farm and in a myriad of other ways.

The potential for the movement of disease from a fully contained recirculatory system, in which access control and biosecurity measures are strictly adhered to is low, while the potential for the movement of disease from open pond and flow through systems is high. In all instances, the most effective means of control is to prevent the introduction of disease causing organisms.

As the existing brood stock of Marron in South Africa has been used for several years, the industry will requires new genetic material at some stage. If new stock is imported, there are risks of disease or parasite introduction which must be considered. The import of crayfish into South Africa is subject to veterinary clearance from the Directorate of Animal Health in the Department of Environment, Forestry and Fisheries (DEFF). In addition to this, the disease protocols and screening for certain notifiable diseases, in terms of the protocols of the World Organisation for Animal Health (OIE), is mandatory and should be applied.

10.3. DISCUSSION OF RISK ENDPOINTS

10.3.1. PHYSICAL ABIOTIC DAMAGE TO THE ENVIRONMENT

The risk of Marron causing any physical damage to the environment is highly improbable as they do not burrow like certain other freshwater crayfish species. Their foraging, reproduction and other life history patterns does not cause physical damage to the aquatic environments in which they occur. Accordingly, this risk has been eliminated from further assessment.

10.3.2. PREDATOR DISPLACEMENT

Marron are not apex predators and their feeding habits support the notion that they will not cause any predator displacement. Accordingly, this risk has been eliminated from further assessment.

10.3.3. COMPETITION - FOOD, HABITAT & OTHER RESOURCES

The establishment of a viable feral population of Marron can occur wherever the biotic and abiotic requirements of the species are met. In South Africa, the primary limiting factor to the survival of a viable population of Marron is water temperature, dissolved oxygen levels and the presence of predators. Where Marron have escaped, they have generally not established viable populations and it is unlikely that the will become invasive.

Were a viable population to establish, competition with other detritus feeders such as crabs is possible. Consideration has been given in the risk assessment to the potential general impact on biodiversity through related ecological consequences, and extended tropic disturbances that are built off competition for food, habitat and other resources. Due to their poor ability to adapt to new environments, their K-selected life history strategy and predation, Marron is not likely to threaten natural resources and native biodiversity.

10.3.4. HYBRIDIZATION

Marron will not hybridise with any indigenous species in South Africa. Accordingly, this risk has been eliminated from further assessment.

10.3.5. IMPACT ON PREY SPECIES

As indicated above, Marron are detritus feeding scavengers that may feed opportunistically on live plants, fish eggs and invertebrates like snails. Little research has been done to quantify the potential impact of Marron on other aquatic organisms on which they may feed, but the risk is considered low.

10.3.6. EFFECTS OF DISEASE

Assemblage of new stock and high stocking densities commonly found in aquaculture, can lead to disease related issues. The potential impacts of novel diseases introduced into an area through aquaculture can be wide-ranging and severe. If unknown diseases are introduced, indigenous species may not have an adequate immune response to cope. It is important to consider the ecological risk of disease against the background of historical and current fish import practices for the aquarium and ornamental trade in South Africa, as very few health checks are done for the import of many species.

Marron can be carriers of undesirable microorganisms and parasites. The "*crayfish plague"* fungus (*Aphanomuyces astaci)* that originated in the United States and spread to Europe, can affect several freshwater crayfish families (de Moor 2002). Marron can also host to a microsporidian parasite (*Thelohania sp*.), commonly known as "*porcelain disease"* (Morrissy *et al*. 1990, Langdon 1991), which affects striated muscle fibers in the tail and which is likely spread by cannibalism. There is no treatment for this disease and the only means of prevention is by ensuring that stocks are disease free. The disease is, however, difficult to detect during the early stages of infection, so the prevention of its importation is likely to be difficult (Langdon 1991). This disease has not been reported in South Africa (DAFF, 2012b) and is unlikely to affect indigenous freshwater species.

There are various worms which are hosted by crayfish without causing the host any harm, but which have the potential to infect other species. For example, the ectocommensal flatwork *Temnocephalan* (which are not native to Africa) is often found in large numbers on the gills or shells of freshwater crayfish. It rarely presents a management problem and can be controlled with salt baths. *Temnocephala chaeropsis* was introduced with Marron in the southern Cape and reduced the marketability of infected individuals, in some cases causing mortalities (Mitchell & Kok 1988). The worms also have the potential to infect a species of indigenous freshwater crab, *Potomonautes warreni* (Avenant-Oldewage 1993) and could potentially affect other indigenous decapods, either by killing or by lowering its fitness to a level which would allow Marron a competitive advantage (De Moor 2002).

10.4. ASSESSMENT SCORING OF RISK LEVELS

With reference to the pathways and risk inventory in Section 10.1, the flowing sections illustrate the outcome of the assessment of risk levels. As a national risk framework, it is impossible to accurately determine the risk levels for each instance in which Marron is proposed for used. Moreover, it is impossible to determine the precise levels of risk based on the design of an individual aquaculture project, and the level of mitigation that will applied. For these reasons, the scoring that follows must be used as a point of departure to provide a generic framework, which will require further detailed assessment for individual projects.

10.4.1. RISK PATHWAYS

The relationship between a risk pathway and the endpoint has been illustrated in Section 9.3. It should be noted that the probably of a pathway such as escape refers specifically to the probability (chance) of escape, and not to the probability of the escape event leading to an impact or endpoint. Likewise, the severity refers to the severity (quantity) of escape, the scope to the distribution of escapees and permanence to the survival and propagation of the escapees. These aspects should not be confused with the characterisation of the endpoints or impacts.

The risks associated with the respective pathways differ greatly between the respective production systems use in aquaculture (i.e. ponds, raceways,

recirculatory systems etc.) For this reason, the tables hereafter depict an aggregate score for South Africa in general.

a. The risk of Marron escaping during transit between hatcheries, from suppliers to farmers and from farms to markets.

Table 10: Risk pathway characterisation related to escape during transport and transit.

Risk	Escape				
Pathway	Escape during transport or transit				
Probability	High	Moderate	Low	Extremely low	Negligible
Severity	Catastrophic	High	Moderate	Low	Negligible
Scope	Extensive	Regional	Local	Project based	Negligible
Permanence	Permanent	Long-lasting	Moderate	Temporary	Short term
Confidence	Doubtful	Low	Moderate	High	Very high
Monitoring	Zero	Low	Moderate	High	Very high
Mitigation	Irreversible	Low	Moderate	High	Very high

b. The risk of Marron escaping through inflow water.

Table 11: Risk pathway characterisation related to escape through the inflow water.

Risk	Escape				
Pathway	Escape through inflow water				
Probability	High	Moderate	Low	Extremely low	Negligible
Severity	Catastrophic	High	Moderate	Low	Negligible
Scope	Extensive	Regional	Local	Project based	Negligible
Permanence	Permanent	Long-lasting	Moderate	Temporary	Short term
Confidence	Doubtful	Low	Moderate	High	Very high
Monitoring	Zero	Low	Moderate	High	Very high
Mitigation	Irreversible	Low	Moderate	High	Very high

c. The risk of Marron escaping through outflow water.

Table 12: Risk pathway characterisation related to escape through the outflow water.

Risk	Escape				
Pathway	Escape through outflow water				
Probability	High	Moderate	Low	Extremely low	Negligible
Severity	Catastrophic	High	Moderate	Low	Negligible
Scope	Extensive	Regional	Local	Project based	Negligible
Permanence	Permanent	Long-lasting	Moderate	Temporary	Short term
Confidence	Doubtful	Low	Moderate	High	Very high
Monitoring	Zero	Low	Moderate	High	Very high
Mitigation	Irreversible	Low	Moderate	High	Very high

d. The risk of Marron escaping through poor design, system malfunction and/or poor maintenance to aquaculture facilities.

Table 13: Risk pathway characterisation related to escape through poor design, system malfunction and/or poor maintenance.

Risk	Escape				
Pathway	Escape due to poor design, system malfunction and/or poor maintenance				
Probability	High	Moderate	Low	Extremely low	Negligible
Severity	Catastrophic	High	Moderate	Low	Negligible
Scope	Extensive	Regional	Local	Project based	Negligible
Permanence	Permanent	Long-lasting	Moderate	Temporary	Short term
Confidence	Doubtful	Low	Moderate	High	Very high
Monitoring	Zero	Low	Moderate	High	Very high
Mitigation	Irreversible	Low	Moderate	High	Very high

e. The risk of Marron escaping through deliberate human actions such as theft or human error.

Table 14: Risk pathway characterisation related to escape through theft or human error.

Risk	Escape				
Pathway	Escape due to human actions such as theft or human error				
Probability	High	Moderate	Low	Extremely low	Negligible
Severity	Catastrophic	High	Moderate	Low	Negligible
Scope	Extensive	Regional	Local	Project based	Negligible
Permanence	Permanent	Long-lasting	Moderate	Temporary	Short term
Confidence	Doubtful	Low	Moderate	High	Very high
Monitoring	Zero	Low	Moderate	High	Very high
Mitigation	Irreversible	Low	Moderate	High	Very high

f. The risk of Marron escaping through predation, where fish are preyed upon and removed as live specimens to the surrounding environment.

Table 15: Risk pathway characterisation related to escape through predation.

Risk	Escape				
Pathway	Escape due to predation				
Probability	High	Moderate	Low	Extremely low	Negligible
Severity	Catastrophic	High	Moderate	Low	Negligible
Scope	Extensive	Regional	Local	Project based	Negligible
Permanence	Permanent	Long-lasting	Moderate	Temporary	Short term
Confidence	Doubtful	Low	Moderate	High	Very high
Monitoring	Zero	Low	Moderate	High	Very high
Mitigation	Irreversible	Low	Moderate	High	Very high

g. The risk of Marron escaping through natural disasters such as flooding.

Table 16: Risk pathway characterisation related to escape through natural disasters.

Risk	Escape				
Pathway	Escape due to natural disasters				
Probability	High	Moderate	Low	Extremely low	Negligible
Severity	Catastrophic	High	Moderate	Low	Negligible
Scope	Extensive	Regional	Local	Project based	Negligible
Permanence	Permanent	Long-lasting	Moderate	Temporary	Short term
Confidence	Doubtful	Low	Moderate	High	Very high
Monitoring	Zero	Low	Moderate	High	Very high
Mitigation	Irreversible	Low	Moderate	High	Very high

h. The risk of Marron serving as vector for the introduction of novel diseases and pathogens (including parasites).

Table 17: Risk pathway characterisation related to spread of novel diseases.

Risk	Spread of disease				
Pathway	Various disease pathways - water, air or direct contact				
Probability	High	Moderate	Low	Extremely low	Negligible
Severity	Catastrophic	High	Moderate	Low	Negligible
Scope	Extensive	Regional	Local	Project based	Negligible
Permanence	Permanent	Long-lasting	Moderate	Temporary	Short term
Confidence	Doubtful	Low	Moderate	High	Very high
Monitoring	Zero	Low	Moderate	High	Very high
Mitigation	Irreversible	Low	Moderate	High	Very high

10.4.2. RISK ENDPOINTS/IMPACTS

It should be noted that the probably of an endpoint or an impact refers specifically to the probability (chance) of impact, and not to the probability of the pathway that led to the impact or endpoint. Likewise, the severity refers to the severity (quantity) of the impact, the scope to the distribution of the impact and the permanence to the duration of the impact. These aspects should not be confused with the characterisation of the pathway.

a. The risk of Marron causing impacts related to competition for food, habitat niches and other resources.

Table 18: Risk endpoint characterisation related to competition for food, habitat and other resources.

Risk	Life history characteristics of Marron				
Endpoint / Impact	Competition for food, habitat niches and other resources				
Probability	High	Moderate	Low	Extremely low	Negligible
Severity	Catastrophic	High	Moderate	Low	Negligible
Scope	Extensive	Regional	Local	Project based	Negligible
Permanence	Permanent	Long-lasting	Moderate	Temporary	Short term
Confidence	Doubtful	Low	Moderate	High	Very high
Monitoring	Zero	Low	Moderate	High	Very high
Mitigation	Irreversible	Low	Moderate	High	Very high

b. The risk of Marron impacting on potential prey species.

Table 19: Risk endpoint characterisation related to impacts on prey species.

Risk	Life history characteristics of Marron				
Endpoint / Impact	Impacts on prey species				
Probability	High	Moderate	Low	Extremely low	Negligible
Severity	Catastrophic	High	Moderate	Low	Negligible
Scope	Extensive	Regional	Local	Project based	Negligible
Permanence	Permanent	Long-lasting	Moderate	Temporary	Short term
Confidence	Doubtful	Low	Moderate	High	Very high
Monitoring	Zero	Low	Moderate	High	Very high
Mitigation	Irreversible	Low	Moderate	High	Very high

c. The risk of Marron acting as a vector for the introduction of disease and pathogens.

Table 20: Risk endpoint characterisation related to disease and pathogens.

Risk	Life history characteristics of pathogen				
Endpoint / Impact	Multiple disease related impacts				
Probability	High	Moderate	Low	Extremely low	Negligible
Severity	Catastrophic	High	Moderate	Low	Negligible
Scope	Extensive	Regional	Local	Project based	Negligible
Permanence	Permanent	Long-lasting	Moderate	Temporary	Short term
Confidence	Doubtful	Low	Moderate	High	Very high
Monitoring	Zero	Low	Moderate	High	Very high
Mitigation	Irreversible	Low	Moderate	High	Very high

10.5. SUMMARY OF RISK PROFILE

The pathway and endpoints of the risks that have been set to analysis above can be summarized to arrive at an overall risk profile. The following table summarises the characterisation of pathways and endpoints (aggregate for all production systems and environments):

Table 21: Risk profile characterised by risk pathways and risk endpoints.

	Risk Pathways								**Risk End Point or Impacts**		
Risk	Transit	Inflow water	Outflow water	Design, malfunction or maintenance	Theft or human error	Predation	Natural disasters	Disease pathways	Competition food, niches & resources	Impact prey species	Disease impacts
Probability	E Low	E Low	Low	Mod	Mod	E Low	Low	Low	Low	E Low	Low
Severity	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Mod
Scope	Local	Local	Local	Local	Reg	Local	Reg	Reg	Local	Local	Local
Permanence	Mod	Mod	Mod	Mod	Mod	Mod	Mod	Long L	Mod	Mod	Long L
Confidence	High	Mod	Mod	Mod	Mod	High	Mod	Mod	Mod	Mod	Low
Monitoring	Mod	Mod	Mod	Low	Low	Mod	Low	Mod	Low	Low	Mod
Mitigation	V High	V High	V High	High	High	High	High	Mod	Low	Low	High

Neg=Negligible, Mod=Moderate, Reg=Regional, Perm=Permanent, E Low=Extremely Low, Proj B=Project Based, Ext=Extensive, Long L=Long Lasting, Short T=Short Term, Temp=Temporary, V High=Very High, Irrev=Irreversible

Using the table above, a numeric scoring can be used to weigh and prioritise the potential risks of greatest concern. Various mathematical methods have been used for risk scoring to prioritise the importance or interrelatedness between the numerical weighting of either probability, severity, scope and/or permanence. In the methodology that has been applied to this BRBA, a selection of 4 consecutive numbers (weights) have been given to each of the five categories under probability and severity; spanning from 1 (high) to 20 (low), to correspond with high to negligible probabilities and very high to negligible severities, respectively. Similarly, a selection of 3 consecutive numbers, spanning from 1 (high) to 15 (low), has been used for scope and permanence, to achieve the greater relevance (weight) to probability and severity, which is sometimes achieved by applying multiplication of the scores in these categories. Given that confidence, monitoring and mitigation are based largely on judgements of value, and not on the actual nature of the impact or risk to the environment, 2 consecutive numbers, spanning from 1 (low) to 10 (high) has been used or these categories.

To illustrate this, the following numeric values are given to the respective scales:

Table 22: Numeric values associated with risk characterisation.

Probability	High	Moderate	Low	Extremely low	Negligible
	1 2 3 4	5 6 7 8	9 10 11 12	13 14 15 16	17 18 19 20
Severity	Very high	High	Moderate	Low	Negligible
	1 2 3 4	5 6 7 8	9 10 11 12	13 14 15 16	17 18 19 20
Scope	Extensive	Regional	Local	Project based	Negligible
	1 2 3	4 5 6	7 8 9	10 11 12	13 14 15
Permanence	Permanent	Long-lasting	Moderate	Temporary	Short term
	1 2 3	4 5 6	7 8 9	10 11 12	13 14 15
Confidence	Doubtful	Low	Moderate	High	Very high
	1 2	3 4	5 6	7 8	9 10
Monitoring	Zero	Low	Moderate	High	Very high
	1 2	3 4	5 6	7 8	9 10
Mitigation	Irreversible	Low	Moderate	High	Very high
	1 2	3 4	5 6	7 8	9 10

Using this method, an impact or risk that is very probable, that has severe effects, a broad scope, long permanence and that is predicted with little confidence, and that is difficult to monitor and mitigate can score a theoretical low overall value/weight of 7. Alternatively, a negligible impact or risk that is unlikely to occur, with limited scope, a short lifespan and which can be predicted with confidence and that can be monitored and mitigated, can score a theoretical high overall value of 100. Using this numeric allocation to illustrate risk is convenient in that low scoring risks pose a threat to the environment, while high scoring risks are acceptable.

The scoring of evaluated pathways and risk endpoints for Marron is as follows (table next page):

Table 23: Score allocation to the risk profile before mitigation.

	Risk Pathways								**Risk End Point or Impacts**		
Risk	Transit	Inflow water	Outflow water	Design, malfunction or maintenance	Theft or human error	Predation	Natural disasters	Disease pathways	Competition food, niches & resources	Impact prey species	Disease impacts
Probability	16	15	12	8	7	16	12	10	12	13	12
Severity	16	16	16	16	15	15	13	13	13	13	11
Scope	9	9	9	9	6	9	6	6	9	9	8
Permanence	7	7	7	7	7	7	7	6	8	8	6
Confidence	8	7	6	6	5	7	5	5	6	6	4
Monitoring	6	5	5	4	4	5	4	5	4	4	5
Mitigation	10	9	9	9	8	8	8	5	3	3	7
Total Score	72	68	64	59	52	67	55	50	55	56	53

Notwithstanding all factors considered, as a general rule, scores above 50 denote acceptable levels of risk and those below 50, unacceptable. The score allocation, although subjective and debatable, has been done based on information in this BRBA.

When considering the pathways for the manifestation of risks, the score for escape through theft or human error (52) and the pathways for disease (50) pose the greatest threat. However, these aspects show a high potential for monitoring and mitigation, meaning that effective risk pathway management could see a lowering of the potential impact to endpoints. Escape of Marron is relevant, but given the low and localised impacts, historical records of failed establishment after escape and the degree to which this can be mitigated, it was assessed as being of less concern.

With due consideration to the pathways above, the score for the ecological endpoints or impacts related to disease (53) is the most relevant. Other potential impacts on the environment have been shown to be of less concern, albeit that the prevention of escape is advocated.

Note that this scoring methodology has been used to grade the potential negative risks and impacts only. The potential positive impacts of establishing a compliant Marron aquaculture sector in South Africa have not been considered (see Section 11 below). Reports abound across South Africa of unlawful distribution of Marron by unscrupulous anglers, farmers, non-abiding aquaculture facilities and aquarium traders. It is for this very reason that the establishment of compliant aquaculture sector is important towards curbing the illegal distribution of these crayfish.

It should be noted that the findings of this BRBA do not apply to the invasive Red Swamp Crayfish (*P. clarkii*), the Australian Redclaw Crayfish (*C. quadricarinatus*) and other freshwater crayfish species.

11. KEY ECONOMIC, SOCIAL AND SOCIETAL CONSIDERATIONS

The risk profile above is based on the potential negative environmental or ecological consequences related to the use and introduction of Marron. These risks must be considered in a balanced manner in conjunction with potential economic, social and societal considerations.

Due to its novelty in the restaurant trade and pressures on stocks of marine crayfish, a demand exists for farmed Marron in South Africa. In response to this, there is an interest in this species as a candidate for farming. This interest can result in illicit distribution of these crayfish, but also of other highly invasive freshwater crayfish species, which could lead to severe ecological risks. The establishment of a formal and lawful Marron based aquaculture sector, in specific areas and in which the risks are known and mitigated, is the most prudent response. This will also contribute to the furtherance and success of aquaculture in South Africa, which is a clear objective of the current policies and strategies adopted by the South African Government, particularly the Department of Environment, Forestry and Fisheries (DEFF). Success in Marron aquaculture will have several socio-economic advantages, which include:

- The creation of rare skills and the application of new technologies.
- The beneficial use of natural resources.
- The creation of economic opportunities in the broader South African contexts. This is especially relevant considering that these opportunities will be created in primary production.
- Direct and indirect food security.

It is important to consider the potential socio-economic consequences that may result from the manifestation of any of the ecological impacts. Were Marron to become established in selected catchments, the socio-economic consequences will be restricted as South African inland waters support a limited fishery and the impacts of Marron are likely to be negligible.

The establishment of Marron (regardless of the probability thereof), holds no direct threat to humans or any human livelihoods.

12. BALANCED COST OF ERADICATION

For this BRBA no examples of active eradication of Marron could be found. It is however known that escapees from range of facilities in the past had not led to the establishment of viable feral populations (Nunes, *pers.comm*).

A balanced view must be taken to the potential ecological cost of Marron invasion and the potential cost of eradicating the crayfish. This cannot be approached as an actual cost as an expense of this nature must be weighed up against the ecological costs and the net gain of benefits that would result from an eradication effort. Given the limited ecological costs (as determined by the limited risk and impact that the establishment of this species could have), the nature of the receiving environment and the insignificant effects that could manifest towards human beings and their livelihoods, it is suggested that the cost of eradicating Marron in the environment would be unwarranted. The climatic and other habitat associated control mechanisms outweigh any benefits that may accrue from the actual expenses associated with eradication.

Despite the balanced view above, the "*polluter pays*" principle in Section 28 of the National Environmental Management Act 107 of 1998 may apply, in terms of which the onus to cover the costs associated with environmental degradation, lies with the developer or proponent, which in this case will be the party responsible for release of Marron into the environment.

13. RISK MONITORING

The potential for monitoring of the respective pathways and risks have been analysed as part of the assessment. Monitoring is a key aspect towards bolstering the acceptability of risk as it provides a mechanism for tracking risks through a project cycle, and it increases confidence in future assessments. Other important reasons for monitoring relate to environmental protection, research, traceability, market requirements and self-assessment of performance.

Threshold limits should be identified before allowing for the use of Marron in any specific area. The full extent of the monitoring programme should be documented in a monitoring plan so that there is clarity on what will be monitored, how, for how long and the manner in which it should be recorded and reported. Monitoring must take account of practicality and especially the cost effectiveness in relation to the levels of identified risks.

The following preliminary monitoring requirements could be considered for inclusion in a monitoring programme associated with the use of Marron in aquaculture. It is further recommended that the monitoring regime be subjected to an external verification by an independent specialist.

- Monitoring regime for all transit and receipt of new batches of crayfish to determine origin, numbers, quarantine procedures and disease status.
- Ongoing monitoring for health and disease.
- A monthly inspection of the sumps, predator ponds, barricade walls, screens, filters and other potential escape routes.
- A monthly inspection of all maintenance, as well as integrity, functioning and contingency planning for the operation of production facilities.
- A three-monthly review of the training levels and ability of personnel, to minimise the risk of human error.
- A six-monthly review of security to prevent theft.
- A six-monthly review of crayfish stock records.

14. RISK CONTROL MEASURES AND MITIGATION

Controlling the spread of an invasive species through prevention is thought to be the most cost-effective means (Leung *et al.* 2002). It was illustrated in the analysis of pathways and risks that mitigation could lead to lowered levels of severity, scope, longevity etc. Such mitigation measures should be recorded, implemented, audited and reported; both internally and, if required, externally by an independent specialist.

The following preliminary mitigation measures could be considered for inclusion as conditions related to the issuing of permits for the use of Marron in aquaculture:

The prevention of escape through transit:

- Obtain crayfish from a single, reputable and permitted supplier.
- Use best packaging materials and techniques, as well as reputable transit agencies.
- Keep accurate dispatch and receipt records of crayfish stocks.
- For live sales, allow only for the selling of male stock.

The prevention of escape through inflow and outflow water:

- Implementation of mechanisms to prevent facilities from flooding due to overfilling or tank/pipe failure.
- The implementation of a dedicated maintenance schedule and the appointment of human resources dedicated to system maintenance.
- Use and maintenance of screens over outlet pipes. Young Marron initially remain with the female and perish if they are dislodged early. This means that a screen mesh size of 1mm will generally prevent escape of the smallest viable individuals (Bursey, *pers. comm*.).
- The creation of physical barriers can be effective in preventing escape (Novinger & Rahel 2003). It is recommended that all pond systems for Marron be fully surrounded by a vertical 0.5 m high impenetrable fence with a smooth surface, which can be made up of corrugated iron of other materials. This practice will prevent predation also.
- In certain instances, gravel beds can be used through which outflow water can flow. A highly effective method of ensuring the prevention of escape by means of outflow water is the establishment of a "*predator pond*" (Bursey, *pers. comm*.). A predatory fish species such as Bass (*Micropterus* spp.) or Sharptooth Catfish (*Clarias gariepinus*) can be hold in a last pond in series with the production system, provided these fish are permissible in the area.
- The prevention of outflow water reaching any surrounding waterways through locating farms well away from natural waterways and use of irrigation and soak-away systems for water discharge.

The prevention of escape cause by design, malfunction or maintenance issues:

- The use of best technology and management to prevent poor design and malfunction, including the implementation of backup systems and contingency plans in case of system failure.

The prevention of theft of crayfish:

- Ensure that access is strictly controlled and that facilities remain locked when personnel are not in attendance.
- Educate personnel in their responsibility towards the maintenance of security.
- Maintain and review an accurate stock record.

For the prevention of human errors:

- The training of personnel to reduce the possibility of human error.
- The appointment of suitably qualified personnel.
- The implementation of adequate supervision systems.

The prevention of escape cause by predation:

- Keep facilities locked when personnel are not in attendance.
- Ensure that predators such as otters and birds cannot access the facilities.

Precautions against escape cause by natural disasters:

- All facilities must remain outside of the flood line. New aquaculture facilities should be sited outside of the 1:100-year flood line, with infrastructure built to resist the impacts of floods.
- Maintenance of facilities to prevent structural failure during storms and wind.

The prevention of risks associated with foreign disease and pathogens:

- Crayfish may only be bought from certified disease-free suppliers and such imports should meet all further requirements that may be determined by the State Veterinarian.
- Upon receipt, all crayfish should be subjected to quarantine.
- Packaging materials for every shipment must be new, and destroyed after shipping.
- Water in which crayfish were transported must be released into the quarantine facilities.
- Limit access to the production facilities.
- Prevent use of equipment from other fish or crayfish farming facilities.
- Once in the production system, a health monitoring program must be applied, cooperatively with a registered veterinarian, and (if need be) the closest State Veterinarian. Animal health experts from the Department of Environment, Forestry and Fisheries (DEFF) may also be approached [South African Aquaculture Fish Monitoring and Control Programme (DAFF, 2015)]

15. BENEFIT / RISK TRADE-OFF

Some authors have determined that Marron could colonize and become established in many waters across South Africa, especially the Highveld, and in the southern and south-western Cape (de Moor 2002). Based on this premise it has been advised that Marron should be eradicated, given the negative impact of introduced parasites and its disappointing results in aquaculture. However, as shown in this BRBA, the introduction of Marron has not resulted in ecological risks or invasion.

In all development, the use of benefit versus risk tradeoffs is common. Most such tradeoffs are done rapidly and without detailed analysis and many involve financial risks and tradeoff between potential gains in profits against the factors that may cause financial losses. In the ecological and environmental context, the tradeoff is between viability of an aquaculture development against levels of acceptable environmental risk. This encompasses the process of precautionary decision making.

It is not possible for a proposed aquaculture activity to have no risk or impact and there is usually a trade-off between acceptable environmental risk and socio-economic benefits. This trade-off is normally defined as acceptable limits of effects.

Benefit and risk tradeoff can become a highly-complicated exercise when assigning objective and comparable values to these. Although this tradeoff is not being pursued in this report, considering the risk profile indicated above in conjunction with the advantages and potential benefits from the use of Marron for aquaculture, one can arrive at an acceptable risk tradeoff in which the use of this species should be permitted after area specific risk assessment and implementation of acceptable monitoring and mitigation measures.

16. RECOMMENDATIONS

Risk assessment techniques have been applied to all the major risk components related to the use of Marron for aquaculture in South Africa. This risk assessment should only serve as a framework around which the risk of any individual project and/or location should be investigated. The focus should remain on preventing the spread or deliberate introduction on Marron into new areas or river systems, but use for aquaculture purposes should be allowed after site specific assessment and implementation of the required monitoring and mitigation measures. Further specific recommendations include:

- Any proposed farming of Marron should be subjected to a site-specific risk assessment based on the framework provided by this BRBA.
- No Marron farming should be permitted within, or in close proximity to National Freshwater Ecosystem Priority Areas (NFEPA), promulgated conservation areas or sensitive areas as determined by a mandated authority.
- Other than Marron, no other freshwater crayfish species should be permitted for use in aquaculture in South Africa, without a detailed assessment of risk that considers the invasive potential.
- The monitoring and mitigation measures in Sections 13 and 14 should be included as conditions of any permit that is issued for the farming of Marron.

17. CONCLUSION

This BRBA has illustrated that the primary risk related to the use of Marron in aquaculture in South Africa is its potential as a carrier of foreign parasites. However, with responsible management and proper implementation of mitigation and monitoring measures, it can be used as a candidate species for aquaculture.

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APPENDIX 1. Risk scoring methodology for *C. cainii* and *C. tenuimanus* in South Africa based on the FI-ISK toolkit (Copp *et al.* 2008).

	Risk query:			
Question	**Biogeography/historical**	**Reply**	**Comments & References**	**Certainty**
1	**Is the species highly domesticated or cultivated for commercial, angling or ornamental purposes?** *Guidance*: This taxon must have been grown deliberately and subjected to substantial human selection for at least 20 generations, or is known to be easily reared in captivity (e.g. fish farms, aquaria or garden ponds).	Y	ACWA 2012; Picker & Griffiths 2011	4
2	**Has the species become naturalised where introduced?** *Guidance*: The taxon must be known to have successfully established self-sustaining populations in at least one habitat other than its usual habitat (eg. Lotic vs lentic) and persisted for at least 50 years (response modifies the effect of Q1).	Y	Picker & Griffiths 2011	3
3	**Does the species have invasive races/varieties/sub-species?** *Guidance*: This question emphasizes the invasiveness of domesticated, in particular ornamental, species (modifies the effect of Q1).	Y	TSSC 2005	4
4	**Is species reproductive tolerance suited to climates in the risk assessment area (1-low, 2-intermediate, 3-high))?** *Guidance*: Climate matching is based on an approved system such as GARP or Climatch. If not available, then assign the maximum score (2).	2	Cubitt 1985	
5	**What is the quality of the climate match data (1-low; 2-intermediate; 3-high)?)?** *Guidance*: The quality is an estimate of how complete are the data used to generate the climate analysis. If not available, then the minimum score (0) should be assigned.	2	Kleynhans et al. 2005	4
6	**Does the species have broad climate suitability (environmental versatility)?** *Guidance*: Output from climate matching can help answer this, combined with the known versatility of the taxon as regards climate region distribution. Otherwise the response should be based on natural occurrence in 3 or more distinct climate categories, as defined by Koppen or Walter (or based on knowledge of existing presence in areas of similar climate).	N	Cubitt 1985	3
7	**Is the species native to, or naturalised in, regions with equable climates to the risk assessment area?** *Guidance*: Output from climate matching help answer this, but in absence of this, the known climate distribution (e.g. a tropical, semi-tropical, south temperate, north temperate) of the taxons native range and the 'risk are' (,e, country/region/area for which the FISK is being run) can be used as a surrogate means of estimating.	Y	Picker & Griffiths 2011	3
8	**Does the species have a history of introductions outside its natural range?** *Guidance*: Should be relatively well documented, with evidence of translocation and introduction.	N	de Moor & Bruton 1985	3
9	**Has the species naturalised (established viable populations) beyond its native range?** *Guidance*: If the native range is not well defined (i.e. uncertainty	Y	de Moor & Bruton 1985	4

	about it exists), or the current distribution of the organism is poorly documented, then the answer is "Don't know".			
10	**In the species' naturalised range, are there impacts to wild stocks of angling or commercial species?** *Guidance:* Where possible, this should be assessed using documented evidence of real impacts (i.e. decline of native species, disease introduction or transmission), not just circumstantial or opinion-based judgments.	N	No record of this	3
11	**In the species' naturalised range, are there impacts to aquacultural, aquarium or ornamental species?** *Guidance*: Aquaculture incurs a cost from control of the species or productivity losses. This carries more weight than Q10. If the types of species is uncertain, then the yes response should be placed here for more major species, particularly if the distribution is widespread.	N	de Moor 2002	3
12	**In the species' naturalised range, are there impacts to rivers, lakes or amenity values?** *Guidance*: documented evidence that the species has altered the structure or function of natural ecosystems.	N	No record of this	3
13	**Does the species have invasive congeners?** *Guidance*: One or more species within the genus are known to be serious pests.	N	GISD 2012	4
14	**Is the species poisonous, or poses other risks to human health?** *Guidance*: Applicable if the taxon's presence is known, for any reason, to cause discomfort or pain to animals.	N	No record of this	4
15	**Does the species out-compete with native species?** *Guidance:* known to suppress the growth of native species, or displace from the microhabitat, of native species.	Y	de Moor 2002	3
16	**Is the species parasitic of other species?** *Guidance*: Needs at least some documentation of being a parasite of other species (e.g. scale or fin nipping such as known for topmouth gudgeon, blood-sucking such as some lampreys)	N	No reference	3
17	**Is the species unpalatable to, or lacking, natural predators?** *Guidance*: this should be considered with respect to where the taxon is likely to be present and with respect to the likely level of ambient natural or human predation, if any.	N	No reference	4
18	**Does species prey on a native species (e.g. previously subjected to low (or no) predation)?** *Guidance*: There should be some evidence that the taxon is likely to establish in a hydrosystem that is normally devoid of predatory fish (e.g. amphibian ponds) or in river catchments in which predatory fish have never been present.	Y	de Moor 2002	3
19	**Does the species host, and/or is it a vector, for recognised pests and pathogens, especially non-native?** *Guidance*: The main concerns are non-native pathogens and parasites, with the host being the original introduction vector of the disease or as a host of the disease brought in by another taxon.	Y	Mitchell & Kock 1988; Avenant- Oldewage 1993	4
20	**Does the species achieve a large ultimate body size (i.e. > 10 cm FL) (more likely to be abandoned)?** *Guidance*: Although small-bodied fish may be abandoned, large-bodied fish are the major concern, as they soon outgrow their aquarium or garden pond.	Y	Picker & Griffiths 2011	4
21	**Does the species have a wide salinity tolerance or is euryhaline at some stage of its life cycle?** Guidance: Presence in low salinity water bodies (e.g. Baltic	N	Cubitt 1985	4

	Sea) does not constitute euryhaline, so minimum salinity level should be about 15%o.			
22	**Is the species desiccation tolerant at some stage of its life cycle?** *Guidance*: Should be able to withstand being out of water for extended periods (e.g. minimum of one or more hours).	Y	Ackefors & Lindqvist 1994	4
23	**Is the species tolerant of a range of water velocity conditions (e.g. versatile in habitat use)?** *Guidance*: Species that are known to persist in a wide variety of habitats, including areas of standing and flowing waters (over a wide range of Velocities: 0 to 0.7 m per sec).	Y	TSSC 2005	3
24	**Does feeding or other behaviours of the species reduce habitat quality for native species?** *Guidance*: There should be evidence that the foraging results in an increase in suspended solids, reducing water clarity (e.g. as demonstrated for common carp).	Y	de Moor 2002	3
25	**Does the species require minimum population size to maintain a viable population?** *Guidance*: If evidence of a population crash or extirpation due to low numbers (e.g. overexploitation, pollution, etc.), then response should be 'yes'.	Y	Need certain number to prevent inbreeding	4
26	**Is the species a piscivorous or voracious predator (e.g. of native species not adapted to a top predator)?** *Guidance*: Obligate piscivores are most likely to score here, but some facultative species may become voracious when confronted with naïve prey.	N	V. Bursey pers. comm.	4
27	**Is the species omnivorous?** *Guidance*: Evidence exists of foraging on a wide range of prey items, including incidental piscivory.	N	No record of this	3
28	**Is the species planktivorous?** *Guidance*: Should be an obligate planktivore to score here.	Y	Read 1985	4
29	**Is the species benthivorous?** *Guidance*: Should be an obligate benthivore to score here.	Y	Read 1985	4
30	**Does it exhibit parental care and/or is it known to reduce age-at-maturity in response to environment?** *Guidance*: Needs at least some documentation of expressing parental care.	Y	de Moor & Bruton 1988	4
31	**Does the species produce viable gametes?** *Guidance*: If the taxon is a sub-species, then it must be indisputably sterile.	Y	No reference	4
32	**Does the species hybridize naturally with native species (or uses males of native species to activate eggs)?** *Guidance:* Documented evidence exists of interspecific hybrids occurring, without assistance under natural conditions.	N	No reference	4
33	**Is the species hermaphroditic?** *Guidance:* Needs at least some documentation of hermaphroditism.	N	de Moor & Bruton 1988	4
34	**Is the species dependent on presence of another species (or specific habitat features) to complete its life cycle?** Guidance: Some species may require specialist incubators (e.g. unionid mussels used by bitterling) or specific habitat features (e.g. fast flowing water, particular species of plant or types of substrata) in order to reproduce successfully.	N	No record of this	4
35	**Is the species highly fecund (>10,000 eggs/kg), iteropatric or have an**	N	Coetzee 1995	4

	extended spawning season? Guidance: Normally observed in medium-to-longer lived species.			
36	**What is the species' known minimum generation time (in years)?** *Guidance*: Time from hatching to full maturity (i.e. active reproduction, not just presence of gonads). Please specify the number of years.	3	Picker & Griffiths 2011	4
37	**Are life stages likely to be dispersed unintentionally?** *Guidance*: Unintentional dispersal resulting from human activity.	Y	Mikkola 1996	3
38	**Are life stages likely to be dispersed intentionally by humans (and suitable habitats abundant nearby)?** *Guidance*: the taxon has properties that make it attractive or desirable (e.g. as an angling amenity, for ornament or unusual appearance).	N	No record of this	3
39	**Are life stages likely to be dispersed as a contaminant of commodities?** *Guidance*: Taxon is associated with organisms likely to be sold commercially.	N	Depends on management practices	3
40	**Does natural dispersal occur as a function of egg dispersal?** *Guidance*: there should be documented evidence that eggs are taken by water currents or displaced by other organisms either intentionally or not.	N	de Moor & Bruton 1988	4
41	**Does natural dispersal occur as a function of dispersal of larvae (along linear and/or 'stepping stone' habitats)?** *Guidance*: There should be documented evidence that larvae enter, or are taken by, water currents, or can move between water bodies via connections	Y	de Moor & Bruton 1988	4
42	**Are juveniles or adults of the species known to migrate (spawning, smolting, feeding)?** *Guidance*: There should be documented evidence of migratory behavior, even at a small scale (tens or hundreds of meters).	Y	Molony et al. 2003	4
43	**Are eggs of the species known to be dispersed by other animals (externally)?** *Guidance*: For example, are they moved by birds accidentally when the water fowl move from one water body to another?	?	No record of this	2
44	**Is dispersal of the species density dependent?** *Guidance*: There should be documented evidence of the taxon spreading out or dispersing when its population density increases.	N	No record of this	3
45	**Any life stages likely to survive out of water transport?** *Guidance:* There should be documented evidence of the taxon being able to survive for an extended period (e.g. an hour or more) out of water. PLEASE NOTE THAT THIS IS SIMILAR TO QUESTION 22. THIS IS AN ERROR WITH THE FISK TOOLKIT AND THE CREATORS WILL BE ALERTED. FOR THE PURPOSES OF THIS STUDY, THE ANSWER HAS BEEN REPEATED.	Y	Ackefors & Lindqvist 1994	4
46	**Does the species tolerate a wide range of water quality conditions, especially oxygen depletion & high temperature?** *Guidance:* This is to identify taxa that can persist in cases of low oxygen and elevated levels of naturally occurring chemicals (e.g. ammonia).	N	Cubitt 1985	4
47	**Is the species susceptible to piscicides?** *Guidance*: There should be documented evidence of susceptibility of the taxon to chemical control agents.	?	No record of this	1
48	**Does the species tolerate or benefit from environmental disturbance?** *Guidance:* The growth and spread of some taxa may be enhanced by disruptions	N	TSSC 2005	4

	or unusual events (floods, spates, desiccation), especially human impacts.			
49	**Are there effective natural enemies of the species present in the risk assessment area?** *Guidance:* A known effective natural enemy of the taxon may or may not be present in the Risk Assessment area. The answer is 'Don't know' unless a specific enemy/enemies is known.	Y	Picker & Griffiths 2011	4