Biodiversity Risk and Benefit Assessment for Pacific oyster (*Crassostrea gigas*) in South Africa

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

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EXECUTIVE SUMMARY

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

This biodiversity risk and benefit assessment (BRBA) has been conducted and documented in relation to the importation, propagation and grow out of Pacific oysters (*Crassostrea gigas*) in South Africa.

The now Department of Environment, Forestry and Fisheries (DEFF), as the lead agent for aquaculture management and development, appointed Anchor Environmental in August 2012 to conduct a biodiversity risk and benefit assessment for the use of Pacific oysters in South Africa. Subsequently (2017), AquaEco was appointed to review, update and recompile this risk assessment in terms of section 14 of the Alien and Invasive Species Regulations, 2014 (Government Notice R 598 of 01 August 2014), promulgated in terms of the National Environmental Management: Biodiversity Act (Act No. 10 of 2004).

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

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

The risk assessment investigated the taxonomy, key characteristics, dietary aspects and history of Pacific oyster culture, while considering its native environment in Japan and South East Asia. It was found that Pacific oysters are highly fecund and persistent, but that the establishment of viable feral populations have been limited to a few Southern Cape coastal estuaries. Pacific oysters have extended into their maximum range along the South African coastline, meaning that their use for aquaculture currently poses little additional biodiversity related risk, aside from the biodiversity risks already caused by the limited and isolated feral populations.

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

The identified pathways that could facilitate risks include:

- The pathway of escape, via various potential routes that include:
    - Escape during handling, seeding, harvesting and transport.
    - Escape directly from the aquaculture infrastructure.
    - Escape caused by poor design, system malfunction or poor maintenance.
    - Escape by means of deliberate or accidental human actions, including theft.
    - Escape due to adverse weather and sea conditions.
- The diverse pathway related to the potential transfer of disease.

The identified risk endpoints include:

- The potential for Pacific oysters to cause physical (abiotic) damage to the marine environment;
- The potential for Pacific oysters to cause species displacement in the environment;
- The potential for Pacific oysters to compete for food, habitat niches and other resources;
- The potential for Pacific oysters to hybridise; and
- The potential threat of new or novel diseases carried into the environment by Pacific oysters as a vector – either directly or indirectly.

During the assessment, it was noted that the overall ecological risk profile for Pacific Oyster was found to be low, apart from the risk of oysters acting as a vector for introduction of diseases and parasites. This finding is based on the fact that Pacific oysters have not become invasive in South Africa, but only having established limited and isolated populations. Moreover, the risk was considered against the fact that establishment of this alien species could result from spawning of existing populations, from introduction through aquaculture, and from ballast water and hull fouling. The potential for monitoring and mitigation related to the use of Pacific oysters in aquaculture was found to be moderate.

Key economic and social matters were considered in a balanced manner in conjunction with the potential biodiversity risks. It was found that a growing aquaculture sector already exists and that this sector is reliant on the importation of seed or spat. For this reason the biodiversity risk associated with the potential introduction and impact of alien diseases and parasites is relatively high. Nevertheless, the farming sector should be promoted, which will also be in alignment with government's objectives and policies regarding aquaculture, aside from the fact that it will contribute towards job creation, scarce skills development and increased local economic activity. Several measures have been proposed for the monitoring and mitigation of the potential risks, and these could be included as conditions related to the issue of permits. Furthermore, strict biosecurity measures should be applied as this relates to the import of seed and spat.

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1. INTRODUCTION

This biodiversity risk and benefit assessment (BRBA) pertains to the importation, propagation and grow out of Pacific oyster (*Crassostrea gigas*) in South Africa.

The BRBA has been structured in accordance with the framework provided in section 14 of the Alien and Invasive Species (AIS) Regulations (Government Notice R 598 of 01 August 2014)[1], promulgated in terms of Section 97(1) of the National Environmental Management: Biodiversity Act 10 of 2004 (NEMBA).

At date of publication, this BRBA will be recognised as a national reference work related to the ecological risks and potential benefits of importing, propagating and growing Pacific oyster in South Africa. In this regard it replaces all preceding risk assessment documents and frameworks for the species.

2. PURPOSE OF THIS RISK ASSESSMENT

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

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

Although this BRBA has been prepared to meet the requirements for risk assessments in terms of the AIS Regulations, as promulgated in terms of NEMBA, it illustrates overarching generic information at a national level relevant to South Africa. The intension is that this

[1] *Note that at the time of publication revised draft regulations had been circulated for public comment dated February 2018 and will be promulgated in due course. This BRBA will require review and update in terms of these revised regulations.*

framework be used as a decision support tool, for existing and future entrants into the sector, to which project- and site-specific information must be added when regulatory approval is sought for the importation, propagation and grow out of Pacific oyster.

The main objectives of this BRBA are:

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

3. THE RISK ASSESSMENT PRACTITIONER

The BRBA was originally prepared by Dr Barry Clark of Anchor Environmental Consulting. It has been reviewed, updated and recompiled by Mr. Etienne Hinrichsen from AquaEco (as commissioned by Enterprises at University of Pretoria). Both authors meet the criteria for risk assessment facilitators (as per Section 15 of the AIS Regulations, 2014) in that:

- They have practised as environmental assessment practitioners.
- They are independent.

- They are knowledgeable insofar as the NEMBA, the AIS Regulations and other guidelines and statutory frameworks that have relevance, are concerned.
- They are experienced in biodiversity planning in the aquaculture sector and have conducted a range of biodiversity risk assessments.
- They comply with the requirements of the Natural Scientific Professions Act 27 of 2003 and are registered as Professional Natural Scientists with the South African Council for Natural Scientific Professions (SACNASP).

4. NATURE OF THE USE OF PACIFIC OYSTER

It is likely that global shipping practices in the twentieth century saw the first free-swimming Pacific oyster larvae arrive in South African waters before they were introduced for aquaculture purposes. Early European settlers to South Africa tried unsuccessfully to implement rudimentary farming systems for the indigenous Cape Rock oyster (*Striostrea margaritacea*), before both the European flat oyster (*Ostrea edulis*) and the Portuguese oyster (*Crassostrea angulate*) were unsuccessfully imported for farming in the 1940's. The first successful farming was undertaken in the Knysna lagoon in the 1950's with imported Pacific oysters. Currently, the South African oyster farming sector, concentrated mainly in Saldanha Bay, still depends on imported spat of this species.

Presently, only one distinct use and user group can be identified for Pacific oyster in South Africa. This is the only oyster species that is commercially produced in the country, with well-established farms serving a predominantly local market with fresh live oysters. The single use for this alien species is however well supported by the wild harvesting of indigenous oyster species along the entire South African coastline.

Oysters have been harvested by coastal communities for thousands of years, with some shell middens on the South African coast dating back some 140 000 years. The first forms of oyster aquaculture were reportedly practiced by the Romans from the first century BCE but may have been practiced in the Far East even earlier. The first approach to farming consisted of simply collecting these sedentary animals and growing them in secluded or secured areas in bays, lagoons or natural harbours, where they could be collected as required. Records of purpose-built oyster growing ponds first emerge from France in the

17th century, but these farming facilities still depended on the harvesting of spat from natural stocks. Shortages of natural stocks led to the establishment of wooded collection stakes against which oyster larvae could attach.

Modern day oyster farming commenced with the development of oyster hatchery techniques in Europe and the United State of America (USA) in the 1960's. Although wild harvested spat is still used today, the supply of hatchery produced spat has transformed the production of various species and has contributed to the global redistribution of species such as the Pacific oyster.

Oyster farming methods vary depending on the environment, the species, available technologies and other factors. The three main farming methods are raised racks and bags, suspended culture and seabed culture. In raised racks and bags a structure is installed into the seabed or substrate, which supports the bags and baskets in which oysters are grown. Conversely, suspended culture involves the suspension of lantern nets, farming bags or baskets from a floating structure. Longline culture in which oyster production baskets are suspended from lines between floating buoys, is a form of suspended culture. Seabed farming involves the seeding of oysters directly onto the seabed or in cages on the seabed.

In South Africa, Pacific oyster farming is practiced through the import of spat (mainly from Guernsey, Chile, Europe, Namibia and the United States) and farmed mainly by means of suspended culture (predominantly by means of longlines). The biodiversity risk is not affected by the production method, in that the oysters are able to spawn into the surrounding environment if climatic conditions allow, regardless of the method of farming.

4.1. REASONS FOR FARMING WITH PACIFIC OYSTER

The FAO estimates that by 2030, fish farming will dominate global fish supplies. With aquaculture already providing more than half of the global seafood demand, it is now considered likely that marine wild harvesting and terrestrial rangeland farming has reached its capacity in many parts of the world. Aquaculture and intensified agriculture remains the only alternative to supplying a growing food need, fuelled by an increasing global population (Alexandratos *et al.* for the FAO, 2012).

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

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

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

Pacific oyster, while alien to South Africa, is a well-established South African aquaculture species. Considering all oyster species, over 5.7 million tonnes are farmed per annum across the world (FAO, 2019) and oysters are a universally recognised aquaculture species that efficiently yields a high-demand product in a competitive manner.

Through their international redistribution as a preferred aquaculture species, Pacific oysters are farmed on every continent except Antarctica. The world leaders in Pacific oyster farming are Korea and Japan that produce 315 000 and 174 000 tonnes per annum, respectively. France (64 000 tonnes), the USA (26 000 tonnes) and Taiwan (23 000 tonnes) are also significant producers, while the entire African continent produces only about 1 200 tonnes per annum. Morocco (411 tonnes), Namibia (400 tonnes) and South Africa (330 tonnes) are the leading African producers.

The indigenous edible Cape rock oyster (*Striostrea margaritacea*), the Natal rock oyster or Hooded oyster (*Saccostrea cucullate*), the Red oyster (*Ostrea atherstonei*) and the Cape weed oyster (*O. algoensis*) occur along the south and east coasts of South Africa. These oysters are harvested and consumed but have not been found to be suitable for aquaculture purposes.

5. LEGAL CONTEXT

The Department of Environment, Forestry and Fisheries (DEFF) is the mandated authority of the National Environmental Management: Biodiversity Act 10 of 2004 (NEMBA), which sets out the framework, norms and standards for the conservation, sustainable use, and equitable benefit-sharing of South Africa's biological resources. The AIS Regulations, 2014 and the AIS Lists (Government Notice R 864 of 29 July 2016)[2] have been promulgated in terms of this Act, providing enabling instruments for the Act.

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

5.1. CATEGORIZATION OF ALIEN AND INVASIVE SPECIES

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

- **Exempted Alien Species** mean an alien species that is not regulated in terms of this statutory framework - as defined in Notice 2 of the AIS List.

[2] *Note that at the time of publication revised draft regulations had been circulated for public comment dated February 2018 and will be promulgated in due course. This BRBA will require review and update in terms of these revised regulations.*

- **Prohibited Alien Species** mean an alien species listed by notice by the Minister, in respect of which a permit may not be issued as contemplated in section 67(1) of the Act. These species are contained in Notice 4 of the AIS List, which is referred to as the List of Prohibited Alien Species (with marine invertebrate species in List 11 of Notice 4).
- **Category 1a Listed Invasive Species** mean a species listed as such by notice in terms of section 70(1)(a) of the Act, as a species which must be combatted or eradicated. These species are contained in Notice 3 of the AIS List, which is referred to as the National Lists of Invasive Species (with marine invertebrate species in List 10 of Notice 3).
- **Category 1b Listed Invasive Species** mean species listed as such by notice in terms of section 70(1)(a) of the Act, as species which must be controlled. These species are contained in Notice 3 of the AIS List, which is referred to as the National Lists of Invasive Species (with marine invertebrate species in List 10 of Notice 3).
- **Category 2 Listed Invasive Species** mean species listed by notice in terms of section 70(1)(a) of the Act, as species which require a permit to carry out a restricted activity within an area specified in the Notice or an area specified in the permit, as the case may be.
- **Category 3 Listed Invasive Species** mean species listed by notice in terms of section 70(1)(a) of the Act, as species which are subject to exemptions in terms of section 71(3) and prohibitions in terms of section 71A of Act, as specified in the notice.

5.2. STATUTORY CLASSIFICATION OF PACIFIC OYSTER

With reference to Notice 3, List 10 (National List of Invasive Marine Invertebrate Species) in the AIS List (Government Notice R 864 of July 2016) and the categorization of alien and invasive species indicated in Section 5.1 above, Pacific oyster is categorized as follows:

- Category 2 (*compulsory permitting*) for all uses.

Further prohibitions and exemptions that apply to Pacific oyster include:

a. Aquaculture facilities within the following areas are exempted from requiring a permit for all restricted activities except for restricted activities a[3] in Notice 1; provided they have a valid permit from the Department responsible for Fisheries:

   i. Algoa Bay: landwards of a straight boundary line with endpoints at the GPS coordinates 33°51’24.82’’S 25°38’11.01’’E and 33°59’20.68’’S 25°40’26.31’’E.
   ii. Upstream of the mouth of the Keiskamma River at the GPS coordinates 33°16’54.26’’S 27°29’26.35’’E.
   iii. Kleinzee: land-based operations with water outflows on the stretch of coast marked in the North by GPS coordinates 29°39’13.44’’S 17°02’20.15’’E and in the South 29°40’15.12’’S 17°02’40.18’’E.
   iv. Knysna River: upstream of the mouth at GPS 34°04'55.64"S 23°03'36.39"E.
   v. Within the Marina Martinique, landwards of the mouth of the Marina marked by the GPS coordinates 34°04’37.23’’S 24°55’21.13’’E.
   vi. Paternoster: land-based operation with water outflows on the stretch of coast marked in the North by GPS coordinates 32°46’41.56’’S 17°54’28.37’’E and in the South by 32°47’14.33’’S 17°54’27.75’’E.
   vii. Port Alfred: Kowie River, upstream of GPS coordinates 33°36’21.59’’S 26°53’50.20’’E.
   viii. Saldanha Bay: within the Bay, north-eastward of a straight boundary line with endpoints at the GPS coordinates 33°02’59.26’’S 17°54’41.34’’E and 33°06’17.54’’S 17°57’09.53’’E.
   ix. Hamburg at the GPS coordinates 33°17’0.78”S 27°28’52.20”E.

   All other persons including all aquaculture facilities whether located inside or outside the areas identified in (a) above are:

b. Exempted from restricted activity (i) in Notice 1: “*Discharging of or disposing into any waterway or the ocean, water from an aquarium, tank or other*

[3] *Activity “a” is: importing into the Republic, including introducing from the sea, any specimen of a listed invasive species.*

receptacle that has been used to keep a prohibited alien species or a listed invasive species."

c. Exempted from restricted activity (e) in Notice 1: "*Selling or otherwise trading in, buying, receiving, giving, donating or accepting as a gift, or in any way acquiring or disposing of any live specimen of a listed invasive species*."

These regulations point to Pacific oyster as being classified in Category 2 as this relates to the general importation, propagation and grow out thereof, with due consideration that exclusionary zones exist around current farms and farming areas in which permitting is only required for import.

It must be noted that most provinces have specific Provincial Ordinances that govern the harvesting, movement and keeping of species such as Pacific oysters. The National Government have confirmed that all provinces should regulate the importation, propagation and grow out of species in terms of the National Regulations, but the repeal of Provincial Ordinances (and compliance thereto) remains a matter under the jurisdiction of each province.

5.3. LIST OF RESTRICTED ACTIVITIES

While Section 1 in Chapter 1 of the NEMBA defines the restricted activities in relation to alien and invasive species, these activities are expanded upon in Section 6, Chapter 3 of the AIS Regulations. All the relevant activities are repeated in Notice 1 in the AIS List (Government Notice R 864 of July 2016) and include:

From the NEMBA:

a. Importing into the Republic, including introducing from the sea, any specimen of a listed invasive species.
b. Having in possession or exercising physical control over any specimen of a listed invasive species.
c. Growing, breeding or in any other way propagating any specimen of a listed invasive species, or causing it to multiply.

d. Conveying, moving or otherwise translocating any specimen of a listed invasive species.
e. Selling or otherwise trading in, buying, receiving, giving, donating or accepting as a gift, or in any way acquiring or disposing of any specimen of a listed invasive species.

From the AIS Regulations:

f. Spreading or allowing the spread of any specimen of a listed invasive species.
g. Releasing any specimen of a listed invasive species.
h. The transfer or release of a specimen of a listed invasive fresh-water species from one discrete catchment system in which it occurs, to another discrete catchment system in which it does not occur; or, from within a part of a discrete catchment system where it does occur to another part where it does not occur as a result of a natural or artificial barrier.
i. Discharging of or disposing into any waterway or the ocean, water from an aquarium, tank or other receptacle that has been used to keep a specimen of an alien or a listed invasive species.
j. Catch and release of a specimen of a listed invasive fresh-water fish or listed invasive fresh-water invertebrate species.
k. The introduction of a specimen of an alien or a listed invasive species to offshore islands.
l. The release of a specimen of a listed invasive fresh-water fish species, or of a listed invasive fresh-water invertebrate species, into a discrete catchment system in which it already occurs.

Aside from restricted activities (h), (j) and (l) above (which are specific to freshwater species), all the remaining restricted activities could potentially apply to the importation, propagation and grow out of Pacific oysters in South Africa. However, the use of Pacific oysters for aquaculture has been exempted from requiring a permit for all restricted activities except for restricted activity (a) (import), provided the aquaculture is practised in the designated areas as identified in Section 5.2 above. All use of Pacific oysters outside of the indicated zones is subject to permitting, but is exempt from restricted activities (e) and (i) in the list above, meaning that permits will still be required for the following activities outside of the gazetted zones:

- Activity (a) related to import, which includes introduction from the sea (as per the inclusive meaning read from the regulations), albeit that Pacific oysters are not farmed in South Africa through collection of wild spat;
- Activity (b) related to possession or exercising physical control over any specimen. This legislative arrangement is not reflected in practice and largely unworkable, given that live oysters are sold from restaurants across South Africa, with virtually no ecological risk.
- Activity (c) related to growing, breeding or propagation, which means that farming outside of the legally recognised zones will require permitting.
- Activity (d) related to conveying, moving and translocating specimens. Here again the legislative arrangement is not reflected in practice, given that live oysters are moved in significant numbers across South Africa for the restaurant trade, with virtually no ecological risk.
- Activity (f) could be triggered through implication that farming contributes to the spread of an alien species, notwithstanding how minor such a contribution may be as this related to Pacific oysters;
- Activity (g) could be triggered through implication that the farming of Pacific oysters could be interpreted as the release of a listed invasive species trough potential spawning into the environment that surrounds a farming activity, albeit that such release has resulted in limited establishment of feral populations on the South African coast; and
- Activity (k) is possible but unlikely, as the farming of oysters does not entail the intentional introduction of an alien or a listed invasive species to offshore islands.

6. TARGET SPECIES: PACIFIC OYSTER

6.1. TAXONOMY

Common Name:	Pacific Oyster
Kingdom:	*Animalia*
Subkingdom:	*Bilateria*
Infrakingdom:	*Protostomia*
Phylum:	*Mollusca*
Class:	*Bivalvia*
Subclass:	*Pteriomorphia*
Order:	*Ostreoida*
Family:	*Ostreidae*
Genus:	*Crassostrea*
Species:	*Crassostrea gigas (Thunberg 1793)*
Taxonomic Code:	79868

Pacific Oyster (*Crassostrea gigas*) has three sub-species:

Crassostrea gigas gigas (Thunberg, 1793)
Crassostrea gigas kumamoto
Crassostrea gigas laperousii (Schrenck)

Other Names:	Pacific giant oyster, Pacific cupped oyster, Japanese oyster, Portuguese oyster, Giant oyster, Immigrant oyster, Miyagi oyster.
Synonyms:	*Crassostrea angulate (Lamarck, 1819)*

6.2. ORIGINATING ENVIRONMENT

Pacific oysters are native to Japan and South East Asia. It is a marine and estuarine species residing in waters of 0 to 40 meters in depth. The preferred habitat is any hard substrate of rock, other shells and debris in the intertidal and shallow subtidal zone, but they can also be found in sandy or muddy areas in dense layers (FAO, 2018).

Due to the global popularity of this species for use in aquaculture (Leppäkoski *et al*., 2002; Wolff and Reise, 2002), its wide range of tolerance to various water and habitat conditions, and the ease with which it can be transported, Pacific oysters have become a cosmopolitan species that can be found along the coasts of Australia, southern Africa, South and North America, in Europe from Norway to Portugal and throughout the Mediterranean (McKenzie *et al*., 1997).

6.3. KEY PHYSIOLOGICAL CHARACTERISTICS

Pacific oyster is a cupped oyster with two tightly fitting and mostly dissimilar rough and solid outer shells (Hughes, 2002) of which the bottom shells forms the "*cup*" and the upper shell a flatter cover hinged to the lower shell. The shells are sculpted with irregular, rounded radial folds that have a laminar structure, and tend to be oblong but are variable and irregular in appearance. The lower shell attaches to the substratum.

They are usually off-white to yellow in colour, often with deep purple patches, but colour can vary. The interior of the shell is white, with a single muscle / abductor scar that can be dark or purple in colour (Robinson *et al.,* 2005). These oysters can grow to a maximum length of 30 cm, but average between 8 and 15 cm in lenght.

Figure 1: Pacific Oyster (*Crassostrea gigas*).

6.4. FEEDING AND DIETARY ASPECTS

Pacific oysters are sedentary filter-feeders that consume phytoplankton (at spat, juvenile and adult stages) and protists (only as adults), which are suspended in the water column (FAO, 2012). In order to feed, oysters relax their single adductor muscle, allowing the valves of the two shells to open slightly. Specialised cilia on the plicate gill draws water into the shell cavity, while other cilia trap particles and direct them to the palps that are liplike structures on which more cilia sort the particles into food grooves. Edible matter is directed to the mouth, while inedible particles such as sediment is rejected as “pseudo-faeces” outside the shell (National Research Council, 2004).

The filtration rate is a function of various environmental factors such as temperature, salinity and the concentration of particulate matter. The Pacific oyster can filter an average of five litres of sea water per gram of body weight per hour; and is capable of increasing this filtration rate up to 25 litres (Ren *et al.*, 2000).

6.5. LIFECYCLE AND GROWTH

Pacific and other oyster species start with the formation of their shells while in the embryonic and larval forms. As they are free-floating during this period (usually 2 – 3 weeks), they can be distributed widely by currents and weather driven oceanic systems (FAO, 2012). This allows for these animals to disperse from the immediate site of the parental stock, enhances genetic mixing, and allows the colonization of new locations (National Research Council, 2004).

When the larvae reach 300 – 340 µm they settle out and seek suitable substrate by moving around with a larval foot. A foot gland excretes a cement-like substance which permanently attaches the animal to the substrate. The attached larvae metamorphose into juveniles (called spat) that can grow by 2 – 3 cm in length after one year, and 3 – 4 cm in the second year (Fey *et al.,* 2010). Initial growth energy is focussed at shell development through sequestering calcium carbonate from the water column, but overall growth rates depend on the availability of food and water quality. Oysters do not regulate their body temperature or the salinity of their body fluids, and their metabolic activity is closely tied to the water quality and availably of food (Shumway, 1996). Growth is possible at temperatures of 5 – 35°C (optimum 11 – 34°C) and salinities of 10 – 30 ppt (optimum 20 – 30 ppt) (Mann *et al.,* 1991 in Shatkin *et al.,* 1997).

Pacific oyster beds typically occur at densities of up to 2 000 animals per square meters, which can collectively weigh about 50 kg. Well-established beds can weigh 140 kg per square meter (Fey *et al.,* 2010). Pacific oysters can live for up to 30 years (Nehring, 2011), with a minimum generation time of two years (Boudry, 2008).

6.6. REPRODUCTION

Pacific oysters are protandrous hermaphrodites as they can change gender (usually from male to female, although the reverse is also possible). When resources (e.g. food and space) are abundant, the sex ratio is skewed toward females, with males predominant when resources become scarce (FAO, 2012). Depending on growth rate, an oyster is capable of spawning at the age of one already. Under normal conditions an oyster will first mature as a male, later becoming a female.

During gametogenesis (the development of eggs and sperm in the gonads) up to 50% of the body mass can be devoted to reproductive capacity (Shatkin *et al.,* 1997). This usually takes place seasonally when the environmental conditions are optimal. In temperate areas oysters spawn during the warmer periods when the optimal water conditions for spawning are reached. This would be water temperatures of between 20°C and 25°C with an optimal salinity of 35 ppt (Shatkin *et al.,* 1997), but a variety of other threshold ranges have been reported depending on the receiving environment. Food availability, and phytoplankton blooms in particular, also play a determining role in the occurrence of spawning.

Members of the genus *Crassostrea* shed their gametes directly into the water, after which fertilization occurs (National Research Council, 2004). Pacific oysters are considered a highly fecund species as an average sized female can produce between 50 and 200 million eggs in a single of many broadcast spawning events (FAO, 2018).

6.7. ENVIRONMENTAL TOLERANCES

The global distribution of Pacific oysters is to some extent attributed to its ability to survive under a diverse set of environmental conditions. They can tolerate salinities of between 3 to 56 ppt (NIMPIS, 2012), and can reportedly survive in water temperatures between -2 and 35°C (FAO, 2018). However, these extremes of temperature and salinity do not represent optimal conditions for growth and reproduction. These tolerances also depend on other factors such as age of the individual and nutritional condition (His *et al.,* 1989). Pacific oysters can survive in an open water marine environment or under estuarine conditions where the ebb and flow water quality can vary greatly.

The *Invasive Species Compendium* (2019) published by the Centre for Agriculture and Bioscience International (CABI) shows that Pacific oysters display different tolerances to environmental variables for each life stage, as well as for survival and spawning success. Highlights from this compendium shows that:

- Dissolved oxygen levels of less than 4 mg/l are harmful to the survival of larvae. However, adults can survive short periods of anoxic conditions and complete desiccation by closing the opposing valves and adapting physiology.
- Salinity levels higher than 35 ppt are harmful to the eggs; levels below 10 ppt and above 34 ppt are harmful to the larvae, while levels below 5 ppt and above 45 ppt are harmful to adults.
- Tolerance to water temperature depends on salinity, meaning that suboptimal salinities will result in a lower tolerance to temperature. Generally, temperatures under 19°C and above 30°C are harmful to eggs; temperatures below 18°C and above 35°C are harmful to larvae, while temperatures below 3°C and above 35°C are harmful to adults.

6.8. NATURAL ENEMIES, PREDATORS AND COMPETITORS

The Pacific oyster can survive in highly competitive coastal environments and is well adapted to compete for food and habitat in these areas. In coastal environments within South Africa it has been noted that the diverse community of indigenous tunicates, bivalves, limpets and barnacles compete with oysters, which may be less tolerant of high wave action (Robinson *et al.,* 2005). This, in combination with environmental conditions, has resulted in limited and localised establishment of feral Pacific oyster populations along the South African coast.

Numerous species are known to prey on Pacific oysters. This includes several species of crab (*Metacarcinus magister, Cancer productus* and *Metacarcinus gracilis*), oyster drills, *Polydora* or marine annelid worms, *Asterias* or starfish species (*Pisater ochraceus, P. brevispinus, Evasterias troschelii* and *Pycnopodia helianthoides*), predatory whelks and some sea birds. Various fish species feed on larvae, young oysters and in some cases vulnerable or exposed adult oysters.

6.9. POTENTIAL TO HYBRIDISE

In the publication *Aquaculture* (Volume 116 of 1993) a review of hybridization among *Crassostrea* species (Gaffneya *et al.,* 1993) indicated that rigid scientific evidence of hybridization within this genus was lacking due to factors such a miss-identification, a lack of genetic data and experimental contamination. However, a number of authors have reported hybridization of the Pacific oyster (*C. gigas*) with the Jinjiang oyster (*C. rivularis*) (Allen & Gaffney, 1993), the Portuguese oyster (*C. angulate*) (Huvet *et al.*, 2002), the Hong Kong oyster (*C. hongkongensis*) (Zhang *et al.,* 2012) amongst others. The Invasive Species Compendium (2019) published by the Centre for Agriculture and Bioscience International (CABI) also records extensive hybridization between a range of *Crassostrea* species. Although no specific records of hybridization with oyster species outside of the *Crassostrea* genus exist, two alleles in populations of Pacific oyster from New Zealand have been recorded only in the Rock oyster (*Saccostrea glomerate)*.

There are no records of hybridization between indigenous South African oysters and Pacific oysters (Robinson *et al*., 2005). Furthermore, none of the indigenous South African oysters belongs to the genus *Crassostrea*, and therefore hybridisation with *Crassostrea* species is deemed unlikely.

6.10. PERSISTENCE AND INVASIVENESS

Due to its fast growth rates, high fecundity and broad environmental tolerances, Pacific oysters generally have a high invasive potential (Troost, 2010). In 2005, it was reported that wild populations of Pacific oysters have become established in 17 of the 66 countries where they are commercially cultured (Ruesink *et al.,* 2005).

The invasive pathways and patterns of Pacific oysters are highly variable, but depend mainly on redistribution through aquaculture, transfer through ballast waters of ships and hull-fouling on marine vessels. Its invasiveness has been demonstrated in several countries and it is regarded as an ecologically noxious species (Ashton, 2001; Blake, 2001; Orensanz *et al.,* 2002). Based on this status, some countries have implemented transfer restrictions and eradication efforts (Ayres, 1991). However, there is a number of countries in which the introduction of Pacific oysters for aquaculture has not resulted in feral establishment and invasion, and where the economic benefits associated with the farming of the species is significant (McKenzie *et al.,* 1997; Leppäkoski *et al.,* 2002; Escapa *et al.,* 2004).

To illustrate an example of the invasiveness of this species, it is recorded that Pacific oysters were first confirmed in the Auckland area of North Island, New Zealand in 1971 (FAO, 2018). By 1977, Pacific oyster had become the dominant farmed oyster, having displaced the indigenous Rock oyster (*Saccostrea glomerata*) through habitat competition and by means of its significantly faster growth rate (FAO, 2018). This, and other global introductions have demonstrated the potential of Pacific oysters to displace native species (FAO, 2018).

Despite their invasive potential, Pacific oysters have not yet demonstrated this invasive tendency in South African waters. Results from a study by Keightley *et al.* (2015) indicated that populations of Pacific oysters have ceased to exist in certain areas (e.g. Knysna River and estuary), numbers have decreased in others (Breede River and related estuaries), and new localised populations have established in areas such as the Swartkops and Kaaimans estuaries. With the well-established Pacific oyster aquaculture industry in Saldanha Bay and other coastal areas, the continued presence of larvae of the species around the South African coastline is a given. The success with which larvae settles in new areas should be monitored, but the limited local distribution currently poses a low risk to indigenous oyster species and the ecosystems at large.

6.11. PROBABILITY OF NATURALISATION

It has been noted in the preceding sections of this assessment report that Pacific oysters have established viable populations in various countries, to the extent that invasion and naturalisation has occurred in certain instances. However, this species has only established isolated populations in South Africa to date (Robins *et al.,* 2005), most likely as a result of larval transfer from spawning in aquaculture facilities. These isolated populations may remain viable through their own spawning, but it is probable that continued use of the species in aquaculture will serve as a source of larvae through which local populations may be sustained, or by means of which new populations may establish.

Feral populations are more likely to establish in estuarine environments than along the open coast (Keigthley *et al.,* 2015), possibly due to more moderate environmental conditions within estuarine environments. Regardless of this habitat preference, the global distribution of Pacific oysters is not likely to decline as naturalisation has already occurred in various localities. Limited naturalisation has been recorded in South Africa and is unlikely to be curtailed by limiting aquaculture.

6.12. ABILITY TO CREATE ECOSYSTEM CHANGE

In certain areas, Pacific oysters can act as ecosystem engineers that can cause major physical impacts in the environment (Dumbauld *et al.,* 2008) when they grow in dense mats or reefs (Escapa *et al.,* 2004, Ruesink *et al.,* 2006). In soft sediment environments, Pacific oysters can be efficient ecosystem engineers by creating biogenic reefs (Crooks 2002, Ruesink *et al.,* 2005). These reef structures can provide a habitat for a variety of species through offering an attachment surface, protection from harsh environmental conditions, shelter from predators and foraging or nursery grounds (Ruesink *et al.,* 2005). Emerging oyster reefs may eventually replace soft-bottom communities with hard-substrate communities, which could have biodiversity implications (Troost, 2010). However, several studies of oyster beds in different locations have found higher densities of benthic invertebrates, including crabs, bivalves and worms living on the hard substrate of oyster beds compared to the surrounding soft substrate (Hosack, 2003; Escapa *et al.,* 2004; Dumbauld *et al.,* 2008).

In addition to changing the benthic environment, oysters are filter feeders that consume suspended plankton and organic matter. Pacific oysters have a high filtration rate (Ruesink *et al.,* 2005), so dense oyster reefs or farms can improve water clarity, but also reduce food availability for native filter feeding species.

Several beneficial impacts of Pacific oysters have been recorded on native species (Dumbauld *et al.,* 2008). Shorebirds spend more time foraging in Pacific oyster reefs, perhaps due to higher prey availability (Escapa *et al.,* 2004), and these reefs create habit niches for a range of animals and plants. In certain instances where Pacific oysters have displaced indigenous oyster species, they fulfil a similar ecological role in housing the same faunal and floral communities and serve as a source of food for local predators. In such cases, ecosystem function remains largely intact despite species displacement.

Oysters filter and clear the water column of suspended phytoplankton, allowing greater sunlight penetration to benefit various species, including aquatic plants. This could however also lead to changes in food-web dynamics, water flows, nutrient availability and utilisation, and oxygen and microbe levels. Oysters can also accumulate biological toxins and industrial pollutants allowing these to move up the food web.

Although Pacific oysters can cause ecosystem change, these impacts are not always negative. The extent of ecosystem change related to the isolated feral populations in South Africa is not documented.

6.13. POSSIBLE IMPACTS ON BIODIVERSITY

In many instances, Pacific oysters grow faster and are more fecund than indigenous oyster species. For this reason, Pacific oysters can outcompete and displace indigenous oyster species (see example in Section 6.10), leading to a reduction in species related biodiversity. Such biodiversity loss through displacement has however not occurred in South Africa, given the presence of limited and isolated feral populations of Pacific oyster along the coast.

Indirect impacts to biodiversity are habitat and area specific. Pacific oysters may compete for habitat and for the same planktonic and particulate food resources as other oyster species, as well as other filter feeding marine animals. This could reduce the viability of these food and habitat competitors, especially in areas where food and habitat availability is marginal. This could lead to a local reduction of biodiversity.

In South Africa, range overlap occurs between Pacific oysters and indigenous species such as the Cape pearl (*Pinctada capensis*) and Cape rock oysters (*Striostrea* *margaritacea*), which may lead to habitat and food resource competition (Picker and Griffiths, 2011). Feral populations of Pacific oysters on the South African coast are however limited and isolated.

6.14. POSSIBLE IMPACTS ON OTHER NATURAL RESOURCES

Through filter feeding, Pacific oysters can remove particulates and excess nitrogen from the marine environment. This could affect water quality and reduce turbidity in some instances, facilitating sunlight penetration and greater levels of photosynthesis in submerged plants and algae.

The remaining lifecycle processes of Pacific oysters occur on a scale that does not have any noticeable impacts on other natural resources, albeit that they contribute to higher plankton densities through a high fecundity and can cause habitat alteration through the creation of dense beds. These effects are limited in South Africa due to the limited and isolated nature of feral Pacific oyster populations.

6.15. ACTING AS A VECTOR OF OTHER ALIEN SPECIES

Globally, the uncontrolled transfer of Pacific oysters for aquaculture purposes does result in the introduction of other species, including marine grasses, parasites and disease-causing organisms (Carlton, 1992; Ruesink *et al.*, 2005). It is estimated that up to half of the marine invasive species along the USA West Coast were introduced through oyster culture activities (Ruesink *et al.,* 2005).

Although imports into South Africa are subject to permitting and controls, this risk remains relevant given that the Pacific oyster farming sector in the country depends on the import of spat from other countries.

Ruesink *et al.* (2005) have documented 78 alien marine algae, invertebrate and protozoan species that were introduced through oyster farming activities into nine regions (i.e. Argentina, the Gulf, eastern and western USA, the Baltic Sea, New Zealand and Australia, as well as the French Atlantic and North seas). Although research into such introductions in South Africa is limited, it is thought that various alien species have been introduced with Pacific oysters into Alexander Bay, Saldanha Bay and the Knysna Estuary (Robinson *et al.,* 2005; Griffiths *et al.,* 2009). These include species such as the Black sea urchin (*Tetrapygus niger*), European flat oyster (*Ostrea edulis*), Montagu's crab (*Xantho incisus*) and the brachiopod *Discinisca tenuis* (Haupt *et al.,* 2010). Because the ecological impacts of these alien species are relatively unknown in South Africa, precautions should be taken to prevent their further spread, as well as the introduction of other species that could associate with imported batches of Pacific oyster spat.

6.16. HISTORY OF TRANSLOCATION AND CULTIVATION

Oyster farming was practiced by the ancient Romans as early as the 1st century BC on the Italian peninsula [Flat oyster (*Ostrea edulis*) and later the Portuguese oyster (*Crassostrea angulata*)]. Initial farming practices consisted of growing oysters in sheltered bays, marsh areas and lagoons. By the 1800's, a drop in the value of salt collected from marshlands on the French Atlantic coast, saw wide-ranging development of Flat oyster (*Ostrea edulis*) culture. Portuguese oysters (*Crassostrea angulata*) were systematically introduced in these areas until they were heavily impacted by disease in the 1970's, which was followed by the extensive introduction of Pacific oysters.

Pacific oysters have been farmed in Japan for many centuries; however, with global introductions to the USA in the 1920's and to France in the 1960's, culture techniques have advanced considerably. Initially, Pacific oysters were cultured using wild seed only, collected by hanging settlement materials in areas of high abundance. Modern oyster farming involves a combination of wild seed and hatchery produced seed (often imported from elsewhere). The global popularity of this oyster species has led to several important developments in culture techniques such as the production of triploid seeds, genetic selection to produce more environmental tolerance, selection for faster growth and introduction of various culture systems (FAO, 2018). The popularity of Pacific oysters for use in aquaculture has resulted in it being introduced into at least 66 regions globally, in which the establishment of viable feral populations was recorded in 17 of these regions (Ruesink *et al.,* 2005). The global distribution of Pacific oysters is largely attributable to transfer for aquaculture purposes, but some redistribution through ballast water discharges and hull fouling has taken place. Secondary transfer has also taken place within certain regions from farming activities and initial feral populations (Nehring, 2011).

The *Invasive Species Compendium* (2019) published by the Centre for Agriculture and Bioscience International (CABI) indicates that the global distribution of Pacific oysters is linked to favourable farming conditions in most temperate regions. Only the equatorial and polar regions are less favourable for culture.

In South Africa, the Pacific oyster was first introduced to the Knysna Estuary in the 1950's. Farming continued in the decades that followed, with new farms being established in areas around Port Elizabeth, Saldanha Bay, Alexandra Bay and others. By the early 2000's, established feral populations of Pacific oysters were identified by means of DNA sequencing in the Breede, Duiwenhoks, Goukou, Knysna, Kromme and Keiskamma estuaries (Robinson *et al.,* 2005). The latter three populations may have resulted from nearby aquaculture activities, but oyster farms had not been established in the former three estuaries. This means that the source of introduction could have been from aquaculture activities elsewhere along the coast, or from shipping activities, or from both. In 2001, the highest Pacific oyster densities were found in the Breede estuary (8.3 individuals per m^2, with a population size of approximately 184 000 individuals) (Robinson *et al.,* 2005).

In 2012, extensive surveying of the Knysna, GouKou and Breede River estuaries revealed a change in distribution since 2001. In direct comparison to the findings of Robinson *et al.* (2005), there were no Pacific oysters found in Knysna (either farmed or established populations); a small population of 15 individuals was identified in the Goukou (and removed as part of the survey); and the Breede population appeared to have spread further, although the population has decreased to an estimated 23 760 oysters (through consultation of Clark, B. with Keightley, J., Tonin, A., Von der Heyden, S. and Jackson, S. during 2012). These results point to the opportunistic establishment of Pacific oysters in certain estuaries on the South African coast, of which populations are vulnerable to environmental change that may cause local extinction. This emphasises that in South Africa the invasive potential of this species is limited.

The 2017 Yearbook of the Department of Agriculture, Forestry and Fisheries (DAFF) reported that seven Pacific oyster farms were operational in South Africa during 2016 (three in the Eastern Cape and five in the Western Cape), producing around 357 tonnes in that year. Production had increased to approximately 400 tonnes by 2018, but the number of operational farms had decreased to only five. The establishment of the Saldanha Bay Aquaculture Development Zone is likely to stimulate a further increase in production.

7. THE RECEIVING ENVIRONMENT

As a national framework document, this risk assessment cannot report on the receiving environment for specific areas, and on specific Pacific oyster projects or restricted activities. Notably however is that most of the South African coastline is within the lethal temperature and salinity tolerance range of Pacific oysters, albeit that warmer areas are not suitable to optimal growth.

It is important to record that Pacific oyster larvae are present in the coastal waters around South Africa, and although feral populations have established in certain estuaries, this species has not demonstrated invasive tendencies. Assuming the continuation of the current aquaculture activities in South Africa, the establishment of more farms is unlikely to change this status.

7.1. CLIMATE AND HABITAT MATCH

In South Africa, areas along the southern coastline are potentially suitable to the naturalisation of Pacific oysters. Although temperature and salinity are primary variables that drive the establishment of feral populations, other factors such as wave energy and exposure, the availability of food, turbidity and others play an important role. This interplay of factors is not yet well understood, but have resulted in the establishment of isolated populations of Pacific oysters in some estuaries of the southern coastline, most notably in the Breede River estuary.

For this risk assessment, the compatibility of this species to local environmental conditions was evaluated by comparing the marine temperature ranges in South Africa to the known environmental tolerance ranges for Pacific oysters. The water temperatures can be broadly grouped as follows (Field & Griffiths, 1991):

- West Coast: 8 – 18°C
- South Coast: 15 – 22°C
- East Coast: 22 – 27°C

Pacific oysters have a broad temperature tolerance (from -2 to 35°C); however, reproduction requires temperatures above 20°C. This may explain why there appears to be no self-sustaining populations on the west coast. Within South Africa, self-sustaining populations of Pacific oyster are only found in estuaries, with no marine based populations. This may be due to habitat availability or wave exposure along the shoreline, or any other limiting factors.

Of the six marine ecoregions, there are five inshore ecoregions which comprise South Africa's 3 100 km of coastline – the Namaqua, the Southwestern Cape, Agulhas, Natal and Delagoa ecoregion (Sink *et al.,* 2012). Although the farming of Pacific oysters would theoretically be possible along the entire South African coastline, the currently known feral populations are located mainly within the Agulhas ecoregion (Picker & Griffiths, 2011). As shown in Figure 2, Pacific oysters have established viable feral populations in only one of the 22 marine eco-zones i.e. the Agulhas Inshore eco-zone.

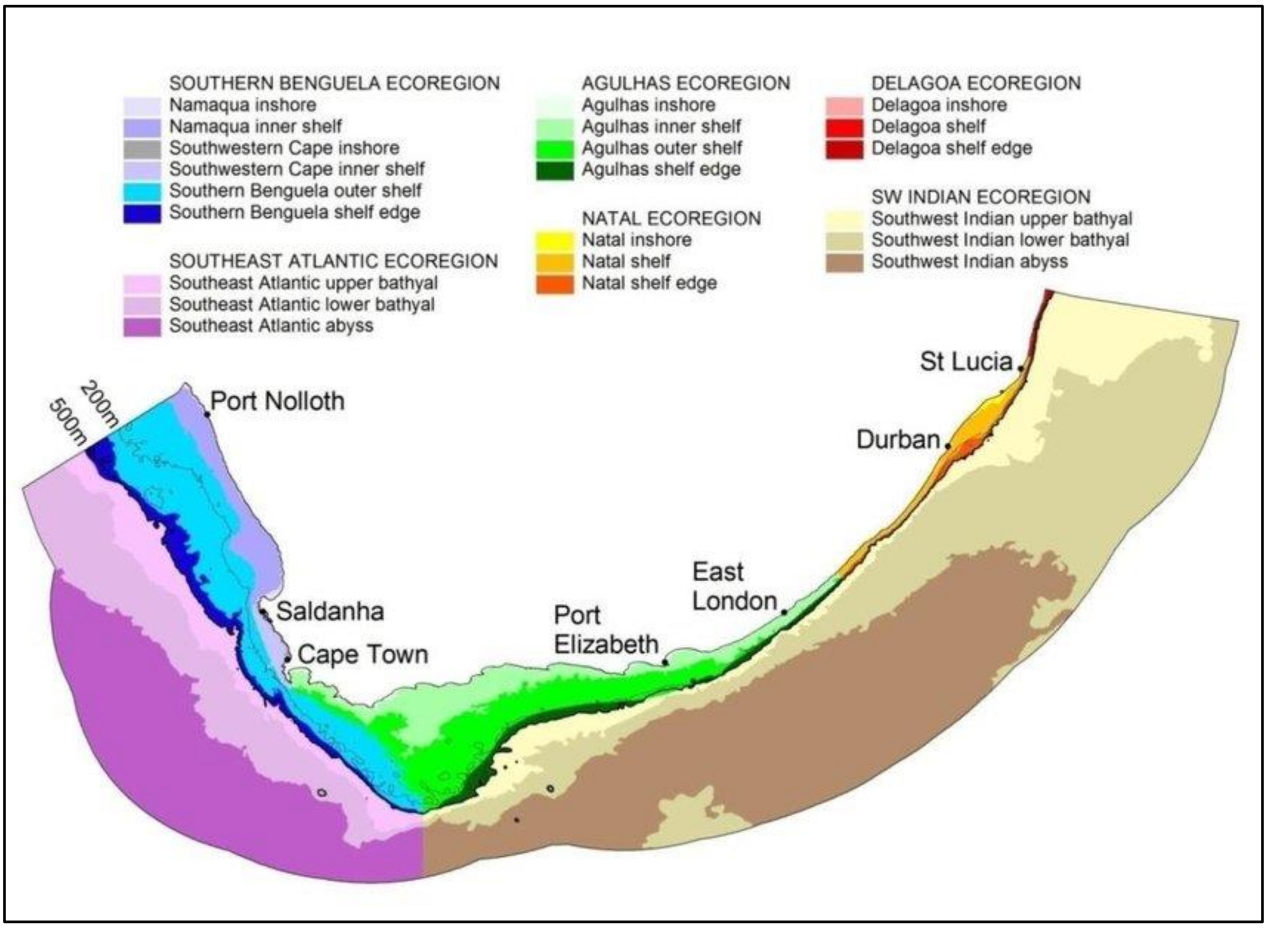

Figure 2: The six marine ecoregions with 22 eco-zones incorporating biogeographic and depth divisions in the South African marine environment (Source: Sink *et al.,* 2011).

Despite the invasive potential of Pacific oysters internationally, they do not appear to behave in an invasive manner in South African waters.

7.2. TOOLS TO IDENTIFY SENSITIVE AREAS

Although Pacific oysters have not acted in an invasive manner along the South African coastline, many national and provincial conservation plans, biodiversity frameworks and mapped marine eco-zones can be used to determine sensitive areas in which this species may pose a biodiversity risk. These include, but are not limited to:

- A range of geographic mapping tools that are published by the South African National Biodiversity Institute (SANBI), through which proclaimed conservation areas, critical biodiversity areas and other sensitive habitats can be identified.

- The South African Institute of Aquatic Biodiversity (SAIAB) conducts research and provides data on aquatic (marine and freshwater) biodiversity.
- In addition to general information that can be accessed from the Oceans and Coasts Branch of the National DEFF, local and provincial biodiversity and conservation authorities can provide regional information of relevance.

8. THEORY BEHIND ECOLOGICAL RISK ASSESSMENT

Ecological Risk Assessment provides an effective tool for assessing environmental effects or actions, and aids in resource based and environmental decision making. The risk assessment approach is widely recognized and much of this document is based on internationally researched risk assessment principles (Anderson *et al.,* 2004, Covello *et al.,* 1993; EPA, 1998; Landis, 2004). To this end, the process is well suited to the establishment of the BRBA framework for the importation, propagation and grow out of Pacific oyster in that it provides a platform from which decisions can be made and from which risks can be identified for management and monitoring.

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

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

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

8.1. THE PRECAUTIONARY AND OTHER PRINCIPALS

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

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

> "*In order to protect the environment, the precautionary approach shall be widely applied by States according to their capabilities. Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation"*.

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

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

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

8.2. METHODOLOGY IN THE RISK ASSESSMENT

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

Many risk assessment methods suffer from bias and these shortcomings must be managed (Burgman, 2001; Hayes *et al.,* 2007) such as to help maintain scientific credibility (FAO, 2015).

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

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

1. A step-by-step process expanded and modified from the aquaculture risk assessment work by Fletcher *et al*. (different authors in 2003, 2005 and 2015), in which an inventory of potential risks is characterized and scored for probability, severity, scope, permanence, confidence, monitoring and mitigation; and
2. The European Non-Native Species Risk Analysis Scheme (ENSARS) (Copp *et al*., 2008) developed by CEFAS (UK Centre for Environment, Fisheries & Aquaculture Science). ENSARS provides a structured framework (Crown Copyright 2007 – 2008) for evaluating the risks of escape and introduction to, and establishment in open waters, of any non-native aquatic organism. For each species, 49 questions are answered, providing a confidence level and justification (with source listed) for each answer. The questions and results of the assessment on Pacific oysters are found in Appendix 1.

The following steps constitute the method that has been expanded and modified from the work by Fletcher *et al*. (different authors in 2003, 2005 and 2015):

- Identification of risks and determination of endpoints (consequences). This is also referred to as problem formulation in risk assessment and determines what is at risk.

- Determination of the endpoints and the acceptability in endpoint levels (the level of acceptable change if a risk or stressor were to occur).
- Modelling of the risk pathway from hazard to endpoint (also called logical modeling).
- Assessing the risk by means of any information resources and experience. This can be divided into two distinct sections: the exposure assessment (nature of the risk / stressor) and effects assessment (nature of the endpoint or effect on the environment).
- Determination whether the risk has the potential to increase the probability of the endpoint occurring. If there is no such potential, such a risk can be eliminated from analysis.
- Describing the probability, intensity (severity) and scale (scope) of the risk to the environment (also called risk characterization).
- Determining the level of uncertainty (confidence) in risk characterization.
- Tabulating the findings according to intensity (severity or degree) of change, the geographical extent of the change (scope), and the duration or permanence of the change.
- Approximating the probability and the uncertainty.
- Addressing areas of weakness where the collated information appears incomplete or inadequate.
- Assessing the acceptability of the proposed activity through reference to the tabled analysis.
- Assessing the opportunity for risk mitigation and monitoring, and the need for additional research to reduce uncertainty.
- Effectively communicating risk in an on-going manner to all relevant stakeholders.

8.3. THE RISK PATHWAY

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

In aquaculture of Pacific oysters, only two pathways exist through which a risk can influence or impact on an endpoint. These are the pathway of escape and the pathway that facilitates the introduction or spread of a potential disease. It is therefore logical that the potential manifestation of species related ecological impacts or endpoints of the identified risks is eliminated if the potential for escape is eliminated (apart from disease), or if the risk is nullified by the preceding occurrence of the species independent of the activity that creates the risk pathway (as is partly the case with Pacific oysters).

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

8.4. SCALES AND CATEGORISATION OF RISK

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

Table 1: Categories of risk probability: Probability of a risk or stressor occurring.

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

Table 2: Categories of risk severity: Severity of the effects of the stressor on the endpoint.

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

Table 3: Categories of risk scope or scale: Scope or scale of the effects of the stressor on the endpoint (i.e. geographic extent).

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

Table 4: Categories of permanence or longevity: Permanence or longevity of the effects of the stressor on the endpoint.

Scale	Explanation and Comments

Permanent	Change to the endpoint caused by the stressor will last for more than one century, regardless of the mitigation measures.
Long lasting	Change to the endpoint caused by the stressor will outlast the expected lifespan of the activity or project.
Moderate	Effects can be measured in years, but it is within the expected lifespan of the activity or project and where effects are measured on organisms, it is usually within the organism's expected lifespan.
Temporary	Effects are usually inside of one year in duration.
Short term	Effects can usually be measured in days.
Periodic	Effects occur more than once within the temporary or short-term classification of permanence.

Table 5: Categories of uncertainty (or certainty and confidence): Uncertainty in the analysis of risks, stressors and endpoints and the interrelationships between these.

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

Table 6: Categories of monitoring: Monitoring of the effects of the stressor on the endpoint within reasonable time and cost.

Scale	Explanation and Comments
Zero	Where no monitoring is possible.
Low	Where limited indicators can be collected and reported about either severity, scope or the temporal nature of the effect or impact of a stressor, and where inferred changes in ecosystem functionally, habitat and species loss is mostly used.
Moderate	Where only certain indicators can be collected and reported about the severity, scope and temporal nature of the effect or impact of a stressor, and where inferred changes in ecosystem functionally, habitat and species loss is used.

High	Where sufficient information (key indicators) can be collected and reported about the severity, scope and temporal nature of the effect or impact of a stressor, to identify major changes in ecosystem functionally, habitat and species loss.
Very High	Where the full severity, scope and temporal nature of the effect or impact of a stressor may be monitored with confidence and reported within the resources of a project.

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

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

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

Table 8: Example of a matrix indicating all categories and scales of risk.

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

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

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

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

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

8.5. PERCEPTION OF RISK

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

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

8.6. RISK COMMUNICATION

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

- Risk assessment is the first step in an on-going process in which risks must be monitored, mitigated and correctly communicated through tools such as assessments, plans, audits, meetings and more.
- The communication of risk must take cognisance of the nature of the parties to which information is given. This should incorporate consideration of factors such as education, manner in which they are being affected by the risk, social and economic character and more.
- Risk communication must be used to improve the understanding and confidence of initial risk assessment.
- Risk communication must always be clear, transparent, timely and unbiased.

- The communication of risk is the means through which information can be provided to decision making authorities to evaluate the granting of rights (authorisations, permits, concessions etc.) in terms of statutory provisions.

9. SPECIFIC FRAMEWORK ASSESSMENT FOR PACIFIC OYSTER

The methodology above meets the requirements for risk assessment as per Section 14 of the AIS Regulations (GN R 598 of 01 August 2014). However, this BRBA is a framework document that users need to populate with specific and detailed project-level information pertaining to the receiving environment and the nature of their own proposed importation, propagation and grow out of Pacific oysters.

9.1. NATURALISED IMPACTS OF PACIFIC OYSTERS

Pacific oysters have established limited and isolated feral populations along the southern coast of South Africa. These feral populations, the existing farming activities and factors such as transfer through ballast water and hull fouling cause Pacific oyster larvae to occur widely in the coastal waters of South Africa, albeit that settlement rates and the establishment of feral populations are limited. This means that control methods for this species, and any mitigation measures implemented to manage the potential biodiversity impacts associated with aquaculture, will have a limited effect on the distribution, naturalisation and impact of this species in South Africa.

Assessment of the ecological risks of Pacific oysters must be considered against the already established feral populations and other sources of larvae, meaning that the scores allocated to the pathways of risk and the endpoints (impacts) must be seen in light of the status of feral establishment, the fact that Pacific oysters have not acted in an invasive manner along the South African coastline, and the nature of the receiving environment.

9.2. INVENTORY OF POTENTIAL PATHWAYS AND RISKS

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

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

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

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

- The potential for physical (abiotic) impact to the environment.
- The potential for species displacement.
- The potential for competition - for food, habitat niches and other resources.
- The potential for hybridisation.
- The potential threat of new or novel diseases.

As indicated, the primary ecological risks in the inventory above are linked to the pathway of escape, and further, with the ability of Pacific oysters to establish a feral and self-propagating population. This ability is determined by the nature of the facilities in which the oysters are farmed, and the life history characteristics of Pacific oysters as described in Section 6 of this assessment report.

9.3. DISCUSSION OF RISK PATHWAYS

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

9.3.1. THE PATHWAY OF ESCAPE

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

- Escape during handling, seeding, harvesting and transport from both land-based and offshore facilities
- Escape directly from the aquaculture infrastructure, be this land-based of offshore
- Escape caused by poor design, system malfunction or poor maintenance
- Escape by means of deliberate or accidental human actions, including theft
- Escape due to adverse weather and sea conditions

Escape during handling, seeding, harvesting and transport

Pacific oyster farming entails extensive handling of the animals, which includes the handling and sorting of spat, the seeding of these spat into production systems, grading, cleaning and harvesting. These actions take place in land-based systems, nearshore and offshore where the oysters are farmed, leading to the reintroduction of oysters into the environment, some of which may survive.

From the above it is concluded that the probability of escape from these actions is absolute, but the contribution of these animals to any feral population is probably negligible. Some degree of mitigation would be possible to reduce this reintroduction to the environment, but this would result in an unnecessary investment of time and effort given that the reintroduction of these oysters will not change the ecological risk profile.

Escape directly from the aquaculture infrastructure

Apart from breakage due to poor maintenance and extreme weather conditions, some oysters may become detached from the production systems depending on the farming method that is deployed.

Apart from the escape of individual animals, oysters will spawn while in production depending on their age, condition and the environment. The results in the release of millions of gametes, creating an extensive larval population in the surrounding waters or in the outflow water of land-based facilities.

From the above it is concluded that the probability of escape directly from the production systems (individual animals) and through spawning is absolute, but that this will have a limited effect in terms of the establishment of invasive populations along the South African coast. Little mitigation would be possible to reduce this reintroduction to the environment, and this would result in an unnecessary investment of time and effort given that the reintroduction of these oysters will not change the ecological risk profile significantly.

Escape through poor design, system malfunction or poor maintenance

A pathway for escape can be facilitated by poor design, system malfunction and poor maintenance of the oyster production infrastructure. The design of any system should ensure that rafts, ropes, platforms, tanks, anchors, buoys and other equipment is sturdy. Likewise, regular maintenance is required to prevent malfunction and breakage.

The collision of boats and ships with offshore oyster production systems is not impossible, but generally unlikely in areas where the sighting of mussel farms is carefully planned and where marine navigation is controlled.

Given the exposure of offshore oyster production systems, some degree of breakage and system failure is normal under severe conditions. In such instances the probability of escape is absolute, but this also will have a limited effect in facilitating the establishment of invasive populations. Mitigation measures include the use of tried and tested production system design and regular maintenance of all equipment.

Escape by means of deliberate or accidental human actions, including theft

Theft is a human characteristic that depends on a combination of socio and economic factors. Escape through theft is possible, given that the incentive for theft is mostly around a means to a meal or for the sale of stolen oysters. However, measures such as security systems, surveillance and restricted access can implemented to prevent theft.

Human error is an unavoidable characteristic of all human endeavour and can be directly linked to factors such as level of training, experience, awareness, employment conditions and the nature of the production facility. As with design and maintenance aspects, it is important that critical points and causes of human errors be identified and that the consequences thereof be anticipated.

From the above it is concluded that the potential for escape through theft and human error does exist, but that this will have a limited effect in facilitating the establishment of invasive populations. A range of measures exist to mitigate against theft and human error.

Escape due to adverse weather and sea conditions

Directly linked to design, maintenance and human error, is the fact that offshore oyster farms are prone to adverse weather conditions and periods of severe seas. This risk is a function of the sighting of the facilities, the design of the facilities and the prevalence of adverse weather conditions.

From the above it is concluded that the probability of escape due to adverse weather and extreme sea conditions is absolute, but that this will have a limited effect in facilitating the establishment of invasive populations. Some degree of mitigation is possible through the correct sighting of farming systems, good design, regular maintenance and weather prediction, but this will not prevent escape and will not change the ecological risk profile of escape significantly.

9.3.2. THE PATHWAY OF DISEASE

Concomitant with all species introductions, there is potential for the introduction of novel diseases (bacterial, viral pathogens and parasites) into the recipient environment, and these could affect indigenous species and the ecology. In the case of oysters, these diseases can originate from introduced stock, as a result of contaminated transport water or packaging materials, through sea currents and through international trade and shipping. Diseases can also be transferred through the moving of farming equipment, on the hands and shoes of people that move through the farms, and in a myriad of other ways.

Under current farming practices for Pacific oysters in South Africa, the potential for the introduction of novel diseases as a result of aquaculture activities is of concern, given that the sector depends on imported spat. Pathways for new and novel diseases thus rest primarily on the import of seed, but also on international movement of the disease-causing organisms by ballast waters and haul fouling.

For the import of Pacific oyster seed, it should be noted that the most effective means of control is to prevent the introduction of disease-causing organisms. The import of oyster spat into South Africa is subject to veterinary clearance from the Directorate of Animal Health and Biosecurity in the Department of Environment, Forestry and Fisheries (DEFF). In addition to this, the disease protocols and screening for certain notifiable diseases, in terms of the protocols of the World Organisation for Animal Health (OIE), is mandatory and should be applied.

The extent of larval movement may lead to a spread thereof throughout their southern African range should novel diseases are to be detected in South African Pacific oyster stocks. Such novel diseases may or may not affect other indigenous oyster species depending on host specificity. It should be noted that Pacific oysters are susceptible to a range of diseases and parasites.

9.4. DISCUSSION OF RISK ENDPOINTS

Although the farming of Pacific oysters in South African waters is not without the potential for environmental impacts, the biodiversity risks (endpoints), regardless of the scale of farming, is reduced by the fact that the limited and isolated feral populations have not become invasive and that various sources of larvae exist in South African marine waters. For this reason, the limited biodiversity impact is likely to occur regardless of the aquaculture activities, which strips the value from identifying and ranking the biodiversity risks that may be associated with the farming activities.

9.4.1. PHYSICAL ABIOTIC DAMAGE TO THE ENVIRONMENT

Pacific oysters can cause some degree of physical impact to the environment through the establishment of very dense and extended beds. These beds can cover suitable habitat, affect flow and sand distribution and act as a protective reef for other marine creatures. Shells of dead oysters may accumulate to some degree in the marine environment and on the shoreline, but these are rapidly recycled through breaking down into sand and inorganic sediments.

9.4.2. SPECIES DISPLACEMENT

Sections 6.10 and 6.13 speaks to the ability of Pacific oysters to displace indigenous oysters. Such displacement has led to a significant decline in indigenous species in certain parts of the world, but this has not been observed in South Africa given that isolated feral populations of Pacific oysters have not become invasive.

The potential ecological risk of species displacement is not of immediate concern but should be monitored. It is not believed that curtailing aquaculture activities will change the displacement related ecological risk profile related to Pacific oysters in South African waters.

9.4.3. COMPETITION - FOOD, HABITAT & OTHER RESOURCES

The limited and isolated feral populations of Pacific oysters in estuaries off the southern coast of South Africa do cause some localised competition for habitat and food. The scale of this impact is however limited in the South African context.

The potential ecological risk of competition is not of immediate concern but should be monitored. It is not believed that curtailing aquaculture activities will change the competition related ecological risk profile related to Pacific oysters in South African waters.

9.4.4. HYBRIDISATION

Although hybridisation is known to occur between Pacific oysters and other species (see Section 6.9), no hybridisation has been recorded with indigenous oyster species along the South African coast.

As there are no indigenous species with which Pacific oysters can hybridise, this risk endpoint has been eliminated from further assessment.

9.4.5. EFFECTS OF DISEASE

Import and assemblage of new stock and high stocking densities commonly found in aquaculture, can lead to disease related issues. The potential impacts of novel diseases introduced into an area through aquaculture can be wide-ranging and severe. Pacific oyster seed or spat used in South African aquaculture is imported, which entrenches the ongoing risk of disease or parasite importation.

Internationally some diseases and a range of parasites have been reported for Pacific oysters. Their transport to some countries has seen them carry parasites such as the Japanese oyster drill (*Ceratostoma inornatum*), the oyster flatworm (*Pseudostylochus ostreophagus*) and the copepod parasite (*Mytilicola orientalis*).

In a study commissioned by the then Department of Agriculture, Forestry and Fisheries in 2017 (*Feasibility Study of Oyster and Mussel Aquaculture in South Africa*), it was reported that pathogens can cause mass mortality in oysters (Mackin, 1961 in Dégremont *et al.,* 2007). Yet, despite the widespread distribution of Pacific oysters around the world, there are relatively few disease problems of major significance (FAO, 2005). A summary of the major diseases and parasites, as well as the symptoms has been adapted from Elston and Wilkinson (1985), Boettcher *et al.* (2000), FAO (2005), ICES (2010) and ICES (2011) and are tabled below.

Table 9: Symptoms of the diseases/parasites which commonly infect Pacific oysters.

Name of disease or parasite	Explanation and Comments
Demon Island disease	A protozoan parasite that causes tissue necrosis (lesion form) and mortalities.
MSX disease	A parasite that reduces shell growth, meat quality and reproductive ability. Can lead to mortalities.
Dermo disease	A parasite that reduces feeding and growth, as well as reproductive ability. Can lead to mortalities.
Juvenile oyster disease	A bacterium that reduces growth rate, causes the development of a fragile and uneven shell margin, cupping of the left valve and mortalities.
Pacific oyster mortality syndrome	Causes mortality.
Nocardiosis	A bacterium that reduces thermotolerance, causes lesions and mortalities.
Herpes-type virus disease	Affecting mainly larvae, this virus affects the digestive organ, causes reduced feeding, lesions and mortalities.
Oyster velar virus disease	This virus causes blister formation and mortalities
Gill disease of Portuguese oyster	This virus causes gill erosion and high levels of mortality. Initial clinical signs of yellow spots on the gills progress to brown discolouration with associated necrosis and degeneration, leaving a perforation. Yellow or green pustules may occur on the mantle or adductor muscle.
Haemocytic infection virus disease	This virus causes mass mortality.
Extracellular giant “Rickettsiae” of oysters	This prokaryotic organism causes disappearance of the apical microvilli and cilia, and lysis of the gill epithelial cells. Multiple tumour-like growths can occur on the gill lamellae.

Harmful algal blooms (commonly known as “red tide”) are not an oyster specific disease, but rather an environmental phenomenon that is driven by nutrient upwelling and climate. These algal blooms (of various species) can locally deplete marine waters of oxygen and in some cases the algal species are able to release toxins that could affect and even kill oysters and other marine life. Due to the filter feeding habits of oysters, the toxins from the algal blooms may periodically accumulate in the flesh of the oysters rendering them toxic for human consumption. The oyster producers along the South Africa coastline monitor for the presence of these toxins continuously. These algal blooms are however an environmental (and biodiversity) impact on marine life and not a biodiversity risk caused by the Pacific oysters.

9.5. ASSESSMENT SCORING OF RISK LEVELS

With reference to the pathways and risk inventory in Section 9.2, the following sections illustrate the outcome of the assessment of biodiversity risk levels. As a national risk framework, it is impossible to accurately determine the risk levels for each instance in which Pacific oysters are used, or in which it is being proposed for use in aquaculture. Moreover, it is impossible to determine the precise levels of risk based on the design of an individual aquaculture project, and the level of mitigation that will be applied. For these reasons, the scoring that follows must be used as a point of departure to provide a generic framework which will require further detailed assessment for individual projects.

As indicated throughout this risk assessment, the biodiversity risks that are posed by the farming of Pacific oysters must be considered in context to the fact that some localised and isolated feral populations have already become established on the South African coast, without showing tendencies for invasiveness. Furthermore, oyster larvae that could lead to feral establishment could come from existing feral populations, aquaculture activities and/or from ballast waters or hull fouling. The contribution from aquaculture is thus of less significance, unless concerted efforts are undertaken to eradicate the feral stocks. For this reason, increased use of Pacific oysters in aquaculture will not necessarily change the biodiversity risk that is already posed by the feral population.

9.5.1. RISK PATHWAYS

The relationship between a risk pathway and the endpoint has been discussed in Section 9.3 and 9.4. It should be noted that the probability of a pathway such as escape refers specifically to the probability (chance) of escape, and not to the probability of the escape event leading to an impact or endpoint. Likewise, the severity refers to the severity (quantity) of escape, the scope to the distribution of escapees and permanence to the survival and propagation of the escapees. These aspects should not be confused with the characterisation of the endpoints or impacts.

The scoring of the biodiversity risk pathways associated with the farming of Pacific oysters creates a false impression, given that the farming systems are by their very

nature prone to escape, and given that these alien oysters have already led to the establishment of limited and isolated feral populations. Note that Table 10 – 15 hereafter depict an aggregate score for South Africa in general.

a. The risk of Pacific oysters escaping during handling, seeding, harvesting and transport.

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

Table 10: Risk pathway characterisation related to escape during handling, seeding, harvesting and transport.

b. The risk of Pacific oysters escaping directly from the aquaculture infrastructure.

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

Table 11: Risk pathway characterisation related to escape from the aquaculture infrastructure.

c. The risk of Pacific oysters escaping through poor design, system malfunction and/or poor maintenance.

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

Table 12: Risk pathway characterisation related to escape through poor design, system malfunction and/or poor maintenance.

d. The risk of Pacific oysters escaping through deliberate or accidental human actions, including theft.

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

Table 13: Risk pathway characterisation related to escape through deliberate or accidental human actions, including theft.

e. The risk of Pacific oysters escaping through adverse weather and sea conditions.

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

Table 14: Risk pathway characterisation related to escape through adverse weather and sea conditions.

f. The risk of Pacific oysters serving as vector for the introduction of novel diseases and pathogens (including parasites).

Risk	Spread of disease				
Pathway	Various disease pathways for the introduction of novel diseases and pathogens (including parasites)				
Probability	High	Moderate	Low	Extremely low	Negligible
Severity	Catastrophic	High	Moderate	Low	Negligible
Scope	Extensive	Regional	Local	Project based	Negligible
Permanence	Permanent	Long-lasting	Moderate	Temporary	Short term
Confidence	Doubtful	Low	Moderate	High	Very high
Monitoring	Zero	Low	Moderate	High	Very high
Mitigation	Irreversible	Low	Moderate	High	Very high

Table 15: Risk pathway characterisation related to spread of novel diseases.

9.5.2. RISK ENDPOINTS / IMPACTS

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

The scoring of the biodiversity risk endpoints associated with the farming of Pacific oysters creates a false impression, given that the surrounding environment could be seeded through larval introduction from various sources. Pacific oysters have already established limited and isolated feral populations and it is not expected that curtailing aquaculture will change the endpoints of impacts of these oysters in South Africa. Note that Table 16 – 19 hereafter depict an aggregate score for South Africa in general.

a. The risk of Pacific oysters causing physical (abiotic) impacts to the environment.

Risk	Life history characteristics of Pacific oysters				
Endpoint / Impact	Physical (abiotic) damage to the environment				
Probability	High	Moderate	Low	Extremely low	Negligible
Severity	Catastrophic	High	Moderate	Low	Negligible
Scope	Extensive	Regional	Local	Project based	Negligible
Permanence	Permanent	Long-lasting	Moderate	Temporary	Short term
Confidence	Doubtful	Low	Moderate	High	Very high
Monitoring	Zero	Low	Moderate	High	Very high
Mitigation	Irreversible	Low	Moderate	High	Very high

Table 16: Risk endpoint characterisation related to physical damage to the environment.

b. The risk of Pacific oysters causing species displacement.

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

Table 17: Risk endpoint characterisation related to species displacement.

c. The risk of Pacific oysters causing competition for food, habitat niches and other resources.

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

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

d. The risk of disease related endpoints/impacts that are facilitated through the farming of Pacific oysters.

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

Table 19: Risk endpoint characterisation related to impact of diseases and pathogens.

9.6. SUMMARY OF RISK PROFILE

The pathways and endpoints of the risks that have been set to analysis above can be summarized to arrive at an overall risk profile. Table 20 summarises the characterisation of pathways and endpoints.

Table 20: Risk profile characterised by risk pathways and risk endpoints.

	Risk Pathways						**Risk End Point or Impacts**			
Risk	Handle, seed, harvest, transport	Direct from aquaculture facility	Design, malfunction or maintenance	Human error or theft	Adverse weather and sea conditions	Disease pathways	Physical damage	Species displacement	Competition food, niches & resources	Disease impacts
Probability	High	High	Moderate	Moderate	Moderate	Moderate	Moderate	Low	Low	Moderate
Severity	Moderate	Moderate	Moderate	Moderate	High	High	Low	Low	Low	High
Scope	Extensive	Extensive	Extensive	Extensive	Extensive	Extensive	Local	Local	Local	Extensive
Permanence	Long-lasting	Long-lasting	Long-lasting	Long-lasting	Long-lasting	Long-lasting	Long-lasting	Moderate	Moderate	Long-lasting
Confidence	Very high	Very high	Very high	Very high	Very high	Very high	Very high	Very high	Very high	High
Monitoring	High	High	High	Moderate	High	Low	Moderate	Moderate	Moderate	Low
Mitigation	Irreversible	Irreversible	Low	Moderate	Low	Moderate	Low	Low	Low	Low

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

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

Table 21: Numeric values associated with risk characterisation.

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

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

The scoring of evaluated pathways and risk endpoints for Pacific oysters is illustrated in Table 22.

Table 22: Score allocation to the risk profile before mitigation.

	Risk Pathways						**Risk End Point or Impacts**			
Risk	Handle, seed, harvest, transport	Direct from aquaculture facility	Design, malfunction or maintenance	Human error or theft	Adverse weather and sea conditions	Disease pathways	Physical damage	Species displacement	Competition food, niches & resources	Disease impacts
Probability	4	4	5	5	5	5	8	12	12	6
Severity	12	12	11	11	8	6	15	16	16	8
Scope	3	3	3	3	3	3	7	7	9	3
Permanence	6	6	6	6	6	5	6	8	9	6
Confidence	10	10	10	10	10	9	9	9	10	7
Monitoring	8	8	8	6	8	4	6	5	3	5
Mitigation	2	2	4	6	4	6	3	3	3	5
Total Score	45	45	47	47	44	38	54	60	62	40

The score allocation, although subjective and debatable, has been done based on information provided in this BRBA. As a general rule, scores above 50 denote acceptable levels of biodiversity risk and those below 50, unacceptable. However, in this case, the fact that Pacific oysters have already established feral populations in certain areas and are not displaying tendencies of invasion, skews the scoring to some extent. Escape from farming operations is absolute, while the farming activities, whether mitigated or not, makes little difference to the ecological endpoints or impacts. The scoring therefore is of limited value in this risk assessment.

When considering the pathways for the manifestation of risks, the score for introduction of disease poses the greatest threat. This aspect shows some potential for monitoring and mitigation, meaning that effective risk pathway management could see a lowering of the potential impact to endpoints. This supports the need for careful screening of imported seed and spat stocks.

With due consideration to the pathway above, the scores for the ecological endpoint or impact related to disease is also relevant. Monitoring and mitigation after the introduction of a novel disease will have little effect on curtailing the potential biodiversity impact, albeit that this impact may manifest regardless of aquaculture activities. The import of unwanted diseases and parasites through aquaculture however remains the risk of greatest concern.

Note that this scoring methodology has been used to grade the potential negative biodiversity risks and impacts only. The potential positive ecological impacts of Pacific oysters include the creation of habitat niches and providing food for a range of smaller marine species. Pacific oysters can improve local water quality by removing particulates and excess nitrogen from the marine environment, reducing turbidity, and thus allowing vegetation to photosynthesise more efficiently. Oyster farms can also serve as sheltered areas for certain fish species and other marine life.

10. KEY ECONOMIC, SOCIAL AND SOCIETAL CONSIDERATIONS

The risk profile above is based on the potential negative environmental or ecological consequences related to the use and introduction of Pacific oysters for aquaculture. These risks must be considered in a balanced manner in conjunction with potential economic, social and societal considerations, as well as the fact that Pacific oysters have not shown a tendency for invasion in South Africa.

The oyster farming sector in South Africa was established solely to supply to local markets and this market has grown steadily through consistent supply. Recent developments have seen the first Pacific oysters being exported from South Africa.

In terms of the oyster production reported to the FAO, South Africa produced 336 tonnes in 2017, valued at approximately U$ 1 514 million. This figure may be slightly overestimated, but oyster output in South Africa is set to grow with the proposed development of new farms that are being planned.

Pacific oyster farming is due to expand in Saldanha Bay, in an area which has been approved as an offshore aquaculture development zone. Given the high productivity of the waters in Saldanha Bay, it is likely that this sector will continue to expand. The biodiversity related impacts of this species in Saldanha Bay is limited.

The oyster sector will continue to contribute to the furtherance and success of aquaculture in South Africa, which is a clear objective of the current policies and strategies adopted by the South African Government, particularly the Department of Environment, Forestry and Fisheries (DEFF). Success in Pacific oyster aquaculture has already resulted in several socio-economic advantages, which include:

- The creation of scarce skills and the application of new technologies.
- The beneficial use of natural resources.
- The production of products for export.
- The creation of economic opportunities. This is especially relevant considering that these opportunities are created in primary production.
- Direct and indirect food security.

It is important to weigh the socio-economic benefits against the manifestation of any of the ecological impacts that may result from farming practices with Pacific oysters. In this case the socio-economic benefits from aquaculture should be encouraged, as the farming will have little effect on the existing biodiversity risk profile.

Important to note that the continued presence of Pacific oysters in South African marine waters pose no direct threat to humans or any human livelihoods.

11. BALANCED COST OF ERADICATION

There is limited information regarding the successful eradication of Pacific oysters. The effort required to eradicate these animals once they have established a feral population is significant.

A balanced view must be taken to the potential ecological cost related to the presence of Pacific oysters and the potential cost of eradication. This cannot be approached as an actual cost as an expense of this nature must be weighed up against the ecological costs and the net gain of benefits that would result from an eradication effort. Given the limited ecological costs, the potentially impacted species, the nature of the receiving environment, the limited and isolated feral populations and the insignificant effects that could manifest towards human beings and their livelihoods, the cost of eradicating Pacific oysters along the South African coastline would not only be impractical, but also unwarranted. The socio-economic benefits coupled with the impracticality of eradication outweigh the benefits that may accrue from eradication.

12. RISK MONITORING

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

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

Given the limited and isolated feral populations of Pacific oysters in South African marine waters, the monitoring regime should justify the value of the monitoring result. If no degree of monitoring will make any change to the biodiversity impact, then monitoring should be limited. Only the following monitoring requirements should be considered for inclusion in a monitoring programme for the use of Pacific oysters in aquaculture (this is aside from the monitoring requirement for non-biodiversity related environmental impacts such as changes in the benthic communities, and the toxicity monitoring conducted from a food safety point of view). At project level, it is recommended that the monitoring regime be subjected to external verification by an independent specialist.

- Ongoing health and disease monitoring, particularly of imported spat.
- An annual review of operational procedures.
- A monthly inspection of all maintenance, as well as integrity and seaworthiness of offshore production facilities.

13. RISK CONTROL MEASURES AND MITIGATION

Adequate mitigation measures generally lead to reduced levels of severity, scope, longevity etc. of biodiversity related risks. Such mitigation measures should be recorded, implemented, audited and reported; both internally and, if required, externally by an independent specialist. However, in the case of Pacific oyster farming, on-farm mitigation will have little effect in stemming the already limited biodiversity related impacts of the feral population of this species in South African marine waters. However, the following mitigation measures could be considered for inclusion as conditions related to the issuing of permits for the use of Pacific oysters in aquaculture:

To prevent the introduction of novel diseases and parasites:

- All imported stock must be subject to health certificates from the supplier and supplying country and be conducted in accordance with the conditions attached to veterinary clearance from the Directorate of Animal Health in the Department of Environment, Forestry and Fisheries (DEFF).

Precautions against inclement weather and severe sea conditions:

- Maintenance of production facilities to prevent structural failure and breakage.

Note that a site-specific Environmental Management Programme (EMPr) should be developed for each oyster farm and compliance thereto should be mandatory.

14. RESEARCH NEEDS

Major knowledge gaps include its ecosystem-level effects and consequences, and its interactions with indigenous organisms (Ruesink et al., 2005). Specifically, how Pacific oysters influence nutrient cycling, hydrodynamics, and sediment budgets compared to other indigenous oysters, and what the likely consequences of these are, still need to be established (Ruesink *et al.,* 2005). In addition, little is known about whether indigenous species of oyster and other co-occurring species use Pacific oysters for habitat and/or food; and there is a lack of knowledge regarding the spatial and temporal extent of direct and indirect ecological effects within invaded and adjacent communities and ecosystems (Ruesink *et al.,* 2005).

Routine monitoring of current Pacific oyster populations and their impacts on habitat, as well as research and modelling of their potential range expansion, taking into account predicted effects of climate change, and survival in the marine environment, are other important research needs.

Given that Pacific oysters have demonstrated considerable invasion success internationally (Ruesink *et al.,* 2005), further research is required on the lack of established natural populations in South Africa to determine the limiting factors (e.g. lack of available habitat or predator interactions).

15. BENEFIT / RISK TRADE-OFF

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

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

Benefit and risk trade-off can become a highly complicated exercise when assigning objective and comparable values to these. Although this trade-off is not being pursued in this risk assessment report, considering the risk profile indicated above in conjunction with the advantages and benefits from the use of Pacific oysters for aquaculture, one can arrive at an acceptable risk trade-off in which the use of this species should be permitted.

16. RECOMMENDATIONS

Risk assessment techniques have been applied to all the major biodiversity risk components related to the use of Pacific oysters for aquaculture in South Africa. Pacific oysters have already established limited and isolated feral populations, and the use of this species in aquaculture operations is unlikely to result in further expansion of its range. Culture of this species should thus be allowed and be promoted to continue in any coastal area, provided that the non-biodiversity related environmental impacts have been adequately assessed and the risk of importing unwanted diseases and parasites is managed. It is also recommended that South African based oyster hatcheries be established so as to minimise the need for and utilisation of imported spat.

17. CONCLUSION

This BRBA has illustrated that the use of Pacific oysters in aquaculture in South Africa harbours no greater a biodiversity risk than the existing feral populations do. Only the importation of new oyster stocks may pose a disease related risk.

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APPENDIX 1. Risk scoring methodology for *C. gigas* and guidance supplied by the F-ISK toolkit (Copp *et al.* 2008)

	Risk query:			
Question	**Biogeography/historical**	**Reply**	**Comments & References**	**Certainty**
1	**Is the species adapted for aquaculture or ornamental purposes?** Guidance: The taxon must have been grown deliberately and subjected to substantial human selection for at least 20 generations, or it must be known to be easily reared in captivity.	Y	FAO 2012	4
2	**Has the species become naturalized where introduced?** Guidance: The taxon must be known to have successfully established self-sustaining populations in at least one habitat other than its usual habitat (e.g. lotic vs lentic) and persisted for at least 50 years (response modifies the effect of Q1).	Y	Robinson et al. 2005; Ruesink et al. 2005	3
3	**Does the species have invasive races/varieties/sub-species?** Guidance: This question emphasizes the invasiveness of domesticated, in particular ornamental, species (modifies the effect of Q1).	Y	GISD 2012	4
4	**Is species reproductive tolerance suited to climates in the risk assessment area (0-low, 1-intermed, 2-high)?** Guidance: Climate matching is based on an approved system such as GARP or Climatch. If not available, then assign the maximum score (2).	0[4], 1[5]	Robinson et al. 2005	4
5	**What is the quality of the climate match data (0-low; 1-intermediate; 2-high)?** Guidance: The quality is an estimate of how complete the data used to generate the climate analysis. If not available, then the minimum score (0) should be assigned.	2	Field & Griffiths 1991	4
6	**Does the species have broad climate suitability (environmental versatility)?** Guidance: Output from climate matching can help answer this, combined with the known versatility of the taxon as regards climate region distribution. Otherwise the response should be based on natural occurrence in 3 or more distinct climate categories, as defined by Koppen or Walter (or based on knowledge of existing presence in areas of similar climate).	Y	NIMPIS 2012; FAO 2012	4
7	**Is the species native to, or naturalised in, regions with equable climates to the risk assessment area?** Guidance: Output from climate matching help answer this, but in absence of this, the known climate distribution (e.g. a tropical, semitropical, south temperate, north temperate) of the taxons native range and the 'risk are' (i.e., country/region/area for which the MIISk is being run) can be used as a surrogate means of estimating.	Y	Robinson et al. 2005	4
8	**Have introductions of the species been successful more often than unsuccessful?** Guidance: Should be relatively well documented, with evidence of translocation and introduction.	N	Ruesink et al. 2005	3

[4] Applicable to West coast culture4
[5] Applicable to South and East coast culture

9	**Has the species naturalised (established viable populations) beyond its native range?** Guidance: If the native range is not well defined (i.e. uncertainty about it exists), or the current distribution of the organism is poorly documented, then the answer is "Don't know".	Y	Robinson et al. 2005	4
10	**In its naturalised range are there impacts to aquaculture, aquarium or ornamental species?** Guidance: Where possible, this should be assessed using documented evidence of real impacts (i.e. decline of native species, disease introduction or transmission), not just circumstantial or opinion-based judgements.	N	No record of this	3
11	**In its naturalised range are there impacts to wild stocks of commercial fish, shellfish, crustacean or algal species?** Guidance: Aquaculture incurs a cost from control of the species or productivity losses. This carries more weight than Q10. If the types of species is uncertain, then the yes response should be placed here for more major species, particularly if the distribution is widespread.	Y	Nehring et al. 2011	3
12	**In its naturalised range are there impacts to estuaries, coastal waters or amenity values (e.g. does it form extensive colonies?)** Guidance: documented evidence that the species has altered the structure or function of natural ecosystems.	Y	Ruesink et al. 2005	4
13	**Does the species have invasive congeners?** Guidance: One or more species within the genus are known to be serious pests.	?	Depends on taxonomic resolution regarding *C. angulata*	2
14	**Is the species poisonous or poses other risks to human health?** Guidance: Applicable if the taxon's presence is known, for any reason, to cause discomfort or pain to animals. In the case of mollusks, which can become poisonous to humans by accumulating algae toxins, restrict this question to animals other than humans.	N	Unless algal blooms or unhygienic preparation	4
15	**Is it likely to out-compete and/or hybridise with native species?** Guidance: known to suppress the growth of native species, or displace from the microhabitat, of native species.	N	S. Jackson pers. comm.	4
16	**Is the species parasitic of other species or may it act a major predator on a native species that was previously subject to low predation?** Guidance: Needs at least some documentation of being a parasite of other species.	N	No reference	4
17	**Is the species unpalatable to predators?** Guidance: this should be considered with respect to where the taxon is likely to be present and with respect to the likely level of ambient natural or human predation, if any.	N	No reference	4
18	**Does the feeding, settlement or other behaviour of the species reduce habitat quality for native species?** Guidance: There should be evidence that the foraging results in an increase in suspended solids, reducing water clarity, changes in water chemistry etc.	Y	Ruesink et al. 2005	3
19	**Does the species host, and/or is it a vector, for recognised pests and pathogens, especially non-native?**	N	DAFF 2012	3

	Guidance: The main concerns are non-native infectious agents, with the host being the original introduction vector of the disease or as a host of the disease brought in by another taxon.			
20	**For crustaceans, does the species achieve an ultimately large body size (e.g > 10 cm body length) or for mussels, does the species form extensive colonies/cluster/aggregations (e.g. >1m^3)?** Guidance: Although small-bodied invertebrates may be abandoned, large-bodied invertebrates are the major concern, as they soon outgrow their aquarium.	Y	Fey et al. 2010	4
21	**Does the species tolerate a wide range of salinity regimes?** Guidance: There should be evidence that the species tolerates a wide range of salinities, from freshwaters to highly saline.	Y	FAO 2012	4
22	**Is the species desiccation tolerant at some stage of its life cycle?** Guidance: Should be able to withstand being out of water for extended periods (e.g. minimum of one or more hours).	Y	No reference	4
23	**Is the species versatile in terms of habitat use?** Guidance: Species that are known to persist in a wide variety of habitats, including areas of standing and flowing waters (over a wide range of Velocities: 0 to 0.7 m per sec).	Y	FAO 2012	3
24	**Does feeding or other behaviors of the species reduce habitat quality for native species?** Guidance: There should be evidence that the foraging results in an increase in suspended solids, reducing water clarity, changes in water chemistry etc. *PLEASE NOTE THAT THIS IS REPETITION OF QUESTION 18. THIS IS AN ERROR WITH THE MI-ISK TOOLKIT AND THE CREATORS WILL BE ALERTED. FOR THE PURPOSES OF THIS STUDY, THE ANSWER HAS BEEN REPEATED.*	Y	Ruesink et al. 2005	3
25	**Does the species require minimum population size to maintain a viable population?** Guidance: Time from hatching to full maturity (i.e. active reproduction, not just presence of gonads). Please specify the number of years. *PLEASE NOTE THAT THE GUIDANCE GIVEN ON THE TOOLKIT, DOES NOT REFER TO THIS QUESTION. THIS IS AN ERROR WITH THE MI-ISK TOOLKIT AND THE CREATORS WILL BE ALERTED. FOR THE PURPOSES OF THIS STUDY, THE GUIDANCE HAS BEEN MODIFIED FROM A SIMILAR QUESTION IN THE PRESCREENING TOOLKIT:* Guidance: There should be evidence of a population crash or extirpation due to low numbers (e.g. overexploitation, pollution, etc.).	Y	Need certain number to prevent inbreeding	4
26	**Is the species a voracious predator?** Guidance: Obligate piscivores are most likely to score here, but some facultative species may become voracious when confronted with naïve prey.	N	FAO 2012	4
27	**Is the species omnivorous?** Guidance: Evidence exists of foraging on a wide range of prey items, including incidental piscivory.	Y	Consumes phytoplankton and protists (FAO 2012)	3
28	**Is the species planktivorous or detritivorous?**	Y	FAO 2012	4

	Guidance: Should be an obligate planktivore to score here.			
29	**Does the species have a wide temperature tolerance range?** Guidance: There should be documented evidence of the taxon being able to survive in extreme low and/or high temperatures.	Y	FAO 2012	4
30	**Does it exhibit parental care (brooding) and/or is it known to reduce age-at-maturity in response to environment?** Guidance: Needs at least some documentation of expressing parental care and/or viable age at maturity under different environmental conditions.	N	FAO 2012	4
31	**Does the species produce viable gametes?** Guidance: If the taxon is a sub-species, then it must be indisputably sterile.	Y	No reference	4
32	**Is the species gynogenetic (e.g. *Melanoides tubercolata* or the marble crayfish)?** Guidance: needs at least some documentation of gynogenesis.	N	No reference	4
33	**Is the species hermaphroditic?** Guidance: Needs at least some documentation of hermaphroditism.	Y	FAO 2012	4
34	**Is the species dependent on the presence of another species or specific habitat features to complete life cycle?** Guidance: Some species may require specialist incubators or specific habitat features (e.g. fast-flowing water, particular species of plant or types of substrata) in order to reproduce successfully.	N	No reference	4
35	**Is the species highly fecund, iteropatric or extended spawning season?** Guidance: Species is considered to have relatively high fecundity for its taxonomic order.	Y	FAO 2012	4
36	**What is the species' known minimum generation time (in years)?** Guidance: Time from hatching to full maturity (i.e. active reproduction, not just presence of gonads). Please specify the number of years.	2	Boudry 2008	4
37	**Are life stages likely to be dispersed unintentionally?** Guidance: Unintentional dispersal resulting from human activity, including as ship ballast or hull foulant	Y	AMCS 1998	4
38	**Are life stages likely to be dispersed intentionally by humans (and suitable habitats abundant nearby)?** Guidance: The taxon has properties that make it attractive or desirable (e.g. as for ornament or unusual appearance).	Y	Ruesink et al. 2005	4
39	**Are life stages likely to be dispersed as a contaminant of commodities?** Guidance: Taxon is associated with organisms likely to be sold commercially.	?	No record of this	2
40	**Does natural dispersal occur as a function of dispersal of eggs and/or the movement of the suitable substratum?** Guidance: There should be documented evidence that eggs are taken by water currents or displaced by other organisms either intentionally or not.	N	No reference	3
41	**Does natural dispersal occur as a function of larval dispersal (along linear and 'stepping stone' habitats)?** Guidance: There should be documented evidence that larvae enter, or are taken by, water currents, or can move between marine areas via connections.	Y	NIMPIS 2012	4

42	**Are juveniles or adults of the species known to migrate (reproduction, feeding, etc.)?** Guidance: There should be documented evidence of migratory behavior, even at a small scale (tens or hundreds of meters).	N	No reference	4
43	**Are eggs of the species known to be dispersed by other animals (externally)?** Guidance: For example, are they moved by birds accidentally when the waterfowl move from one marine area to another?	?	No record of this	2
44	**Is dispersal of the species density dependent?** Guidance: There should be documented evidence of the taxon spreading out or dispersing when its population density increases.	N	No record of this	3
45	**Is any life history stage likely to survive out of water transport?** Guidance: There should be documented evidence of the taxon being able to survive for an extended period (e.g. an hour or more) out of water. *PLEASE NOTE THAT THIS IS SIMILAR TO QUESTION 22. THIS IS AN ERROR WITH THE MI-ISK TOOLKIT AND THE CREATORS WILL BE ALERTED. FOR THE PURPOSES OF THIS STUDY, THE ANSWER HAS BEEN REPEATED.*	Y	No reference	4
46	**Does the species tolerate a wide range of water quality conditions, especially oxygen depletion & high temperature?** Guidance: This is to identify taxa that can persist in cases of low oxygen and elevated levels of naturally occurring chemicals (e.g. ammonia).	Y	FAO 2012	4
47	**Is the species susceptible to chemical control agents?** Guidance: There should be documented evidence of susceptibility of the taxon to chemical control agents.	?	No record of this	2
48	**Does the species tolerate or benefit from environmental disturbance?** Guidance: The growth and spread of some taxa may be enhanced by disruptions or unusual events (coastal turbidity due to river floods and/or spates), especially human impacts (coastal dredging, desiccation, trawl fishing, etc.).	?	No record of this	2
49	**Does the species have effective natural enemies present along the coasts of the risk assessment area?** Guidance: A known effective natural enemy of the taxon may or may not be present in the Risk Assessment area. The answer is 'Don't know' unless a specific enemy/enemies is known.	Y	Humans (no reference)	3