Marron Crayfish Feasibility Study

Final Report

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Executive Summary

The Department of Agriculture, Forestry and Fisheries (DAFF), Chief Directorate: Aquaculture and Economic Development aims to "*develop a sustainable and competitive sector that will contribute meaningfully to job creation, economic development, sustainable livelihoods, food security, rural development and transformation*" in South Africa. In line with this mandate, research and development has been done on several freshwater and marine fish species which are important and valuable to the South African aquaculture sector.

The marron industry is an infant industry in South Africa, with only two known producers who are located in the Eastern Cape. Currently, the only production system considered suitable for marron production in both Australia and South Africa is pond culture as other production systems have not been developed and/or tested for marron. There is limited production and technical information available on marron, particularly with regards to feed habits, breeding behaviour and the potential to use alternative production systems.

Marron have a lengthy production cycle of two years (24 months) with harvesting occurring only once a year. Research and development are currently underway, both locally and globally to look at improved genetic performance that could reduce the production cycle length and to test alternative production systems, specifically the recirculating aquaculture system (RAS). In South Africa, marron are considered an Alien Invasive Species (AIS). As a result, they are classified on the NEMBA Category Two (2) species list which requires marron producers to apply for national and provincial permits. Given that marron are known to escape from ponds and survive out of water for a few days, they pose a biosecurity risk, thus specific pond design guidelines must be adhered to by producers.

The local and international market is under supplied, with the key issue being identified as production challenges and achieving stable, year-round production volumes. From the analysis it is clear that the market itself is not a limiting factor for the industry and many opportunities exist both within the local and the international markets. In South Africa, production is limited, with four (4) tons of marron being produced in 2015.

The following production guidelines provided in the table below give a brief overview of important factors that should be considered when looking at marron production in South Africa.

Table 1-1: Marron Production Guidelines

Optimal Temperature Range	20-24°C
Water Conditions	Optimal pH: 6.5 – 8.5 Oxygen: 7 – 10 ppm (Above 6 mg/l)
Average cost of juveniles	R 10-00
Average Feed Cost	R 15-00/kg
Stocking density	0 year +: 4 crayfish/m² 1 year +: 3 crayfish/m²
Typical Survival rate	60%
Maximum Marketable size	24 months (175 grams)
Average farm gate price	R 250/kg

The generic economic model for marron was developed through inputs from technical experts, industry stakeholders and peer-review workshops. Key assumptions used in the model are mentioned above, as well as several other production and system related assumptions were incorporated into the model**. The table below illustrates an example of results** generated from the generic economic model.

Table 1-2: Example: Financial Analysis: Marron in a Pond System

Production and Financial Assumptions	
Province	Eastern Cape
System	Pond
Selected selling weight	175 grams (24 months)
Average market price	R 250/kg
Target market	Local Market
Applicant details	Start-up farmer - no existing land, infrastructure, or facilities
Education level	Formal Education (certificate, diploma, degree)
Finance option	Debt/Equity (20%)
Interest Rate	8.25%
Generic Economic Model Results – Minimum Profitable Production Volume (4 tons)	
Total Capital Expenditure	R 5 085 854.27
Working Capital	R 2 480 919.32
Infrastructure expenditure	R 2 604 934.96
Profitability Index (PI)	1.41
Internal Rate of Return (IRR)	7%
Net Present Value (NPV) over 10 years	R 7 175 300.04
Number of employees required in year 1	4
Farm size required	1.5 hectares

As seen in the table above, the minimum profitable production volume for marron is estimated to be four (4) tons per production cycle based on the results from the generic economic model. When considering marron production, two key factors should be considered, firstly, the first marron sales will only occur after 24 months, and secondly a key factor which impacts the profitability of a marron operation is the limited harvesting window, which occurs for approximately two months per annum. During the annual harvesting period, an estimated 40 to 100 kg of marron can be supplied to the market on a weekly basis.

The total capital expenditure needed to produce four (4) tons of marron per production cycle is approximately R 5 085 854, which is a combination of both the working capital costs of R 2 480 919 and infrastructure costs of R 2 604 934. The infrastructure cost accounts for constructed, earthen ponds that are designed specifically for marron production. At four (4) tons of production, a Profitability Index (PI) of 1.41 is achieved, indicating that for every R1 spent, a return of R 1.41 can be expected. The Internal Rate of Return (IRR) is 7%, indicating that marron could have good investment potential in South Africa.

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1. Introduction

1.1. Project Background

In South Africa, aquaculture has been identified as a key economic sector and employment cluster. Various policies, programmes and initiatives have been developed and implemented to assist with the development of the aquaculture sector. In support of aquaculture development, key initiatives such as the National Aquaculture Strategic Framework (NASF), the Aquaculture Development and Enhancement Programme (ADEP), and Operation Phakisa were established. The primary goal of the various policies, programmes and initiatives is to accelerate the growth of the aquaculture industry in order to assume a critical role of supplying fish products both locally and internationally; improving job creation, and contributing to the national economy, among other aspects. The sector has also been identified as a key industry that can impact the development and reindustrialisation of the rural communities and townships in South Africa.

Aquaculture is one of the fastest growing food sectors in the world, yet in South Africa, the sector remains small and underdeveloped despite the high-growth potential offered by the sector. In recent years, South Africa has seen improved access to aquaculture technology, increasing amounts of research and development, as well as support from various government departments. This, coupled with the increasing support and interest in the development of the aquaculture industry, presents opportunities to overcome some key challenges faced mainly by aquaculture producers. Some of these challenges include but not limited to access to suitable production areas, shortage of skills and poor knowledge of production systems, lack of access to markets, as well as poor aquaculture value chain development.

South African aquaculture industry demonstrates a good growth potential that can contribute significantly and become valuable from an economic and social aspect. Through continued Research and Development, education and skills development, continued support, and value chain development, the South African aquaculture industry can experience a positive growth trajectory.

This report focuses specifically on marron Crayfish production in South Africa and considers pond culture as the primary production system.

1.2. Purpose of the Feasibility Study

This feasibility study will focus on the following aspects:

I. Marron Crayfish Background,
II. Geographical distribution of marron in South Africa,
III. Potential production systems,
IV. Global and local level market assessment,
V. Potential barriers to entry,
VI. SWOT Analysis and mitigation measures,
VII. Technical Assessment,
VIII. Financial Analysis, and
IX. Recommendations.

In addition to the feasibility study conducted, a generic economic model was developed for marron. The generic economic model is aimed at assisting DAFF, industry stakeholders, role-players, and new entrants to the marron industry to determine the financial viability of marron projects in South Africa.

1.3. Feasibility Study Outline

The feasibility study is made up of nine (9) sections. Each section is discussed in more detail below to provide an overview of the report.

- **Section 1:** This section provides a project background and provides the main aspects that are covered within the feasibility study.
- **Section 2:** This section focuses on providing a species background, and the key biological and physical characteristics for marron.
- **Section 3:** A detailed explanation of the potential production systems that can be used for marron in South Africa is provided. These production systems are included in the generic economic model to determine the financial viability of each system.
- **Section 4:** This section looks at the geographical distribution of marron in South Africa, and provides a high-level suitability assessment, and identifies key requirements for profitability.
- **Section 5:** This section provides a detailed global, regional, and local market analysis for marron. Marketing, pricing, demand and supply, and the barriers to entry are key factors to be considered before implementing an aquaculture operation.
- **Section 6:** A SWOT Analysis gives a high-level overview of the marron industry in South Africa. Mitigation measures are discussed to address key weaknesses and threats identified.
- **Section 7:** A technical assessment provides a brief overview of key production assumptions and guidelines that can be used for marron production. These assumptions were used in the development of the generic economic model.
- **Section 8:** This section provides a financial analysis for the potential production systems based on the results obtained from the generic economic model. A high-level cost-benefit analysis is discussed to compare the feasibility of the potential production systems. A best-case scenario is provided to highlight the minimum viable tonnage, recommended selling price and investment potential offered by the potential production systems in the nine provinces.
- **Section 9:** The last section provides the conclusion on the feasibility study and provides recommendations for the growth and development of the marron industry in South Africa.

Disclaimer: *Production information and assumptions in this report may be subject to change over time as certain production variables can be expected to fluctuate. Technical assumptions were utilised from various industry experts and stakeholders. Due to the sensitive nature of information shared by stakeholders, personal details of stakeholders will not be included in the report. Stakeholders will be referenced as "Personal Communication" in the document, and reference list.*

2. Marron Crayfish

2.1. Species background

The marron Crayfish (*Cherax chanini*), is a freshwater crayfish species and native to the south-western region of Western Australia, (Bryant & Papas, 2007). Marron are the largest freshwater crayfish in Western Australia, and the third largest freshwater crayfish in the world. The species has been widely transplanted in both natural and artificial water bodies and has been translocated to other countries such as North America, South Africa, New Zealand, Japan, Zimbabwe, China, Chile, and countries within the Caribbean region. It is thought that marron were first introduced to South Africa in 197, with the first records showing successful marron farming taking place in the Western Cape in 1982, however, today only two known farms can be identified in the Eastern Cape. The potential for marron to establish populations in the natural environment has yet to be established, however when considering marron for aquaculture, it is important to consider the design of the aquaculture system to reduce the risk of escapement (DAFF, 2012).

As with other crayfish species, the body of marron crayfish is made up of a head and thorax that is protected by a hard shell called a carapace, a muscular abdomen, and a tail. Marron are decapod crustaceans, which means they have 10 legs. These include large claws called chelipeds used for grasping food, fighting, and moving. The next pair of legs consists of two small pincers for picking up food particles and stuffing them into their mouths. Marron have two eyes at the end of their eyestalks but also rely heavily on touch and taste, using one pair of large antennae and smaller antennules. Marron Crayfish have been known to grow more than 350 millimetres (mm) in length and have been found to weigh 2.4 kilograms (kgs) in some cases. Marron are considered commercially viable when they weigh between 75 and 125 grams depending on the market requirements.

2.2. Legislative Requirements for Marron Production

As marron are native to Australia, and have been introduced to South Africa, they are classified as an alien invasive species (AIS). According to the National Environmental Biodiversity Management Act (NEMBA), marron are classified as a Category Two (2) invasive species since 2004. A Category 2 species is one that has been identified as being either invasive, or potentially invasive, and as such as permit is required to carry out specific, restricted activities. For marron production, permits and permissions are required for aquaculture activities, and under the NEMBA AIS legislation, the catch and release of marron from a water source is prohibited (DAFF, 2012; Department of Environmental Affairs, 2016; Invasive Species South Africa, 2018). In addition to the NEMBA: AIS legislation, some key legislation that should be considered when establishing a marron aquaculture operation include, but are not limited to the following:

- Fertilizers, Farm Feeds, Agricultural and Stock Remedies Act, 1947 (Act No. 36 of 1947),
- The National Environmental Management Act, 1998 (Act No. 107 of 1998),
- The Animal Health Act,2002 (Act No. 7 of 2002),
- Animal Diseases Act, 1984 (Act No. 35 of 1984),
- The National Water Act,1998 (Act No. 36 of 1998),
- Land Use Planning Ordinance, 1985 (Ordinance 15 of 1985), and

- Municipal town planning schemes (specific to location of the site).

2.3. Biological characteristics

According to Read (1985), marron are temperate water species, but will tolerate temperatures as high as 30°C and as low as 8°C, with adults being more resilient to lower temperatures (Cubitt 1985). Marron can tolerate salinities of up to 18 parts per million (ppm) but cannot survive very low oxygen concentrations or high nutrient conditions (Cubitt,1985). Marron are known to tolerate acidic conditions and have been successfully cultured with a pH of between 5 and 6.5 (Safriel & Bruton,1984). Marron require good quality water with minimal environmental disturbance (TSSC,2005). Like other crayfish species, marron can survive out of water for several days, which increases the biosecurity risk they pose as an alien invasive species in South Africa (Ackefors & Lindqvist,1994). As discussed above, marron are typically produced in semi-intensive pond systems, as they are bottom feeders, that require a low light environment for feeding and moulting.

Marron grow by a process of moulting, where the old shell of the marron is discarded and shed, allowing marron to grow a new body shell that starts off soft in texture. Marron then take up water within its body to expand its size and stretch the new body shell. The new shell begins to harden by absorbing calcium and nutrients that are stored within the marron's body. Moulting occurs frequently in juveniles but reduces in frequency as the marron get older (Fotedar, et al., 2015).The entire lifecycle of the marron is completed in a freshwater environment. Typically, marron mate in late August or early September, however depending on the temperature conditions as well as culture systems, this lifecycle can be advanced by a month.

Sexual maturity differs in marron, with some mating as early as 18 months while other marron mate in the third spring of their life at approximately 30 months old. However, it has been indicated that marron will breed earlier if they are exposed to warm temperatures for long periods of time, and this is useful for marron producers who seek to increase production volumes and alter breeding behaviour. Depending on the size of the marron female, the number of eggs produced ranges from 90 to 900 eggs and are carried by the female for about 12 to 16 weeks before they hatch. Once the eggs have hatched, they undergo two development stages before free swimming larvae that resemble marron adults can be identified (Fotedar, et al., 2015).

When considering the use of semi-intensive pond systems, the pond design and construction is important to ensure optimal conditions for marron to grow. According to Fotedar, et al. (2015), commercial marron operations typically utilise 1000 m² ponds, which can be supplemented by smaller grow-out and breeding ponds if required and the site area allows for additional ponds. In South Africa, the two marron operations identified stock their ponds with five (5) to seven (7) marron per m², which indicates that marron are typically stocked at low densities. It is estimated that in culture conditions, marron yields can range from two (2) to three (3) tons per hectare per annum (tons/ha/annum). However, when marron live in natural conditions, it is estimated that they yield 400 - 600 kg/ha/annum.

Marron aquaculture operations typically breed their own juveniles on site in specific breeding ponds. The generic economic model production cycle accounts for the initial purchasing of juvenile marron at start-up, which are grown out for a 24-month period. During this time the fastest growing males and females are selected as brood stock. The model allows for 5% of the marron grown per batch to be diverted away from sales and used for breeding. This model uses the assumption that marron are selected on the basis of mass selection, and not according to genetic relatedness. The model also accounts for 10% of the juvenile marron required, to be introduced from other juvenile suppliers or farmers to ensure some genetic diversity is maintained. It should be noted that gene pools for marron are limited in South Africa and acquiring juveniles or broodstock from a reputable Australian breeders every few years should be considered and breeding system that that does not allow for inbreeding be adopted. Such systems will however take considerable monitoring, tracking, and time to record each marron (i.e. ancestry/pedigree) or for genetic testing of each specimen. In order for the marron sector in South Africa to grow, new genetic stock from Australia will likely be required.

2.4. Physical requirements of the species

Physical requirements include feeding patterns and requirements, as well as water conditions that affect the production of marron such as water temperature, salinity, water pH, and oxygen requirements. These physical requirements are discussed below and were used to inform the production assumptions for the generic economic model.

2.4.1. Feeding

Marron feeding, and nutrition is a key challenge for producers as there is little known or published information available. While marron can go for weeks without food, they require regular and good quality feed for optimal growth and to be commercially viable (Fotedar, et al., 2015). When selecting marron feed, it is important to consider pellet size, and colour to ensure that marron will be attracted to the feed. Pellets should sink when dropped in water and should remain in pellet form for two (2) to three (3) hours but no longer than five (5) hours. It is important to ensure feed is of good quality and meets the needs of the marron. Given that access to good quality feed is a challenge in South Africa, the two marron producers in the Eastern Cape produce their own feed, which is typically sold for R15/kg (Bursey, 2017). Marron have somewhat messy eating habits, and regardless of the type and quality feed used, a percentage of the feed will be ingested by the marron while the rest of the feed will remain in the pond (Fotedar, et al., 2015).

For semi-intensive production systems (specifically ponds), there is little evidence on the optimal nutrient requirements of marron to ensure optimal growth rates are achieved. The primary manufacturer of marron feed in Australia (*Speciality Feeds),* has developed a specific feed aimed at reducing feed costs and meeting the nutritional needs of marron. The composition of the marron feed can be seen in Table 2-1 below.

Table 2-1: Marron Feed Nutritional Parameters

Protein	21.60 %
Total Fat	7 %
Crude Fibre	8 %
Metabolic Energy	11 MJ/kg
Dry Matter Digestibility	48.50 %
Calcium	1.50 %
Phosphorus	1 %

Adapted from (Specialty Feeds, 2009)

According to the Speciality Feeds guidelines, marron feeding rates are linked to the water temperature and the size of the marron, however the total intake in a pond system is normally 1.5 to 3% of the biomass weight per day (Specialty Feeds, 2009). A key factor identified when considering marron nutrition was the quality and type of pellets used. Pellets that are unstable and breakdown in the water are often ignored by the marron, thus pellets should be stable and last a sufficient period of time for the marron to feed before they start dissolving (Jussila & Evans, 1996). Recent data and studies on marron feeding and optimal nutrition in culture systems, specifically in South Africa is limited. Currently research and trials are being conducted in Australia to better understand marron feeding habits, ideal feed requirements and programmes required for optimal marron production.

2.4.2. Temperature

Although the optimal temperature range for marron production is between 20°C - 24°C (NDA,2012), marron crayfish can handle temperature ranges between 4°C and 30°C, however, according to Fotedar, et al. (2015), marron mortalities can be expected if temperatures exceed 26°C, and the growth of marron will be affected in temperatures lower than 12.4°C. Adult marron crayfish are more tolerant to cold temperatures than juvenile marron, especially during their developmental stages (Cubitt,1985). As such, it is advised that water temperatures should not remain at 12°C or less for more than three months of the year as this may affect production (Savage, 2017; Bursey, 2017).

2.4.3. Oxygen levels

Dissolved Oxygen (DO) in the culture system needs to be monitored constantly. As the marron breath, oxygen needs to be replaced in the pond to maintain its concentration. In South Africa, a DO level of about 7 to 10 ppm is recommended for marron production. According to Fotedar, et al (2015), DO levels that are lower than 6mg/L will stress the marron. DO levels in the water remains essential for maximising production and ensuring the survival of marron. The use of aeration in ponds is recommended to maintain the recommended oxygen levels and avoid stagnant water or stratifications in the pond.

2.4.4. pH Requirements and Water Hardness

The recommended pH for marron crayfish ranges between 6.5 and 7.5, if the pH is less than or greater than this, it will affect the growth rates of the marron (Safriel & Bruton,1984). Currently, producers in South Africa maintain pH levels between 6.5 and 8.5, and no higher than 9. Measures to control the pH include citric acid which reduces high pH levels, and lime which increases low pH levels (Personal Communication,2017). The water hardness should be above 100mg/L. When the hardness is below 50mg/L the marron shell softens, causing the production and growth rates to decline.

2.4.5. Ammonia and Nitrite Requirements

When considering marron production, the relationship between pH levels, nitrogen and ammonia levels is an important factor to consider. If pH levels of 7 - 8 are recorded, coupled with warm temperatures of 25°C to 35°C, the nitrification process will be rapid, ultimately impacting on the ammonia levels within the pond system. Furthermore, if ammonia levels become too high, feeding should be stopped, and marron stock levels should be reduced in the pond until the levels of ammonia have reduced or stabilised.

2.4.6. Water and Turbidity Requirement

Marron cannot tolerate a very high organic load in the water. This refers to water that is enriched by runoff from agricultural lands, continued additions of composts, or a high organic loading from plant remains in a dam (such as when grown in rice paddies). Water clarity is important because marron tend to feed at night when the light intensity is low. The turbidity of the water should support low light conditions in the ponds as it will assist with extending the feeding period daily (ACS Distance Education, 2017).

Ideally marron ponds should not be located downstream from dams or rivers, particularly when surface water is the primary water source. Marron are sensitive to chemicals, and any foreign contaminants will be toxic, and could potentially cause the failure of a marron project (Fotedar, et al., 2015; ACS Distance Education, 2017). When located downstream from dams or rivers, marron ponds may be contaminated with pesticides, herbicides, and other chemicals. While the presence of algae is not always ideal in aquaculture systems, beneficial algae presence is sometimes encouraged in marron ponds as the marron feed off the algae in addition to the feed being given to them. However, the algae levels need to be monitored to ensure there are no major algae blooms.

3. Potential Culture Systems for Marron Crayfish

The potential production systems identified are considered in the generic economic model to determine the financial feasibility of each system from an economic perspective. Each production system is unique in terms of the infrastructure requirements and operational costs associated with the system. The potential culture systems that could be used to culture marron in South Africa include the following:

3.1. Recirculating Aquaculture Systems

The use of Recirculating Aquaculture Systems (RAS) for marron production in South Africa, and globally remains untested and undocumented, making it a challenge to provide information and technical requirements for RAS system. This section will provide a general overview of RAS. According to technical experts in South Africa, tests that have been done to produce marron in a RAS showed high mortality rates, thus the success and viability of this system is yet to be determined.

RAS offers a dual objective of sustainable aquaculture, (i.e. to produce food while sustaining natural resources) which is achieved through the minimum impact the system has on its surrounding environment and the eco-system in general. RAS is sometimes referred to as indoor or urban aquaculture, reflecting its independency of surface water to produce fish. Water recirculating methods of aquaculture production is ideally suitable for areas with scarce water resources. The benefits of using recirculation technology include the possibility of more regulated temperatures, and securing high and constant water quality, which can lead to improved growth potential and health of the animal. The capital investment for farm construction is often higher for RAS when compared to that of conventional aquaculture systems (pond culture, cage culture, flow-through systems etc.). As such, the system should be designed and constructed in a manner that would allow for the system to be managed at less running costs in order to compensate for the initial capital investment.

Advantages of using the recirculating aquaculture systems

I. RAS requires a smaller land area and water than conventional aquaculture,
II. Allows higher stocking densities, and provides greater control over the culture environment,
III. Allows for intensive aquaculture production to be undertaken on a smaller footprint,
IV. Can be located in areas that do not have sufficient water resources for conventional aquaculture operations,
V. Provides opportunities to reduce water usage, improve waste management and increase nutrient recycling,
VI. Allows for better hygiene, disease management, biological pollution control and reduction of visual impact of the farm,
VII. Given that marron is an alien invasive species, RAS is the recommended production system in terms of biosecurity and reducing the risk of marron escaping into natural water systems.

Disadvantages of using the recirculating aquaculture systems

I. The operation of the system requires some level of skills and expertise,
II. There are many different bio filtration systems involved in operating a RAS. These would need to be screened and adapted to marron production,
III. Large capital investment is required for building and starting up facilities,

IV. Costs of operating the RAS,
V. Managing disease outbreaks may pose specific challenges in RAS, in which a healthy microbial community contributes to water purification and water quality,
VI. Minerals, drug residues, hazardous feed compounds and metabolites may accumulate in the system and affect the health, quality, and safety of the marron,
VII. Recirculating water may not be suited for marron production.

3.2. Aquaponics Systems

The culturing of marron in aquaponics systems remains untested, and undocumented in South Africa, and globally, making it a challenge to provide detailed information and technical requirements for the aquaponic system. Currently it assumed that Aquaponics is unsuitable for marron, due to the marron's low tolerance of high nutrient content in water and the low oxygen levels which can be experienced in standard aquaponic systems.

3.3. Flow Through Systems

The culturing of marron in flow-through systems in South Africa, and globally remains untested, and undocumented, making it a challenge to provide detailed information and technical requirements for the flow-through systems. Marron do not require regular water exchanges, or a water current/moving water for production, thus flow-through is not currently considered as a viable option for marron.

3.4. Raceway Systems

The use of raceway systems for marron production in South Africa, and globally has not been tested, and as a result there is limited information, technical requirements, or data available. Marron don't require a current or fast flowing water as they are bottom feeders and prefer still water conditions. Raceway systems are not recommended for marron production.

3.5. Cage Culture

Cage culture is a system which could be used in countries with access to large bodies of water. In this system, it is possible to grow out a large amount of crayfish in huge cages that have been manufactured from mesh. Mesh is usually used in manufacturing the cage system as it allows water to pass freely through the system. Modern cage cultures began with the advent of synthetic materials for cage construction. Most systems are fixed in one location. These moving systems can help to keep the environmental impact on the area within acceptable limits. The use of cage culture for marron is currently not applicable due to the high risk of escape, low oxygen levels and potential production challenges as marron are bottom feeders.

3.6. Ranching System

Ranching would involve raising marron in a hatchery for a brief period then releasing them into water bodies for further development. When the marron have reached their maximum size, they would then be harvested. Ranching is widely practised in areas with sandy or rocky bottoms, about 15 to 20 metres deep. Records of ranching systems used for crayfish production in Australia have been identified, however ranching crayfish is considered an extensive farming method, where large, non-drainable dams or lakes are used, often with a "stock-and-forget" approach. This type of extensive approach is not suited for commercial marron operations, as the semi-intensive approach allows for better management, monitoring, and ease of harvesting for marron producers (Holdich, 1993).

3.7. Pond Culture Systems

Pond culture is the preferred and dominant culture system for marron, in both South Africa and globally. Marron have been produced in farm dams, irrigation dams, earthen ponds as well as purposefully constructed ponds. The use of earthen ponds is the most common, with the water being oxygenated by making use of paddlewheel aerators. Unlike flow-through, raceway and RAS systems, the pond system requires partial water changes every few weeks to ensure the removal of sediment and dead marron, and to ensure that the water quality is maintained. While earthen ponds and dams are commonly used, they pose several challenges, specifically regarding the control of environmental factors, feeding programmes, aeration techniques, and variable production yields that can be achieved.

Semi-intensive, constructed ponds are increasing in popularity as they offer the highest degree of control and yields, however this method of pond culturing requires a higher level of capital investment to establish and manage. Marron pond design takes into consideration the harvesting, restocking, and monitoring of the marron, thus ensuring the production system is user-friendly and implementable. As the culture system maintains a constant environment for marron, yields are expected to be higher than marron occurring naturally or in dams.

There are several key considerations that should be made before designing, constructing, or stocking a marron pond. Firstly, site selection is a crucial aspect that can determine whether marron production will fail or succeed, as a site needs to support the filling and draining of marron ponds being used. In addition to site selection aspects such as topography, slope, clay and soil conditions, climatic conditions and water sources should also be considered carefully (Fotedar, et al., 2015). A constant supply of water is required, and if surface water is selected as the main water source, caution should be taken as unwanted fish may enter the marron ponds. Water should therefore be filtered to remove any ova, fingerlings, adult fish or any other animals or insects that may attack or consume young crayfish (ACS Distance Education, 2017).

Furthermore, when considering earthen marron ponds, the pond preparation process is based on the soil type and conditions for the selected site. Ideally, the soil should have about 32% - 36% clay content to assist with water retention and reduce the need for additional construction. In addition to clay content, soils that present high levels of organic matter can result in higher yields due to the presence and productivity of both healthy algae and zooplankton. Pond systems, although less technical and complex than other culture system, require careful thought and consideration, especially with regards to site conditions, environmental factors as well as physical construction and design of ponds. Poor pond design can result in low productivity or in extreme cases, the failure of the marron operation (Fotedar, et al., 2015).

Advantages of using pond systems

- Can be specifically designed to produce marron,
- Semi-intensive ponds have higher yields than dams or natural occurring marron populations,
- Semi-intensive ponds allow for monitoring, and stricter production programmes,
- Entire life cycle of marron can be completed in freshwater pond systems (reproduction, growth & harvesting phase),
- Can be incorporated into existing farming operations with ease,
- Require less technical infrastructure in comparison to other culture systems, and
- Can be done on small, medium, or large scale.

Disadvantages of using pond systems

- Earthen ponds or dams have several challenges that affect marron production,
- Marron can be cannibalistic – juveniles should be separated from adults,
- Culture systems must be enclosed to ensure marron cannot escape,
- Pond systems can experience threats from wildlife, (birds, predators etc),
- Materials used to construct ponds can affect mortality, growth, and survival rates,
- Poor design and/or construction of ponds can affect the success of the operation, and
- Site selection and environmental conditions play large role in success of operation.

Marron Pond Design

When considering the design of a pond for marron production, it is important to consider aspects such as topography, slope, water quality and source as well as the availability of infrastructure on the site, specifically electricity. According to Fotedar, et al. (2015), the following consideration should be made when selecting a pond site:

I. **Topography:** The site should be located far away from major sources of pollutants, contaminants, or flood prone areas,

II. **Slope:** It is recommended that the site should have a slope of approximately 2% - 4%, which means that a drop of two (2) to four (4) metres per 100 metres of length. When constructing ponds for commercial production, a slope over 5% can increase construction costs and increase land requirements,

III. **Soil:** Soil should have approximately 32% to 36% clay content to assist with water holding capacity,

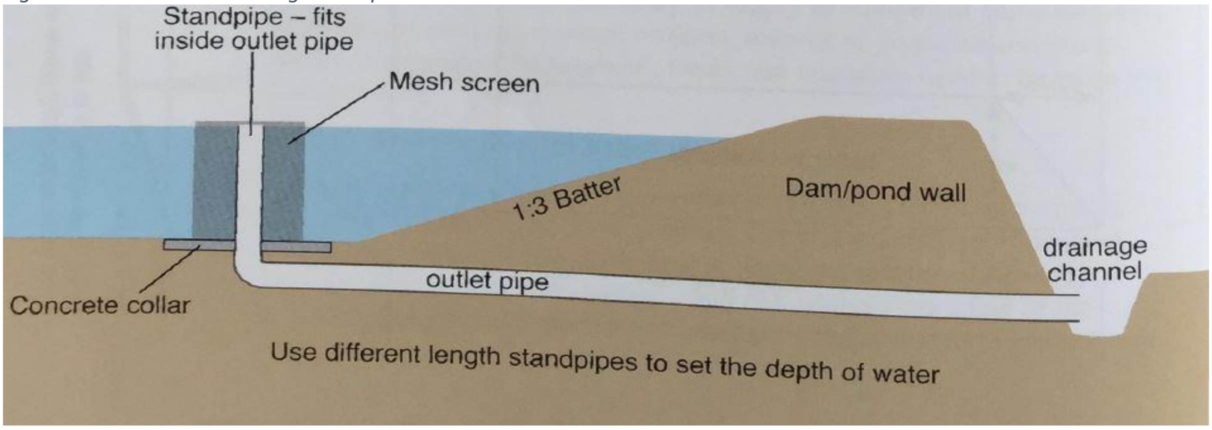
IV. **Water:** Water should not contain any chemicals or pollutants as this will affect production. It is estimated that water usage ranges between 14 -28 megalitres per hectare per annum, depending on evaporation rates and temperature at the pond location.

Ideally for commercial production, the size of the pond should equal to a minimum of 1000 square meters (m^2). Ponds should be rectangular to assist with natural aeration where applicable. While a 1000 m^2 pond is considered the minimum, and optimal size, ponds larger than this can be challenging to manage. In addition to the main production pond, breeding or nursery ponds can be included, although smaller in size (400 -500 m^2), these ponds can be a valuable addition to marron operations.

The maximum depth of the pond should be between 1.8 – 2 metres at one end of the pond and sloping down to approximately one (1) metre at the opposite end. However, it should be noted, in areas where very high summer temperatures are experienced, ponds can be made deeper to account for temperature increases.

To drain the pond for cleaning and harvesting, careful consideration must be made when designing the pond to ensure ease of cleaning and draining the ponds, as seen in Figure 3-1 below.
Ponds should have a bottom water take-off pipe to control water levels, and an outlet pipe that allows for a sufficient drainage rate. Size and design of the outlet must be related to the pond volume selected, and as such for a 1000 m² pond, and outlet pipe should be an estimated 150 mm in diameter.

Figure 3-1: Marron Pond Design Example



Source: (Fotedar, et al., 2015)

In addition to pond design, consideration must be given to water aeration and keeping the marron in the ponds. Water aeration is particularly important in summer or in warmer months of the production cycle as marron use more energy and oxygen during this time. In terms of keeping the marron in the ponds, this is an important aspect to consider, specifically due to the Alien Invasive Species (AIS) of marron in South Africa. Ponds should be covered with netting to prevent birds from eating and/or removing the marron from the ponds. Other provisions such as fencing, or mesh should be placed around the ponds to prevent marron from escaping. In terms of marron production in South Africa, the following guidelines should be followed when considering pond culture:

I. Aquaculture ponds and dams must be designed and constructed to allow for complete drainage,
II. Aquaculture ponds and dams should have adequate overflow capability and flood protection (e.g. by means of stabilized spillways) but should also allow for early detection of rising water levels that could cause flooding. This means that inflow and outflow control is of importance,
III. Where earthen ponds and dams are used, the inner walls must have a suitable slope to prevent internal erosion and collapse. Furthermore, the effects of surface wind and wave erosion must be combated by means of vegetation establishment or stone packing,
IV. If pond or dam's sediments are removed, these must be disposed of responsibly or used as compost,
V. Trees and other large plants should not be allowed to grow on the retaining walls of earthen ponds and dams as their roots may weaken the structure,

VI. Adequate control measures should be put into place to prevent moles and crabs from digging into the retaining walls of earthen ponds and dams as these may destabilize the structure,

VII. Aeration apparatus (e.g. agitators, paddlewheels, etc.), pumps and water inlets should be placed and managed to prevent internal erosion of earthen ponds and dams, and

VIII. Electrical installations associated with pond culture (e.g. for pumps, aerators, and electric fences, etc.) should be safe and well maintained (Provincial Government of the Western Cape, 2007).

3.8. Culture System Summary

Having presented the advantages and disadvantages of various culture systems for marron production in South Africa based on local and international literature, Table 3-1 below provides a summary for each production system and gives an indication of whether the system is viable or non-viable for marron production in South Africa.

Based on the system status, the generic economic model was developed to provide additional insights into the financial viability of the potential systems, and this will be discussed in the financial analysis section.

Table 3-1: Marron Crayfish Production Systems Summary

System	System Overview	System Status
Pond Culture	I. Tested and utilised system in South Africa II. It is the most typical culture system for marron III. Risk of escapement is high but can be mitigated IV. Water quality and soil type is very critical for successful operation V. Pond design and management is essential for success VI. Long turn-around time on investment VII. Breeding occurs once in a year; no monthly rotation can be done	Viable
Cage Culture	N/A	N/A
Aquaponics	I. Marron not tolerant of water with high nutrient levels or low oxygen which can be associated with aquaponics	Non-viable
RAS	I. Currently being tested in South Africa II. Preferred system for biosecurity purposes and for alien invasive species	Untested
Flow-through systems	I. Untested system	Untested
Raceways	I. Untested system	Untested
Ranching	I. Used as extensive farming method in Australia II. Not recommended in South Africa -high biosecurity risk III. Not suited for commercial production scale	Non-viable

From the table above, it can be seen that pond culture is currently the only viable system in South Africa for marron. Other systems discussed above such as aquaponics, RAS, flow-through and raceway systems have not yet been tested or they are considered unsuitable for marron in South Africa. As such, no conclusion can be drawn on them to determine whether or not they are economically viable for marron production.

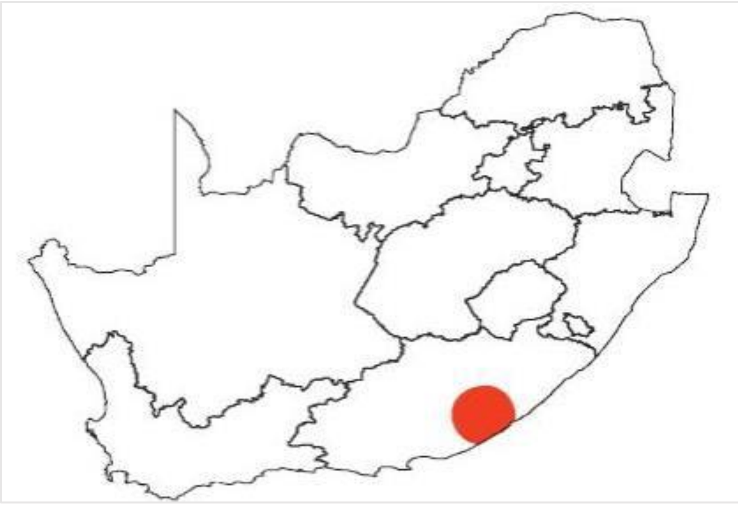
4. Geographical distribution of marron crayfish in South Africa

As the climatic and geographic conditions differ across South Africa, it is important to understand the suitability of the nine provinces for marron production. Temperature is a key influencing factor for aquaculture as it determines and impacts the type of production systems that can be used, and has financial implications related to water heating and infrastructure costs. All these factors have been taken into consideration in the generic economic model for marron.

4.1. Distribution and Suitability Assessment

A key factor considered in determining the suitable regions for the production of marron in South Africa, is the optimal temperature under which they can survive and grow. Other factors such as water quality, soil quality, topography, and infrastructure are also important, these factors should be considered at a site-specific level. The tolerable temperature range for marron is 4°C - 30°C, however, the optimal temperature range for marron is between 20°C and 24°C. This restricts the growing season to the warmer months in South Africa, and the areas that can be utilised for marron production. Currently in South Africa, only two marron operations are recorded, both of which are located in the Eastern Cape Province. These findings correlate with Figure 4-1 below.

Figure 4-1: Introduced range of Marron in South Africa



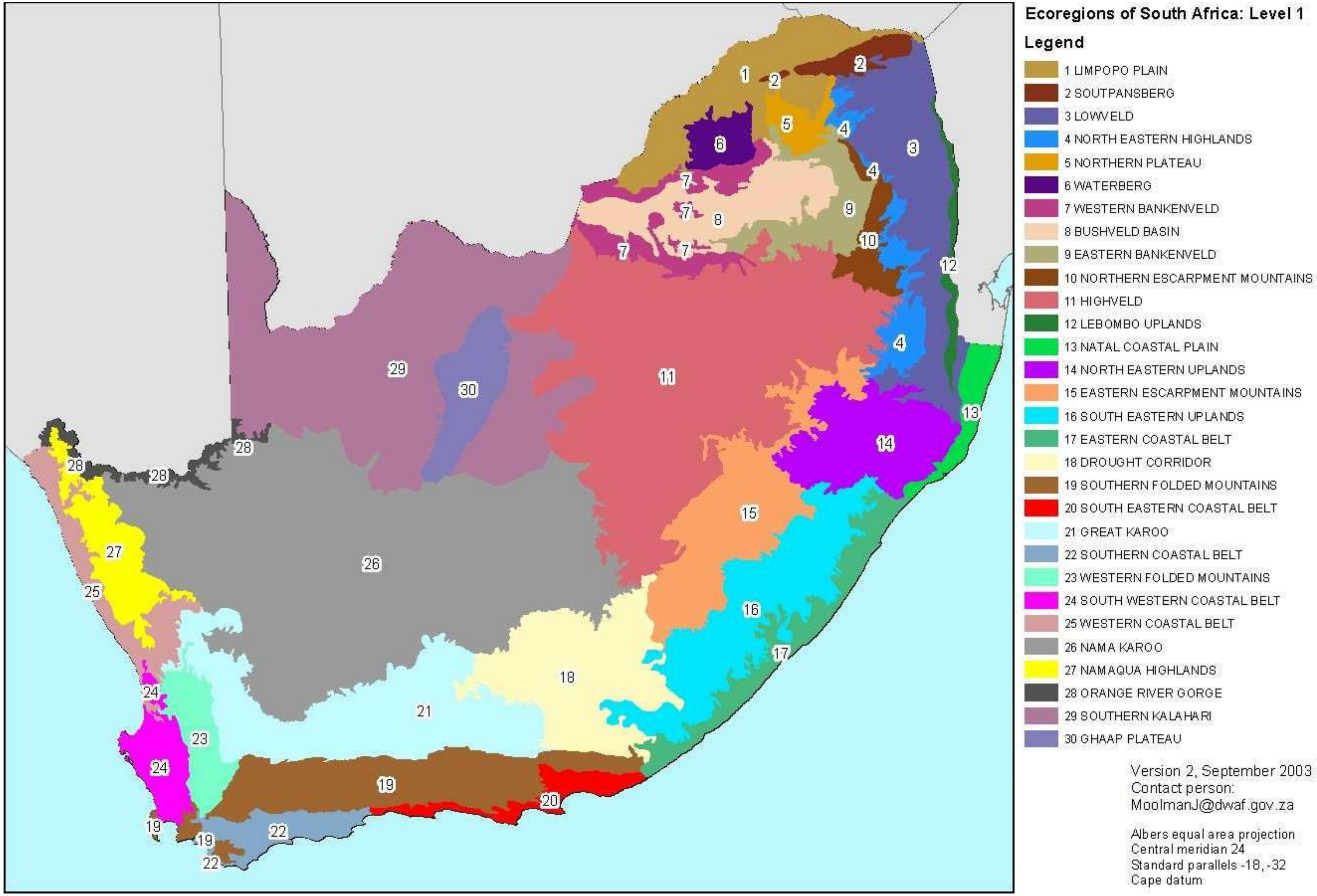
Source: (DAFF, 2012)

Although the figure above identifies the existence of marron only in the Eastern Cape Province, through the *Cherax Cainii (previously named C. tenuimanus) Biodiversity Risk and Benefit Assessment (BRBA),* it was identified that out of the 31 eco-regions[1] in South Africa, marron can survive in all but one region, which is the eastern escarpment mountains (region 15) within the Eastern Cape as the winter temperatures are too low. The ability of marron to survive in such a wide range of temperatures make it suitable for pond culture almost anywhere in South Africa. This, however, is a biosecurity risk as should marron escape from an aquaculture operation, they would be able to survive and reproduce within the natural environment, posing a threat to the indigenous species and eco-systems. The eco-regions identified are suitable based purely on altitude and temperature basis, however, based on climatic conditions and current production trends, the Eastern Cape, Limpopo,

[1] *The eco-regions are based on air temperature and not water temperature ranges.*

Kwa-Zulu Natal, Gauteng and North West are recommended as potential areas most suited to marron production.

Figure 4-2: South Africa's Eco-regions



Source: (DAFF, 2012)

4.2. Key Location and Site Requirements

Typically, marron production is incorporated into an agri-business or an established farm environment, as the establishment of a marron farm on its own is capital intensive and can be a risky investment. There are several factors that can influence the success of an aquaculture enterprise; site selection is one of the most important factors and often does not get adequate attention. Important factors that have to be considered in selecting a specific site for marron production are:

I. Climate (water and environmental temperature),
II. Slope and topography (avoid flood prone areas),
III. Soil type (applicable to open culture systems),
IV. Proximity to natural water bodies – biosecurity risk,
V. Quantity and quality of water must be analysed (pH, alkalinity, ammonia, nitrite, etc.), and
VI. Proximity to market (market research, demand, price etc.).

4.3. Key requirements for profitability

In addition to the financial results obtained from the generic economic model, the following factors should be considered as they could impact on the profitability of a marron farm:

I. Permits for the production of marron,
II. Appropriate water temperature,
III. Appropriate water quality and quantity,
IV. Suitable site with right soil type, slope, and topography,
V. Economies of scale and consistent volume of production,
VI. Size of the operation – two hectares of ponds can yield two tons according to South African producers,
VII. Good access to production inputs and support services,
VIII. Good management practices,
IX. Access to markets, and
X. Biosecurity management.

5. Marron Crayfish Market assessment

In this section of the report, the overall global freshwater crustaceans' industry, crayfish farming and the South African farmed marron as well as its role in the market will be assessed. The section will cover the production and consumption trends of marron, both globally and locally focusing on marketing channels, market requirements, and barriers to entry.

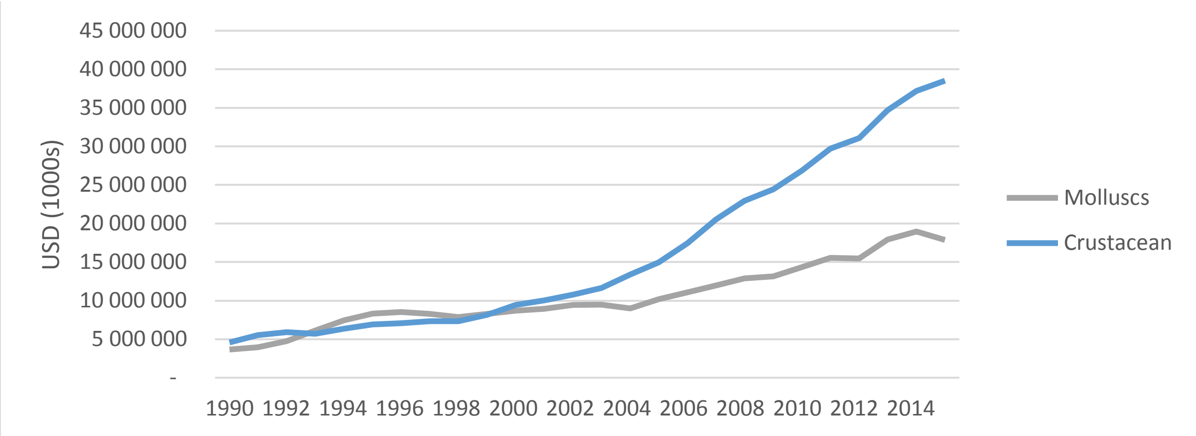
5.1. Production and consumption

The production and consumption analysis provides an overview of the global, regional, and local supply, demand, and consumption trends for marron.

5.1.1. Global Supply Analysis

Crustacean aquaculture is a multi-billion-dollar global industry, estimated to be worth approximately USD 40 billion in 2015, and has been expanding rapidly since early 2000's. The crustacean industry is thought to be worth nearly double that of the mollusc industry as seen in Figure 5-1 below (FAO, 2017).

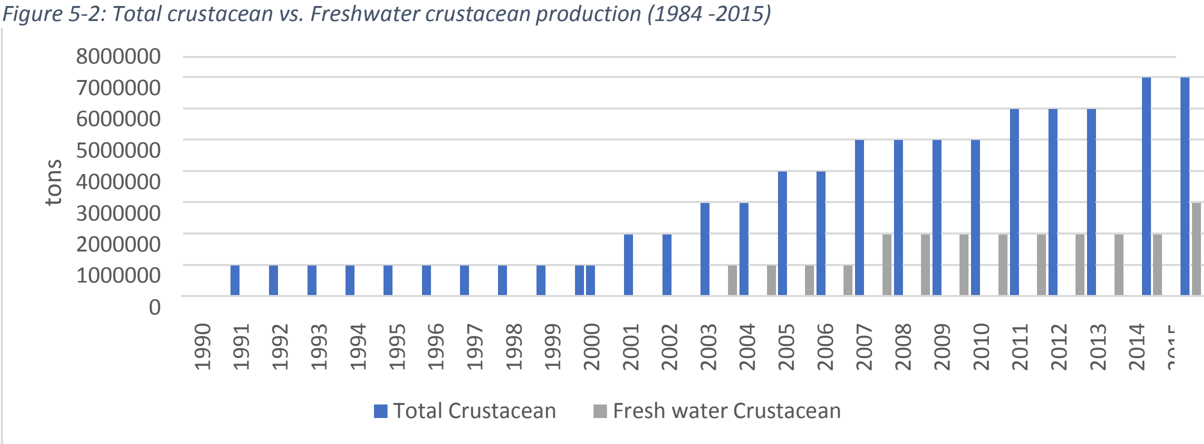
Figure 5-1: Comparison of Molluscs and Crustacean global production (in value) (1990 -2015)



Source: (FAO, 2017)

Within the commercial crustacean aquaculture, freshwater crustacean has become a dominant component since early 2000's, contributing about 40% of production of the industry (an estimated value of USD 15 billion) in 2015 (Figure 5-2).

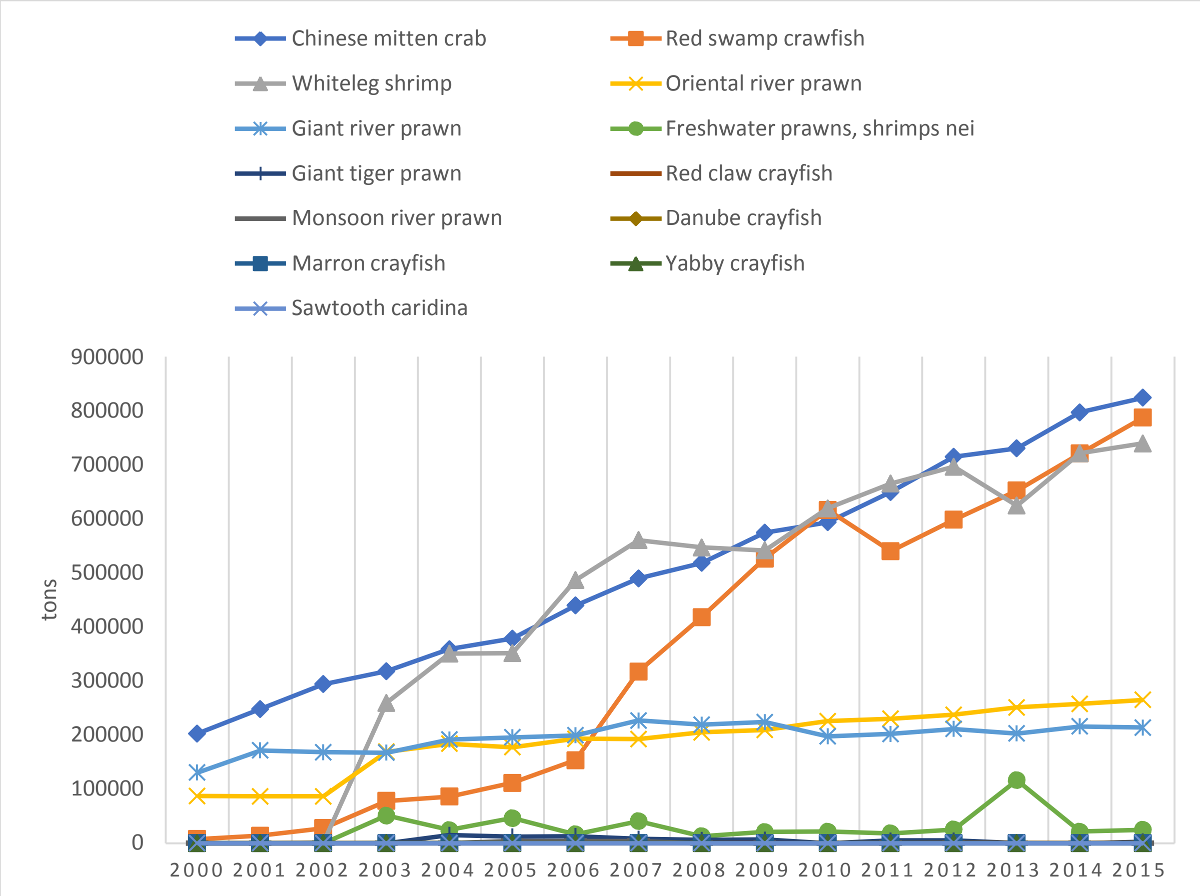
Figure 5-2: Total crustacean vs. Freshwater crustacean production (1984 -2015)



Source: (FAO, 2017)

Of the farmed freshwater crustacean species, Chinese mitten, Red swamp crawfish and Whiteleg shrimp contributed the highest in production and value (2000-2015), followed by freshwater prawn namely the Oriental river prawn and Giant river prawn as seen in Figure 5-3 below (FAO, 2017).

Figure 5-3: Freshwater crustacean production composition (per key species) (2000-2015)



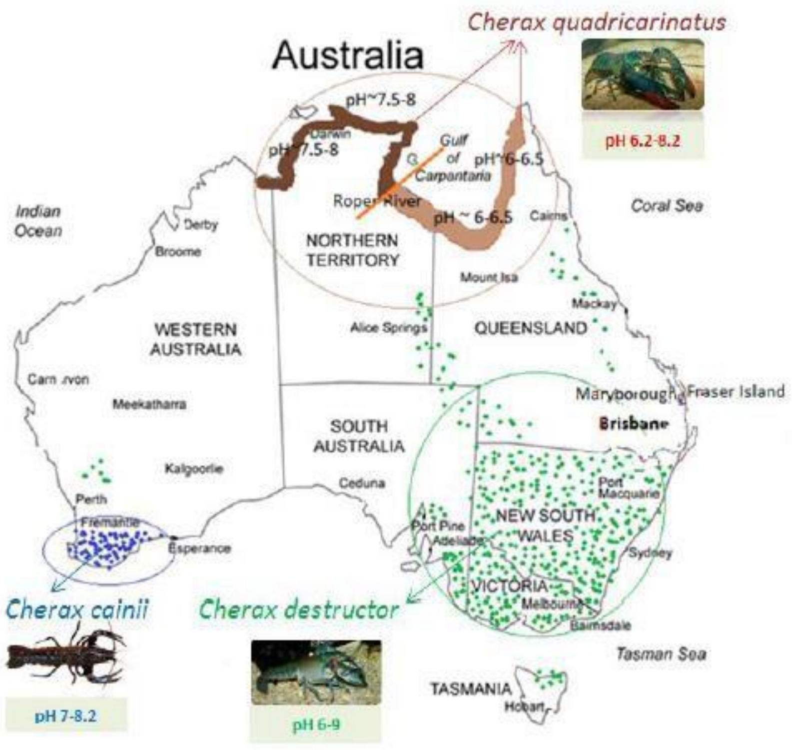
Source: (FAO, 2017)

Although the freshwater sector is dominated by the Red swamp crawfish, the Chinese mitten, and the freshwater prawn's species, additional commercial value exists specially within the crayfish species (Crayfish are freshwater species as opposed to lobster which is a marine species, and they are larger animal than the crawfish, shrimp, and prawn species).

A variety of crayfish species are currently being farmed around the world. They can be divided into smooth crayfish, spiny crayfish, and burrowing crayfish. Species showing the best commercial potential are the smooth crayfish species, including: the yabby (*Cherax Destructor and Cherax. Albidus*), the Redclaw (*Cherax. Quadricarinatus*) and the marron (*Cherax. cainii*) (Government of Western Australia, 2015).

These commercially important Cherax species, endemic to Australia, have a range of natural distributions across a diverse range of aquatic habitats as shown in Figure 5-4 below. Hence, the relative commercial suitability of each species depends on locality, climate, and habitat (Australian Government Department of Agriculture, 2015).

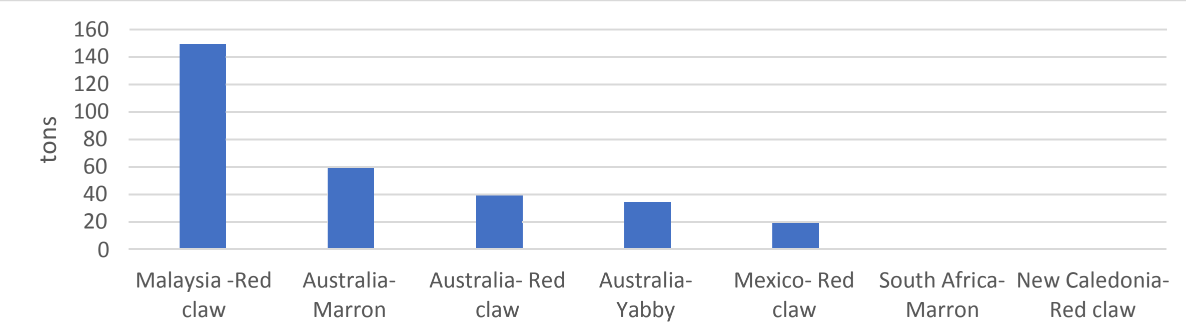
Figure 5-4: Natural distribution of Cherax Quadricarinatus (Redclaw), C. Destructor (Yabby) and Cherax Cainii (Marron) within Australia



Source: (Muhammad, 2016)

All of the Cherax species have been developed for aquaculture production around the world, most notable is the farming of the Red claw in Malaysia, Australia, Mexico New Caledonia and in Ecuador, Uruguay, Argentina and China (Muhammad, 2016); marron in Australia and South Africa; and yabby in Australia as seen in Figure 5-5 below (FAO, 2017).

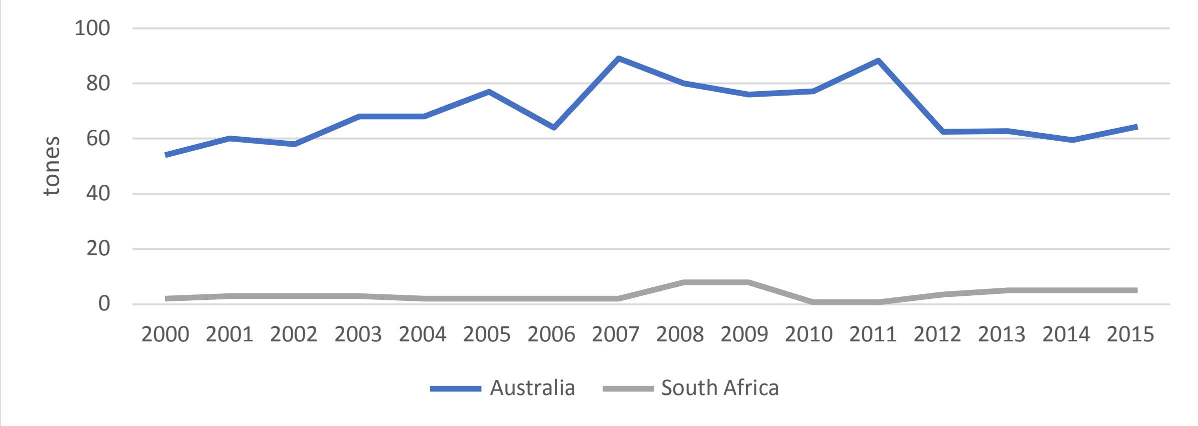
Figure 5-5: Global crayfish (Cherax species) production per a country during 2015



Source: (FAO, 2017)

Among the species mentioned above, marron, which is the top third largest crayfish species in the world (Government of Western Australia, 2015), present a good trading value and business opportunity. Marron farming is restricted to natural environments in South-West Australia, while in South Africa, the species has experienced limited production volumes (FAO, 2017) (refer to Figure 5-6 below). Total production in 2015 recorded in Australia was at 64.3 tons while in South Africa, production reached approximately four (4) tons during 2015 (DAFF, 2017).

Figure 5-6: Production of Marron in Australia and South Africa (2000-2015)



Source: (FAO, 2017)

5.1.2. Local Supply Analysis

In South Africa, the *Cherax caini (smooth marron)*, was introduced into the country in the early 1970's and since then, it is considered as an attractive candidate for the aquaculture sector. Despite it's potential, the industry has not developed substantially in size, which is mostly due to production challenges (Bursey,2017; de Moor, 1988). With regard to South African based marron operations, during 2016, one marron farm located in the Eastern Cape was reported to be producing smooth sarron, using tanks during the juvenile phase, followed by the semi-intensive pond culture for grow-out stage (DAFF, 2017). During stakeholder engagement, an additional farm (operational for 23 months) was identified in the Port Elizabeth region with an estimated capacity of over one tonne a year (Savage, 2017).

5.1.3. Demand Analysis

Global aquaculture markets trends indicate that market expansion will grow faster in value than in volume. This can be attributed to the rapidly expanding middle class in the world (specifically in China) with the highest preference for high-value seafood consumption such as crustaceans (Rabobank, 2016). Crayfish are case in point, whereby a growing market such as in China has developed since the 1990's into a multi-billion-dollar industry worth about USD 2.15 billion during 2015 with consumption of 879,300 tons of which the Red swamp crawfish (also known locally as" little lobster") contributed was about 723,207 tons (South China Morning Post, 2017; FAO, 2017). This market growth could be explained by the change of local Chinese consumer behaviour who in the past disliked crayfishes and today it is considered as a lucrative food and is part of their expensive cuisine (South China Morning Post, 2017).

Other key markets for crayfish include the USA, EU, and Russia. The USA's crayfish (known as the crawfish) industry is well developed with about 63690 reported tons of Red swamp crawfish produced for the local USA market with an overall value of USD 172 million (FAO, 2017). The market is expanding further with the supply by the importation from China (Welovecrawfish.com, 2017). The EU market is dominated by several countries with the highest trade value including: France, Germany, Belgium, Spain, and Romania as seen in Table 5-1 below.

Table 5-1: Top EU markets in value during 2017

Country	Market Size (EUR 1000)
France	5.851
Germany	0.886
Belgium	3.216
Spain	1.712
Romania	1.216

Source: (Eurofish, 2017)

The most common crayfish consumed in the EU is the European crayfish (*Astacus astacus*) ranging in size from 12-16 cm in length. These crayfish are indigenous and widespread throughout Europe extending from Russia and Ukraine in the east, to Finland, Sweden, Norway in the north, to Greece in the south, and the United Kingdom and France in the west. The EU market is mostly served by its local production (Eurofish, 2017). The Russian seafood market is noticeable in size. Of the total Russian market, crustaceans and molluscs are taking 10%, and during 2013 FAO reported that Russia imported about 3,865 ton of crayfish (FAO, 2017). This positioned the Russian market as an important international crayfish market.

The above information demonstrates the location and size of various international crayfish markets, which existing and new marron farmers could penetrate in future. Benefiting from its large size, the marron could either outcompete existing supply or offer a new niche product by differentiating itself from the Crawfish, Red swamp crawfish and the Noble crayfish (European species). The global marron production confined mostly to Australia, is consumed by the local Australian market. The year around demand is met by mixing harvested animals from the semi-intensive farms and the extensive farms (who can supply in different time of the year) (Fotedar, 2015). South Africa faces a similar situation where all the marron produced are consumed by local markets, with a focus on the coastal region upper-class restaurants aim during the holiday seasons. The potential for additional local producers is unknown at this stage but from industry engagements, the markets could easily absorb a few more tons a year (Bursey, 2017).

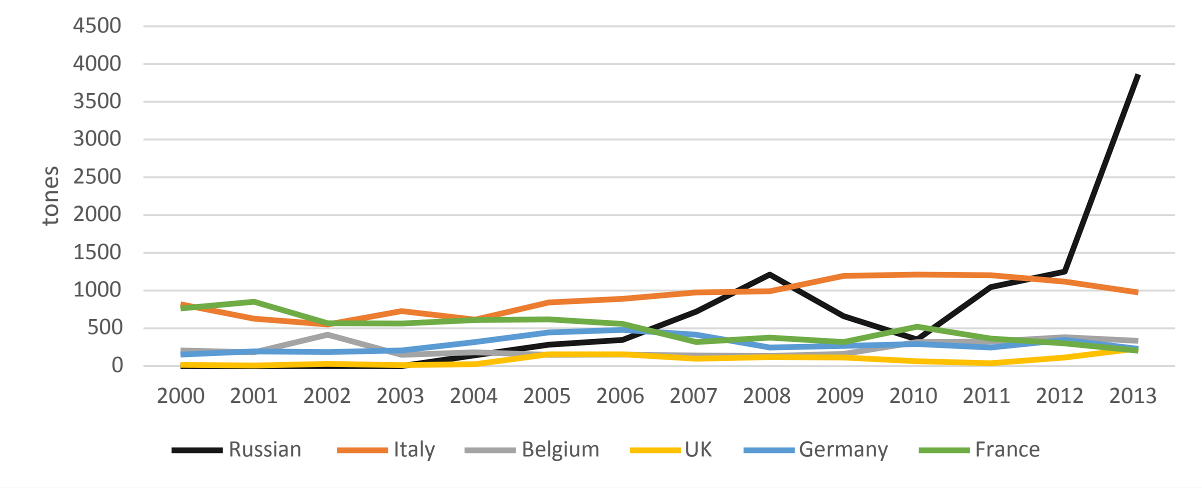
5.2. Marketing channels

The marketing channels look at the global and local trade of Crayfish, with a specific focus on marron in South Africa. The generic economic model takes both local and international markets into consideration and offers flexible pricing options which are dependent on the size of the marron being produced and the target market identified. The pricing of the marron, and the target market impact on the financial results obtained when using the generic economic model, as these two factors play a key role in determining the profitability of an operation. Understanding the markets, pricing and preferred products for the market is essential.

5.2.1. Global Marron Trade

Global trade of crayfish can be divided into frozen and fresh products. For purpose of this report, which assumes that marron is typically traded as a live animal, fresh product trade will be discussed. According to the FAO (2017), the top global 6 countries that import freshwater crayfish are Russia, Italy, Belgium, the United Kingdom, Germany, and France as seen in Figure 5-7 below (FAO, 2017).

Figure 5-7: The top leading global importer countries of freshwater crayfish (2000-2013)



Source: (FAO, 2017)

Limited information is available on the Russian crayfish trade however, the overall size of the Russia crayfish market is significant in size and was estimated to be 3865 ton during 2013. The crayfish export trade information is also very limited and fragmented, with records from 2013 available from FAO database including 105 tons exported from China, 15 tons from Armenia, 11 tons from Morocco and 5 tons from Turkey (FAO, 2017). In the EU countries, significant quantities of crayfish are exported to other markets. Most EU exports of crayfish find markets in other EU Member States. In recent years, the largest export markets include France, Germany, Belgium, Spain, and Romania. Together these importers accounted for approximately 69% - 84% of total exports between the year 2012 and 2015 (Eurofish, 2017).

5.2.2. Local Trade of Marron

The Australian marron trade is mostly focused on the domestic market. Most off-takers are local restaurants in key urban areas. Potential trade is foreseen on the global markets, focusing specifically on the restaurant and hospitality industries (Fotedar, 2015).

The demand for marron in South African currently outweighs the supply. Continued local enquiries from major urban markets in Johannesburg, Durban and Port Elizabeth for supply cannot be supplied due to limited production in the country (Bursey, 2017). Local demand and trade increases during the holiday seasons particularly between December and January, where approximately 60 to 100 kilograms of marron are supplied weekly, through one main wholesaler /distributor who transports the marron by air from the farm in the Eastern Cape into a holding facility and then re-distributes the marron to Cape Town's top restaurants (Baker, 2017; Bursey, 2017).

Potential export markets to Hong Kong or Japan present an additional specialised market opportunity for South African producers with an animal size of 100 - 120 grams (Savage, 2017). However, due to limited and seasonal stock offered, no export trade currently exists.

5.3. Market requirements

Market requirements look at the status of global and local markets to provide an overview of consumer and market preferences, as well as potential market opportunities that can be targeted by the marron industry.

5.3.1. Global Markets

Both freshwater and marine crayfish species are a popular choice with consumers, holding a social and cultural significance and are commonly eaten during festive warm-weather occasions.

Many smaller crayfish producers develop their own markets, either through direct sales to restaurants and catering services. Some producers sell their product to larger producers who act as wholesalers. Crayfish are most often marketed live, while the rest marketed in fresh or frozen forms (Eurofish, 2017; Government of Western Australia, 2015; Fotedar, 2015). Live crayfish can be transported long distances provided that they are kept cool and moist. Fresh or frozen crayfish, like other crustaceans, deteriorate quickly after death and have a shorter shelf life. Fresh or frozen crayfish can be marketed either whole or as tail meat only. Whole crayfish are priced by size, with larger crayfish commanding higher prices. Product quality, appearance (e.g. no missing legs) and consistency of supply are also important marketing factors (Eurofish, 2017).

In the EU, crayfish are marketed in a variety of forms, and therefore have different retail prices. In one of the UK online retailers, a 2-kilogram block of whole crayfish was offered for EUR 21,78/kg, while a 1-kilogram block of peeled tails was priced at EUR 48,03/Kg (Eurofish, 2017). Retail stores in the main European markets showed that retail prices for crayfish in EU supermarkets varied considerably by country and product form. Highest prices were recorded in Netherlands for EUR 34.90/Kg for frozen crayfish, fresh tails were priced at EUR 37.40/Kg in Germany, and Denmark, frozen cooked tails were priced at EUR 39,20/Kg (Eurofish, 2017).

In the USA, crawfish is sold at local outlets, as boiled and cooked dishes, which is a popular favourite with the consumers. Prices to producers are seasonal and are highest in winter and early spring when supply is relatively low. Prices decline significantly in late spring and summer when supply and demand for other locally produced fresh seafoods such as shrimp and crabs increase.

Figure 5-9: Crawfish Outlet in the USA

Figure 5-8: Peeled & Cooked Crawfish

The marron industry remains relatively small, the potential for the growth and development of the industry is evident as it can be identified by opportunities enjoyed by other freshwater crayfish species. The Australian marron market primarily supplies local restaurants who prefer a regular supply of two size classes, namely 500-gram marron or 130 grams or less (Fotedar, 2015). Prices of live marron sold on ice is dependent on the product size as shown below:

- 150-200 grams for USD 33/Kg,
- 200-300 grams for USD 35-40/Kg,
- 300-400 grams for USD 46/Kg, and

- 400 grams or more for USD 50/Kg.

5.3.2. The South Africa Market

On the South African market, the preferred marron size ranges from 100 - 120 grams, and producers can receive up to R200 per kilogram (Bursey, 2017; Savage, 2017). Larger marron that are traded at a weight of approximately 350 grams can receive as much as R300 per kilogram at local high-end restaurants. Consumer preference is driven by visuals such as size (mostly small and medium around 100 - 120 grams), complete body (two claws), freshness, clean, as well as the natural colour of the marron (Bursey, 2017). Potential international export markets for South African growers could include Hong Kong and Japan who prefer frozen or live marron 100 - 200 grams in size (Bursey, 2017).The generic economic model takes into consideration Australian marron production data which assumes marron are grown and sold at a weight of 175 grams over a 24 month period (Fotedar, et al., 2015).

5.4. Barriers to entry and limitations of the market

Barriers to entry and market limitations are an important consideration when looking at the feasibility of a product. Various aspects such as market saturation, trade barriers, market competition and potential market restrictions are important for this market assessment.

5.4.1. Market Supply

Key issues with establishing the marron industry is the inconsistence supply of the producer. Currently, the inconsistent supply of marron, which is supplied in volumes of approximately 60 to 100 kilograms per week during December to January (Bursey, 2017). This implies that the value-chain of this industry will remain undeveloped, and that further engagements with larger local or international off takers will not be possible.

5.4.2. Competition

Currently, there is no competition among marron producers given that only two farms are operational in South Africa. In terms of overall competition with the marine crayfish industry (i.e. lobsters), the response from the marron distributor was that the freshwater and marine crayfish product profile is very different in terms of flavour and size. Hence no competition exists between the freshwater and the marine crayfish (Bursey, 2017).

5.4.3. Logistics Challenges

Marron are typically sold live and therefore require suitable holding facilities and air cargo transportation services which both distributors and air cargo services can address. Although marron is resilient and can withstand lengthy transportation (Up to 72 hours when packed in polystyrene with ice packs), good proximity to international airports and major market centres should be considered to reduce on transport costs and transport times (Savage, 2017).

5.4.4. Trade Restrictions

As aforementioned, marron is an invasive species and therefore subjected to stricter conditions where permitting is concerned. This will include firstly the permit required to produce marron at any new location. Trade permits are required to transport marron in South Africa, which is difficult to obtain for the transfer of marron within South Africa (commonly done with live products). This is a challenge for the distributor who must fly the live animals from the farm to consumers across provinces. Once production in South Africa increases and the value chain is more advance, the export market may become more attractive for local producers. Should the local marron industry experience increased production volumes and growth, it would be required to aligned itself to the other aquaculture industries. The export requirements include a suitable national monitoring system with NRCS certification for the international export markets (Bursey, 2017).

6. SWOT analysis and Mitigation Measures

6.1. SWOT Analysis

Table 6-1 below presents the strength, weaknesses, opportunities, and the threats faced by the marron Crayfish industry in South Africa.

Table 6-1: Marron Swot Analysis

Strengths	Weaknesses
• High demand for marron • Existing local markets • Crayfish are a popular commodity • Creates jobs and learning opportunities • Can be linked with existing Agri-businesses	• Access to good quality feed • Under developed value chain • Limited market opportunities • Lack of recent production data available • Lack of expertise and professionals • Limited to one production system
Opportunities	**Threats**
• Opportunity to market marron as niche product • Potential to investigate export markets • Investment opportunities • Potential to test and utilise other production systems in the future • Investigate and develop local industry to increase production and supply greater volumes	• Invasive species legislation • Escape of marron from production systems • Permits (trade and production) • Shortage of extension services, skills, and support • Climate variability in the country • Lack of the right technology and high technology costs

The generic economic model considered some key weaknesses and threats that would impact the profitability of marron operations. The model assists with developing a risk profile for producers, which is then used to determine interest rates and loan repayments based on education levels and skills, access to land, infrastructure, and facilities. Factors such as permit costs and current feed prices are built into the model to provide accurate operational expenditure requirements.

6.2. Mitigation Measures

The mitigation measures identified in the table below aim to address threats and weaknesses identified in the SWOT analysis discussed above. It is essential for marron producers to take note of the potential risks and weaknesses identified to ensure they can implement mitigation measures and understand the challenges they may face.

Table 6-2: Marron Mitigation Measures

Risks Identified	Mitigation Measures
1. Under developed value chain	• Focus on research and development specifically feed, juvenile marrons, post production and marketing aspects • Apply well developed value chain examples such as abalone value chain to the marron industry
2. Limited market	• Identify ways to increase production to ensure year-round

Risks Identified	Mitigation Measures
opportunities	supply • Focus on developing the local market • Developing NCRS testing and production regulations to comply with the EU and USA market standards
3. Lack of production data/information	• Encourage the existing producers to supply regular production volumes to DAFF for annual reporting
4. Lack of skills, expertise & support for the industry	• Encourage engagement between current producers, extension services and new or interested marron producers • Engage with the Australian marron industry to exchange information • Develop strategic guidelines for marron Production in South Africa
5. Permits & regulations	• Include regulatory & permit requirements in Strategic guideline document • Identify how permit/regulatory process can be streamlined to assist producers
6. High Capital & operating costs	• Research and development looking at improved technology, reducing feed costs and system design to reduce costs
7. Lack of research on marron	• Fund and support research and development on marron production – specifically looking at the lifecycle and habits of the marron.
8. Limited production systems	• Research and development looking at marron in other systems to better understand how/why they could work • Pilot projects to test various systems in South African conditions
9. Escape of marron from aquaculture operations	• Provide pond design guidelines and biosecurity measures that are required within the proposed Strategic guideline for marron production in South Africa. • Standard practice in South Africa is the enclosing of ponds with a ‘baffel fence’ (low fence of corrugated iron or similar) that is high enough to prevent crayfish walking out of ponds into the surrounding environment. Pond outlets are screened. Additionally, pond effluent is typically channelled into a ‘predator sump/pond’ where predatory fish will consume any small individuals that may escape though water outlets.

7. Marron Technical Assessment

The technical assessment below provides a summary of assumptions used within the economic model for marron, as well as data presented in the species overview and biological characteristics section. The technical assessment covers the following information:

- Water conditions,
- Broodstock/Breeding,
- Juvenile marron production,
- Production performance, and
- Additional information.

Industry experts, stakeholders and relevant literature sources provided the technical information below. This information may be subject to change.

Table 7-1: Marron Technical Assessment

Latin name	*Cherax cainii*
Common name	Marron crayfish
NEMBA Status	Alien invasive Species. Category 2 – permits required for production
Biological requirements	
Salinity	Requires at least 100-200 mg. l-1. Can tolerate up to 17 000 mg. l-1 (half the salinity of sea water).
Temperature	Tolerable range 12-30˚C. Optimal range is 24-26˚C.
Broodstock/breeding	
Mating	Mating in marron is achieved by the male depositing a spermatophore near the oviducts of the female. The female carries the spermatophore for a while before laying eggs. When eggs are laid, the female will fertilise them using the male's sperm and attach the eggs to the underside of her tail (on her pleopods). Mating occurs in August/September when water temperatures increase above 13˚C.
Age at sexual maturity	Typically, 18 months.
Brooding	Includes the following steps: a. Attachment of eggs to pleopods under female's tail b. Incubation of eggs through 2/3 larval stages (12-16 weeks) c. Maternal care – juveniles hatch and remain on females tail through two to three moults before becoming free-living (two months) d. Swim off the mother during mid-summer, already advanced stage of development
Genetic selection	Currently being researched in Australia. None in South Africa.
Breeding Programme	The generic economic model production cycle considers mass selection and breeding, which is currently common practice. The following considerations were made: • 10% stock replacement per annum to bring in new genetic stock • 5% of marron produced per annum are kept as broodstock
Juvenile Marron production	
Hatchery	• Experimental hatchery in Australia, none currently in South Africa. Breeding done on each farm in breeding ponds. • Breeding can occur spontaneously if pond conditions are favourable.
First feed requirement	• None. • Large egg with yolk to feed larval stages and first juvenile moults.

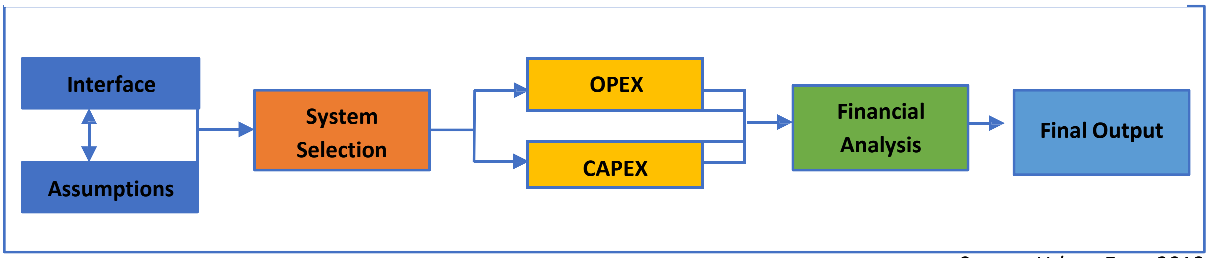
Production performance	
Typical FCR	Information not available. Pond farming relies on natural pond ecosystem production (algal, zooplankton, microbial growth, etc.) in ponds to feed marron Crayfish, with supplementation by pellet feeding.
Feed requirement	Ponds need to be "fertilised" to produce natural ecosystem growth. Supplementation, with pellets is common
Typical survival rate	60%
Typical growth rate	No published data.
Stocking densities	0 year + - 4 crayfish/m² 1 year + - 3 crayfish/m²
Disease	Key considerations - disease free in natural extent, but at risk to white spot syndrome recently affecting Australian prawn farms.
Production	
Production system	Pond farming.
Type of Pond	Specifically designed, constructed pond
Pond Size	• 25 metres x 40 metres x 1.25 metres (1000 m²) • Smaller ponds can be utilised for breeding/holding broodstock
Intensity	Semi-intensive production
Main producers	Australia.
Additional Information	
Research and Development	Current research is focused on: • Alternate production systems – specifically RAS in South Africa, • Breeding behaviour, • Survival/mortality rates, • Genetic selection to improve growth rates, and • Feeding behaviours.

8. Marron Financial Analysis

8.1. Introduction

The generic economic model provides users with the opportunity to individual producer data, proposed production volumes and scales and financial data. Through the model, the users will receive financial outputs which include capital and operational costs and financial indicators which will guide the user in determining whether the proposed aquaculture project is feasible, and a viable investment opportunity. A high-level overview of the model process can be seen in the figure below.

Figure 8-1: Generic Economic Model Overview



Source: Urban-Econ,2018

The generic economic model can be customised to provide results for individual producers based on selections made with regard to the location of the aquaculture operation (at a provincial level), type of operation (start-up or existing), the scale of operation, type of production system, size and pricing of the marron, education level and type of financing that will be used by the project.

8.2. Key Economic Model Assumptions

The generic economic model for marron was developed using data from various information sources. As the marron industry is infant and underdeveloped in South Africa, the assumptions are based on information gathered from the *Marron Growers Association of Western Australia,* current producers of marron in South Africa, and researchers involved with marron research in South Africa.

8.2.1. Production Assumptions

To develop the generic economic model, specific production assumptions for marron were identified and utilised. Some key assumptions used can be seen in Table 8-1 below.

Table 8-1: Marron Production Assumptions

Juvenile marron	R 10 -00 per marron
Production cycle length	24 Months
Survival Rate	60%
Mortality Rate (24 months)	40%
Average Feed price	R 15 -00 per kilogram
Stocking Density (0+)	4 Crayfish/m²
Stocking Density (1+)	3 Crayfish/m²

Industry experts recommended the assumptions seen above, however, they may differ from farm to farm. Prices are based on 2017/2018 prices and are subject to change over time.

8.2.2. Capital Expenditure

The capital expenditure costs for marron production focused on the establishment of built/constructed marron ponds. The capital expenditure is determined by the scale of production, and the selected production cycle length. Some of the key factors to note include the following:

1. **Pre-development costs** for construction phase, concept design, specialist consultations, town planning alignment (zoning, rezoning etc.), and development of bulk infrastructure (roads, installation of electricity to the site, bulk water services etc.) were excluded from the model as this is site specific and not suitable to model at a provincial level,

2. **Land costs** were included should an individual/business not have an existing farm. A value of R 246 346 per hectare was applied, based on average farm prices for 2017/18, however this can differ from province to province, and will be site specific,

3. **Services** such as the costs of water and electricity were included in the model, and vary between the nine provinces,

4. **Buildings** such as storerooms, offices, cold storage, and a feed room were considered,

5. **Aquaculture system** costs focused on the development of land-based, constructed ponds and included additional costs (bird netting, marron hides, harvesting nets etc.),

6. **A storage dam** was included in the capital expenditure costs, and

7. **Infrastructure costs** are calculated as a once-off, lump sum amount to be spent in year one, however a producer can choose to phase in production which would split the costs up depending on how the production is phased in.

8.2.3. Operational Expenditure

Operational expenditure, or working capital was determined by looking at the variable costs of production, and fixed costs. Costs can be divided into fixed and variable costs. **Variable costs** include juvenile marron, fertilisers, feed, transport, and water costs. It should be noted that it is was assumed that aquaculture producers in South Africa are currently not charged for water unless using municipal water sources (DAFF,2018). **Fixed Costs** include costs such as salaries, insurance, electricity, legal/licensing costs, veterinary services, and general expenses (telephone, electricity, health and safety apparel, stationery etc.). Reserve and unforeseen costs are also been included the generic economic model (calculated at 2% of the variable cost total).

8.2.4. Scale of production

From the generic economic model, two production volumes were identified. Firstly, the minimum production volume which indicates at what tonnage a producer would first be profitable. Secondly, the optimal production tonnage was identified, which indicates where the optimal return on investment and profitability is achieved, based on the generic economic model.

8.2.5. Market Information

Marron market information was based on industry experts and research conducted. The average sale price of R 250 per kilogram (kg) is recommended. This price may differ depending on the market being supplied, size and quality of the marron. Currently marron producers rely on the local markets as no marron are exported.

8.3. Marron Production Financial Analysis

Using the generic economic models and the assumptions listed in Table 8-2 below, a financial analysis was conducted for marron, focusing specifically on pond culture as it is currently considered to be the only suitable production system for marron.

Table 8-2: Marron financial and production assumptions

Province	Eastern Cape
Market	Local
Selling Price	R 250/kg
Minimum profitable tonnage	4 tons per production cycle
Optimal tonnage	270 tons per production cycle
Operational Status	Start-up farmer with no existing farm, facilities, or infrastructure
Skills Level	Formal education (certificate/diploma)
Payback Period	20 years
Financing Option	Debt/Equity with an investor (surety)
Debt Percentage	20%
Production Cycle	24 months (175 grams)
Additional Information	• The models exclude the construction phase. The models consider from when production starts. The ponds considered are constructed ponds of one set size of a 1000 m². • The model excludes consultancy, contractors, and specialised service provider fees, with the exception of veterinary services.

Based on the assumptions above, the results obtained from the generic economic model are presented in more detail below.

8.3.1. Capital Expenditure

Table 8-3 below provides a summary of the infrastructure and built environment costs required to establish a pond culture system for marron production.

Table 8-3: Total Capital Costs for Marron Production in the Eastern Cape

Production Scale	4 tons	270 tons
Land Required	R 369 519	R 61 077 450
Basic Earthworks (levelling/site clearing)	R 40 000	R 200 000
Infrastructure (Buildings & Storage Dam)	R 308 100	R 2 742 792
Pond culture system	R 1 391 460	R 86 444 801
Additional equipment	R 495 856	R 29 513 722
Total Capital Expenditure	**R 2 604 935**	**R 179 978 766**

8.3.2. Operational Expenditure

Table 8-4 below provides a summary of the operational costs required for marron production. The operational expenditure is shown for the first year of operation.

Table 8-4: Operational Expenditure for Marron Production in the Eastern Cape (Year 1)

Production Scale	4 tons	270 tons
Variable costs	**R 448 364**	**R 29 747 427**
Juvenile Marron	*R 351 009*	*R 23 693 131*
Fertiliser	*R 1 466*	*R 93 720*
Feed	*R 90 288*	*R 5 948 976*
Consumables – water quality	*R 2000*	*R 8 000*
Fixed Costs	**R 682 877**	**R 25 241 663**
Total Operational Costs	**R 1 131 241**	**R 54 989 090**

Based on the table above, it can be seen that the juvenile marron required contribute to a large portion of the variable costs incurred, followed by feed costs. Currently feed prices are relatively high and have a large impact on the profitability of an operation. With regard to water costs, the model excluded water costs as per discussions with DAFF. If a producer is required to utilise municipal water, they may incur water charges which will be decided when applying for water use rights as required by the Department of Water and Sanitation (DWS).

8.3.3. Pond System Financial Overview

Table 8-5 below provides an overview of the capital expenditure required, as well as financial indicators and a high-level overview of the production requirements including land size, estimated number of juvenile marron required in month one (1), and the estimated number of employees required in the first year of production.

Table 8-5: Marron Pond System Financial Overview in the Eastern Cape

Production Scale	4 tons	270 tons
Financial Indicators		
Total Capital Expenditure	R 5 085 854.27	R 304 860 178.88
Loan Amount – Working Capital	R 2 480 919.32	R 124 881 412.67
Loam Amount - Infrastructure	R 2 604 934.96	R 179 978 766.21
Interest Rate	8.25%	8.25%
Profitability Index (PI)	1.41	4.71
Internal Rate Return (IRR)	7%	30%
Net Present Value (NPV) over 10 years	R 7 175 300.04	R 1 434 989 557.00
Pay-back period (years)	20	20
Year until profitable	6	3
Production Indicators		
Farm Size	1.5 hectares	247.9 hectares
Number of juveniles required (Month 1)	35 101	2 369 313
Number of employees required (Year 1)	4	96

The table above highlights the minimum production volume and the financial results obtained at this volume, as well as the optimal production volume required to achieve optimal return on investments.

For a producer to break-even, they will be required to produce five (5) tons of marron per production cycle when selling the marron at 24 months old (175 grams), and at a price of R 250/kilogram. Although a producer will break-even at five (5) tons, the optimal return on investment is found at 251 tons of production, where producers achieve an Internal Rate of Return (IRR) of 34%, and a Profitability Index (PI) of 4.92. Marron production does offer some employment opportunities; however, this is dependent on the tonnage being produced. With the minimum tonnage of five (5) tons, four (4) employees would be required in year one to manage production, while at 251 tons, it is estimated that 90 employees would be required.

8.4. Cost Benefit Analysis

Based on the economic model, Table 8-6 below provides a cost-benefit analysis for marron production at a provincial level. As previously mentioned, pond culture is currently the only system considered for marron production in South Africa. It should be noted that the figures and analysis discussed below are based at a provincial level and were obtained with the general assumptions used in the economic model. While at a provincial level a system and tonnage may show a positive return and profit, this may differ at a site-specific level depending on the site-specific conditions.

Table 8-6: Marron Cost Benefit Analysis

	KZN	GP	LIM	MP	EC	NW	FS
Min. Tonnage for Profitability	4	4	4	4	4	4	4
Average Market Price (R/kg)	250	250	250	250	250	250	250
Profitability Index	1.41	1.41	1.35	1.35	1.41	1.35	1.35
IRR	7%	7%	6%	6%	7%	6%	6%
Optimal Tonnage	270	270	270	270	270	270	270
Average Market price(R/kg)	250	250	250	250	250	250	250
Profitability Index	4.71	4.71	4.63	4.63	4.71	4.63	4.63
IRR	30%	30%	29%	29%	30%	29%	29%

As seen in the table above, four (4) tons has been identified as the minimum tonnage required in the seven recommended provinces for a marron producer to break-even. However, although the producers will be breaking even, the IRR achieved is lower than the recommended 15% required by investors for an operation to be considered a good investment opportunity.

The optimal tonnage for marron producers to achieve maximum return on investment ranges is estimated to be 270 tons per annum. At 270 tons per annum, an IRR of 29% or 30% (province specific) can be achieved. Although the large production volumes will result in a high return on investment, it should be noted that both in South Africa, and Australia, marron operations are relatively small in size, with the total production in South Africa recorded at four (4) tons per annum, while Australia production records estimate a total annual production of 60 tons.

Kwa-Zulu Natal, Gauteng, and the Eastern Cape achieve the highest return on investment when producing 270 tons with an IRR of 30%, and a PI of 4.71. It can be said that these four provinces offer the best conditions for marron production when considering the return on investment that can be achieved. The Northern Cape and Western Cape are not recommended for marron production due to the climatic conditions.

8.5. Best Case Scenario

Through the generic economic models, it is possible to determine "Best Case Scenario" for pond culture at a provincial level. To do this, the following categories and criteria were used to assess the economic model.

I. **Minimum Tonnage required for each production cycle**
The minimum tonnage was identified to determine the minimum tonnage that a marron producer needs to produce to be profitable. Profitability was measured by looking at the Profitability Index (PI), which should be one (1) or more, and ensuring the Internal Rate of Return (IRR) was greater than 0%.

II. **Optimal Tonnage required for each production cycle**
The optimal tonnage was identified to determine the optimal tonnage required to ensure the producer achieves maximum return on investment (or the highest IRR) when using the generic economic model.

III. **Price**
The price received for marron has a major impact on the profitability and sustainability of a marron operation. The minimum recommended selling price identified for marron in South Africa is R 250 per kilogram. When comparing local and international market prices, the upper range sales price that can be achieved is assumed to be R 358 per kilogram.

IV. **Finance Type**
The generic economic model provides three financing options for producers, however for this analysis the **debt/equity** finance option was selected with a 20% debt ratio. This assumes that a producer contributes 20% of their assets and receives funding for the remaining 80%.

The table below indicates the best-case scenario when using the recommended sales price, versus the upper range sales price.

Table 8-7: Marron Best Case Scenario

	KZN	GP	LIM	MP	EC	NW	FS
Market Price (R/kg)	250	250	250	250	250	250	250
Minimum Viable Scale	4	4	4	4	4	4	4
Optimal Production Scale	270	270	270	270	270	270	270

As seen in the table above, at the recommended sales price of R 250/kg, marron producers require a minimum of four (4) tons of marron per production cycle to achieve profitability, and 270 tons per annum to achieve maximum return on investment.

9. Conclusion and Recommendations

9.1. Conclusion

It can be said the marron industry is underdeveloped in global terms, specifically in comparison to the other species in the crayfish sector, and the freshwater aquaculture industry. South African marron production is limited to two (2) farms which makes accessing recent production data, and technical information challenging, however, the Australia marron industry is well established and is valuable source of knowledge and information. Although marron production is reliant on pond culture systems, this allows the marron operations to be established on various scales on different sites, as well as be incorporated into other agricultural activities such as farming and urban agriculture. Major challenges faced by producers include an undeveloped value-chain, legislative and regulatory issues, the need for marketing and product development, and the lack of knowledge and access to support in South Africa. To reduce the costs and the likelihood of operating an unsuccessful pond culture system, certain measures must be taking into consideration. These measures include ensuring good farm management practices, selection of a suitable production site (with appropriate climate, soil, topography, water quality and quantity, etc.), accurate system design, adequate skills, and training on producing marron, a good marketing strategy; and sound product distribution and logistics, etc.

The following factors were identified as optimal operational requirements for marron production to be profitable:

I. Appropriate water temperature,
II. Appropriate water quality and quantity,
III. Suitable site with right soil type, slope, and topography,
IV. Economies of scale and consistent volume of production,
V. Good access to production inputs and support services,
VI. Good management practices, and
VII. Access to markets.

The local and international market is under supplied, with the key issue being production challenges and achieving stable, year-round production volumes. It can be said that the market itself is not a limiting factor for the industry and many opportunities exist both within the local and the international markets (e.g. USA, Asia, Russia etc.), however, the limited and seasonal supply of marron has a major impact. In South Africa, the industry is facing the same challenges i.e. production capacity, and a limited knowledge on how to increase production. Further analysis is required in terms of optimal value-chain design to ensure producers can maximize their margins by a direct sell to stores and restaurants. Such operation/business models could be combined with the tourism industry (e.g.: the established wine industry in the Western Cape Province).

Kwa-Zulu Natal, Gauteng, and the Eastern Cape offer the most profitable outcomes for marron producers, while the Northern Cape and Western Cape were not recommended for marron production. It was found that the minimum tonnage required per production cycle is five (5) tons, while the optimal tonnage required to achieve maximum return on investments is 251 tons when producing marron in the most profitable provinces.

9.2. Recommendations

Based on the study conducted, the following recommendations have been made:

I. Research and development on marron production is essential for the growth of the industry. Focus should be placed on improving growth rates, local feed manufacturing and supply, feeding behaviours, optimal nutrient requirements, and optimal production conditions,

II. The importation of juvenile marron from Australia on an annual basis may be required to introduce new genetic stock, however, currently no genetic improvement programme exists in Australia or South Africa, therefore research and development into breeding programmes and genetic improvement is required,

III. Existing research and development on additional culture systems, specifically the RAS should be monitored and supported, as additional culture systems could assist with improved productivity,

IV. Strategic guidelines relevant to South African marron production should be developed. These guidelines should specify details such:
   a. Legislative and regulatory information (i.e. females can only be transported of the farm on ice or dead, males can be transported live etc.),
   b. Environmentally based studies on where marron can be produced,
   c. Optimal pond design to ensure marron are not able to escape,
   d. Waste water management to reduce biosecurity risk, and
   e. General production information to increase awareness on marron production.

V. Existing marron farmers should be engaged with to better incorporate them into the freshwater aquaculture industry,

VI. Funding and support could be directed into developing the marron value and supply chain within South Africa should more individuals and companies become involved with marron production, specifically looking at feed and access to juvenile marron,

VII. Regulations for testing and market supply, specifically to target the EU and USA markets should be established to expand on the existing local market base,

VIII. The marron generic economic model should be updated annually to ensure the assumptions and costings are accurate. The updates will ensure the long-term use and sustainability of the generic economic model, and

IX. Collaboration between relevant environmental and fisheries departments must be established to ensure the marron population in South Africa is controlled, while still supporting marron as an aquaculture species.

10. List of References

ACS Distance Education, 2017. *How to Farm Crayfish and other Crustaceans.* [Online] Available at: https://www.acs.edu.au/info/livestock/other-animals/fresh-water-crayfish.aspx [Accessed 14 December 2017].

Australian Government Department of Agriculture, 2015. AQUAVETPLAN Enterprise Manual. *Australian Aquatic Veterinary Emergency Plan*, p. 203.

Baker, R., 2017. *Marron Crayfish Production and Markets* [Interview] 2017.

Bryant, D. & Papas, P., 2007. *Marron Cherax cainii (Austin) in Victoria – A Literature Review,* Heidelberg: Arthur Rylah Institute for Environmental Research Technical Report Series No. 167. Department of Sustainability and Environment.

Bursey, V., 2017. *Marron Crayfish Production* [Interview] 2017.

DAFF, 2012. *Biodiversity Risk and Benefit Assessment : Cherax tenuimanus,* Pretoria: DAFF.

DAFF, 2017. *Aquaculture Yearbook 2016 South Africa,* Cape Town: Aquaculture and Economic Development: The Department of Agriculture, Forestry and Fisheries.

de Moor, I., 1988. *Atlas of alien and translocated indigenous aquatic animals in southern Africa. A report of the Committee for Nature Conservation Research National Programme for Ecosystem Research,* Port Elizabeth, South Africa: South African Scientific Programmes Report .

Department of Environmental Affairs, 2016. *National Environmental Management : Biodiversity Act (Act No. 10 of 2004) : Alien and Invasive Species List.* Pretoria: Department of Environmental Affairs.

Eurofish, 2017. *Market Prospects for Aquaculture Species,* s.l.: s.n.

FAO, 2017. *Fishery and Aquaculture Statistics. Global aquaculture commodities and trade 1976-2013 (FishstatJ). In: FAO Fisheries and Aquaculture Department [online},* s.l.: s.n.

FAO, 2017. *Fishery and Aquaculture Statistics. Global aquaculture production 1950-2015 (FishstatJ). In: FAO Fisheries and Aquaculture Department [online},* Rome: s.n.

Fotedar, R., 2015. *Marron Aqauaculture in Western Australia: Manual for Growers,* s.l.: Marron Growers Association of Western Australia.

Fotedar, R. et al., 2015. *Marron Aquaculture in Western Australia: A Manual for Growers.* 1st ed. Manjimup: Marron Growers Association of Western Australia.

Government of Western Australia, 2015. *Department of Primary Industries and Regional Development.* [Online] Available at: http://www.fish.wa.gov.au/Species/Marron/Pages/default.aspx

Holdich, D. M., 1993. A review of astaciculture : freshwater crayfish farming. *Aquatic Living Resources,* 6(4), pp. 307-317.

Invasive Species South Africa, 2017. *Invasive Species South Africa : Marron.* [Online] Available at: https://www.invasives.org.za/legislation/item/796-marron-cherax-tenuimanus [Accessed 26 February 2018].

Invasive Species South Africa, 2018. *Invasive Species South Africa.* [Online] Available at: https://invasives.org.za/ [Accessed 23 April 2018].

Jussila, J. & Evans, L. H., 1996. On the factors affecting marron, Cherax tenuimanus, grown in intensive culture. *Freshwater Crayfish,* 11(0), pp. 428-440.

Jussila, J. & Evans, L. H., 1996. On the factors affecting marron, Cherax tenuimanus, grown in intensive culture. *Freshwater Crayfish,* 11(0), pp. 428-440.

Muhammad, A., 2016. *Characterization of the carbonic anhydrase gene family and other key osmoregulatory genes in Australian freshwater crayfish (genus Cherax),* Brisbane, Australia: PhD thesis, Queensland University Technology.

Personal Communication, 2017. *Stakeholder Consultation.* Pretoria: Urban-Econ.

Provincial Government of the Western Cape, 2007. *Generic Environmental Best Management Practice Guideline for Aquaculture Development and Operation in the Western Cape,* Cape Town: Provincial Government of the Western Cape.

Rabobank, 2016. *Dynamics in Aquaculture.* New York City, IntraFish.

Savage, C., 2017. *Marron Crayfish Production* [Interview] 2017.

South China Morning Post, 2017. *China's craving for crayfish creats US2 billion business.* [Online] Available at: http://www.scmp.com/business/companies/article/2100001/chinas-craving-crayfish-creates-us2-billion-business

Specialty Feeds, 2009. *Marron Pellets,* Glen Forrest: Specialty Feeds.

Welovecrawfish.com, 2017. *Crawfish production.* [Online] Available at: http://www.welovecrawfish.com/crawfish-industry.htm