Biodiversity Risk and Benefit Assessment for Mediterranean mussel (*Mytilus galloprovincialis*) 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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CONTENT

SUMMARY

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

This Biodiversity Risk and Benefit Assessment (BRBA) has been conducted and documented in relation to the propagation and grow out of Mediterranean mussel (*Mytilus galloprovincialis*) in South Africa.

The Department of Environment, Forestry and Fisheries (DEFF), as the lead agent for aquaculture management and development, appointed Anchor Environmental Consultants in August 2012 to conduct a Biodiversity Risk and Benefit Assessment (BRBA) for the use of Mediterranean mussel in South Africa. Subsequently (2018), AquaEco was appointed to review and update these risk assessments in terms of Section 14 of the Alien and Invasive Species Regulations of 2014 and the National Environmental Management: Biodiversity Act 10 of 2004.

The aim of this assessment was to consider the appropriateness (benefit) of the use of the exotic Mediterranean mussel (*Mytilus galloprovincialis*) 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 Department of Environment, Forestry and Fisheries (DFF) , 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 culture of Mediterranean mussels

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 Mediterranean mussel 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 Mediterranean mussel culture, while considering its native environment in the Mediterranean, Black and Adriatic Seas, as well as the eastern Atlantic. It was found that Mediterranean mussels are a highly fecund, persistent and invasive species, and that it has invaded the full extent of its physiological tolerance limits along the South African coast from the Namibian border to East London. The use of this species for aquaculture will not result in further expansion of its range, nor will it augment additional biodiversity related environmental impacts.

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

During the assessment, it was found that the overall ecological risk profile for Mediterranean mussels was a poor representation of the factual situation, given that invasion and naturalisation of the species has already taken place. The pathways of risk, as well as the biodiversity impacts are already entrenched, regardless of the scope or scale of any aquaculture operations. The potential for monitoring and mitigation does exist but monitoring and mitigation measures on account of any aquaculture operations will not diminish the biodiversity impacts that these exotic mussels have already had.

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 self-sufficient in terms of stock, given the significant feral pool of larvae and spat. For this reason, the development of the sector should be promoted, which will also be in alignment to government's objectives and policies around aquaculture, apart from the fact that it will create employment, rare skills and local economic activity.

Few measures have been proposed for the monitoring and mitigation of the potential biodiversity risks, as these are futile considering the significant feral and naturalised population. Nevertheless, the import of new stock should be prohibited or subjected to strict biosecurity protocols to prevent the introduction of novel diseases which may affect indigenous mussel species, and which may threaten the aquaculture sector itself.

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1. INTRODUCTION

This Biodiversity Risk and Benefit Assessment (BRBA) pertains to the propagation and grow out of Mediterranean mussel (*Mytilus galloprovincialis*) in South Africa.

The BRBA has been structured in accordance with the framework provided in the Alien and Invasive Species (AIS) Regulations (Government Notice R 598 of 01 August 2014)[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 propagating and growing Mediterranean mussel 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 propagating and growing Mediterranean mussel 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 propagating and growing Mediterranean mussel, and to evaluate these risks in determining possible justification through allowance by permitting.

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

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

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

The main objectives of this BRBA are:

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

3. THE RISK ASSESSMENT PRACTITIONER

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

- They have practised as environmental assessment practitioners.

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

4. NATURE OF THE USE OF MEDITERRANEAN MUSSEL

Mediterranean mussel did not initially find their way into South Africa as an aquaculture species, but most likely through the ballast waters of ships. These mussels were first recorded in South Africa in 1970 (Boersma et al., 2006), and have since invaded more than 2000 km of the South African coastline, including the entire West Coast on the Atlantic seaboard and eastwards on the Indian Ocean coast up to East London.

Mediterranean mussel were harvested recreationally and semi-commercially, with other indigenous mussel species soon after it invaded parts of the South African coastline. By the late 1980’s the first interest was shown for the farming of this species in Saldanha Bay.

Today, two distinct uses and user groups can be identified for Mediterranean mussel in South Africa:

- Use of the species in recreational and semi-commercial harvesting of wild stocks. Although this is mainly for human consumption, a small portion is also used as bait in recreational fishing.
- Mediterranean mussel is a key species in the South African aquaculture sector as it has a greater aquaculture potential than other indigenous mussels. The farming of Mediterranean mussel sin well-established in Saldanha Bay.

Mussels have been harvested by coastal communities for thousands of years, with some shell middens on the South African coast dating back 140 000 years. The first form of mussel aquaculture was likely developed in Europe (dating back to the 13th century in France) and based on the placement of intertidal wooden pols on which mussels grew and from which they could be harvested. By the start of the 1970's various countries developed and improved mussel culture techniques to include culture on vertically suspended ropes attached to rafts or to longlines (FAO, 2004).

Mediterranean mussel farming in South Africa is practiced year-round. The farming of these mussels in Saldanha Bay is done by means of allowing naturally occurring larvae to settle on growing ropes that are suspended from mussel farming rafts and longlines. The biodiversity risk is not affected by the production method, in that this invasive species is already fully distributed within its range of tolerance along the South African coastline.

Photograph 1 (top left): A elongated mussel raft or barge from which the prediction ropes are suspended (Photograph from E. Hinrichsen, Saldanha Bay)

Photograph 2 (top right): A mussel production rope to which the mussels adhere (Photograph from E. Hinrichsen, Saldanha Bay)

Photograph 3 (bottom): A service barge boat tending a mussel long-line system (Photograph from E. Hinrichsen, Saldanha Bay)

5. REASONS FOR FARMING WITH MEDITERRANEAN MUSSEL

The FAO estimates that by 2030, fish farming will dominate global fish supplies. With aquaculture already providing more than half of the global seafood demand, it is now considered likely that marine harvesting and terrestrial rangeland farming has reached its capacity in many parts of the world. Aquaculture and intensified agriculture remain 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 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.

Mediterranean mussel, while alien to South Africa, is the leading South African aquaculture species by volume of production. Considering all mussel species, over 2 million tons are farmed per annum across the world (FAO, 2016) and mussels are a universally recognised aquaculture species that efficiently yields a high-demand product in a competitive manner.

Through their international redistribution, mainly by shipping activities, Mediterranean mussel are not only farmed in Mediterranean countries, but also on the shores of the Black sea and in China, making them the fourth most commonly farmed mussel species after Chilean mussel (*M. chilensis*), Blue mussel (*M. edulis*) and Green mussel (*Perna viridis*).

Although three indigenous mussels species could be considered for aquaculture, two show less suitability to farming, less favourable production performance and lower market acceptance [these being the Ribbed mussel (*Aulacomya ater*) and the Black mussel (*Choromytilus meridionalis*)], while the Brown mussel (*Perna perna*) occurs in the more subtropical waters of the East Coast, where production conditions are less favourable.

6. LEGAL CONTEXT

The Department of Environment, Forestry and Fisheries (DEFF) is the mandated authority over the National Environmental Management: Biodiversity Act 10 of 2004 (NEMBA), which sets out the framework, norms, and standards for the conservation, sustainable use, and equitable benefit-sharing of South Africa's biological resources. The AIS Regulations and the AIS List (Government Notice R 864 of 29 July 2016)[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.

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

6.1. CATEGORIZATION OF ALIEN AND INVASIVE SPECIES

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

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

6.2. STATUTORY CLASSIFICATION OF MEDITERRANEAN MUSSEL

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 6.1 above, Mediterranean mussel is categorized as follows:

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

Further prohibitions and exemptions that apply to Mediterranean mussel include:

a. Aquaculture facilities are exempted from requiring a permit for all restricted activities except for restricted activities a[3], f[4], g[5], and k[6] in Notice 1.

   All other persons 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 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 Mediterranean mussels as being classified in Category 2 as this relates to the general propagation and grow out thereof, with due consideration that certain activities remain in place.

It must be noted that most Provinces have specific Provincial Ordinances that govern the harvesting, movement and keeping of species such as Mediterranean mussels. The

[3] *Activity "a" is: importing into the Republic, including introducing from the sea, any specimen of a listed invasive species.*
[4] *Activity "f" is: spreading or allowing the spread of any specimen of a listed invasive species.*
[5] *Activity "g" is: releasing any specimen of a listed invasive species.*
[6] *Activity "k" is: the introduction of a specimen of an alien or a listed invasive species to offshore islands.*

National Government have confirmed that all provinces should regulate the 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.

6.3. LIST OF RESTRICTED ACTIVITIES

While Section 1 in Chapter 1 of the NEMBA defines the restricted activities in relation to alien and invasive species, these activities are expanded upon in Section 6, Chapter 3 of the AIS Regulations. 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, all the remaining restricted activities could potentially apply to the propagation and grow out of Mediterranean mussel in South Africa. However, the use of Mediterranean mussels for aquaculture has been exempted from requiring a permit for all restricted activities except for restricted activities a, f, g, and k (see statutory classification of Mediterranean mussel in Section 6.2 above).

The means by which Mediterranean mussels are generally farmed in South Africa could trigger certain of the qualifying restricted activities above by implication, as explained in the bullets below:

- Activity a could be triggered through implication that import includes introduction from the sea (as per the inclusive meaning read from the regulations), albeit that mussels are generally not specifically imported from abroad;
- 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;
- Activity g could be triggered through implication that the seeding of mussels onto production ropes could be interpreted as the release of a listed invasive species, albeit that such release occurs into an environment which is already invaded; and
- Activity k is possible but unlikely, as the farming of mussels does not entail the intentional introduction of an alien or a listed invasive species to offshore islands.

7. TARGET SPECIES: MEDITERRANEAN MUSSEL

7.1. TAXONOMY

Common Name:	Mediterranean mussel
Kingdom:	*Animalia*
Subkingdom:	*Bilateria*
Infrakingdom:	*Protostomia*
Phylum:	*Mollusca*
Class:	*Bivalvia*
Subclass:	*Pteriomorphia*
Order:	*Mytiloida*
Family:	*Mytilidae*
Genus:	*Mytilus*
Species:	*Mytilus galloprovincialis (Lamarck 1819)*
Taxonomic Code:	79456

Mediterranean mussel has no sub-species.

Other Names:	Bay mussel, Blue mussel

7.2. ORIGINATING ENVIRONMENT

Mediterranean mussels are native to the Mediterranean coastline, Black and Adriatic Seas, and the eastern Atlantic to Northern Africa (GISD, 2018). In its native range, these mussels can be found from exposed rocky outer coasts to sandy bottoms (Ceccherelli and Rossi 1984) in the intertidal zone, where they attached by means of strong byssal threads to a firm substrate. The species thrives on temperate rocky coastlines with a high rate of water flow.

7.3. KEY PHYSIOLOGICAL CHARACTERISTICS

Mediterranean mussels are large, smooth-shelled black to blue mussels, typically 50 mm in length, but can reach 120 mm (Picker and Griffiths, 2011). Shell shape varies from region to region, but generally the two shells are equal in size and nearly quadrangular (four-sided) in shape (GISD 2018). Generally, the one side of the rim of the shell ends with a pointed and slightly bent umbo (beak of a bivalve shell) while the other side is rounded. The two bilateral shells are hinged and enclose the soft body within.

All *Mytilus* species look similar, but Mediterranean mussels have the following distinguishing characteristics (Green 2014):

- Umbones turning downwards tending to make the basal line of the shell concave;
- Valves are higher and less angular on the upper margin and tend to grow larger; and
- The mantle edge is darker, becoming blue or purple.

Figure 1: Mediterranean mussel (Mytilus galloprovincialis).

7.4. DIETARY ASPECTS

Mediterranean mussels are sedentary filter-feeders that pump water through their enlarged sieve-like gills (Branch et al. 2010; Picker & Griffiths 2011). The filter feeding mechanism relies on the pumping of water through cilia or gill lamellae that move food particles towards the mouth. An adult mussel can filter a litre of water in 20 minutes (Boersma et al., 2006).

They primarily feed where water flow is high and where inorganic sediment is low, often associated with the upwelling of oceanic nutrients. They filter feed for phytoplankton and organic particles that accumulate on the gill lamellae (FAO, 2018).

7.5. LIFECYCLE AND GROWTH

After settlement, Mediterranean mussels grow into dense beds of individuals. Colonies can reach numbers in the millions (Green 2014). On the West Coast of South Africa dense multi-layered beds extend for several hundred metres along rocky shores.

Mediterranean mussels can grow rapidly under ideal conditions and reach 70 mm within its first year (Picker & Griffiths 2011). Generally, the greatest settlement and fastest growth is observed at exposed sites in comparison to sites that are sheltered from wave action, due to the greater availability of food. However, opportunities for attachment may diminish at extremely exposed sites (Branch & Steffani 2004).

This species lives for between one and two years, however, they have the potential to live for up to twenty years (Boersma et al., 2006).

7.6. REPRODUCTION

Mediterranean mussels reach sexual maturity at 1 to 2 years in age (MarLIN2009). The gonads (which are cream in males and pink in females) extend throughout the body. Mussels are gonochoristic broadcast spawners, which means that gametes are simultaneously released into the surrounding water for external fertilisation.

Mediterranean mussels are highly fecund, capable of producing in excess of 120% of their body mass in gametes per annum (Van Erkom, Schurink & Griffiths 1991). Although spawning peaks with a rise in water temperatures, they are able to produce gametes throughout the year depending on specific environmental conditions (Bayne 1976).

Fertilised eggs undergo gametogenesis, developing into free-swimming planktotrophic larvae that disperse widely – up to 200 km and more depending on water movement, (Suchanek *et al*., 1997). The microscopic larvae drift for several weeks before settling down onto submerged or partially submerged substrate (Green 2014). They initially settle as pediveligers (larvae) and actively explore the substratum by crawling with a foot, which is a muscular and glandular organ with cilia that is also used for byssus secretion. If they find a suitable substratum, they deposit an adhesive plaque and byssal thread (Carl et al. 2012), which anchors the mussel.

7.7. ENVIRONMENTAL TOLERANCES

Mediterranean mussels are exclusively a marine species, due to a low tolerance for decreased salinity. Mortality occurs when they are exposed to salinities of 15 - 20 ppt for extended periods (Brooks 2007).

Mediterranean mussels display rapid growth rates and extreme tolerance to a wide range of other environmental conditions. High levels of mortality have been recorded at water temperatures above 24°C, while complete die-off has been observed when exposed to temperatures of 30°C for 20 days (Anestis et al. 2007). Minimum temperature tolerances are not known, but these mussels thrive in areas off the South African West Coast where seasonal water temperatures can drop to 7°C. Fastest growth has been recorded between water temperatures of 10°C and 20°C (van Erkom, Schurink & Griffiths 1992).

Mediterranean mussels do not survive in sandy conditions and have a lower tolerance to siltation when compared to other indigenous species such as the Ribbed mussel (*Aulacomya ater*) and the Brown mussel (*Perna perna*) (Branch & Steffani 2004). The indigenous Black mussel (*Choromytilus meridionalis*) thrives in sandy conditions (Hockey & van Erkom Schurink 1992).

The tolerance of these mussels to air exposure and complete desiccation is extremely high; more so than in other indigenous South African mussel species. Experiments in which mussels were held for 42 weeks at the high tide mark where they experienced 7 days of continuous exposure to air, resulted in 92% of the Mediterranean mussels surviving (Branch and Steffani 2004), contributing to their success as an invasive species.

7.8. NATURAL ENEMIES, PREDATORS AND COMPETITORS

The Mediterranean mussel can survive in highly competitive and high-energy coastal environments and is well adapted to compete for food and habitat in these areas. They are subjected to relatively high levels of predation but compensate for this through very high fecundity, rapid resettlement and fast growth.

Predators of mussels include starfish, seabirds, marine worms, some fish and other marine species. In South Africa, predators such as the endangered Black oyster catcher (*Haematopus monquini)* and certain whelk species (*Nucella cingulate*) have benefitted greatly from the abundance of food provided by the high density of these alien mussels (Branch and Steffani, 2004). The reproductive potential of the Black oyster catcher has increased due to the invasion of Mediterranean mussels (Kohler et al. 2011; Green 2014).

7.9. POTENTIAL TO HYBRIDISE

Hybridisation between Mediterranean mussels and other species of *Mytilus* has been recorded off the Pacific coast of North America and in Europe (Rawson et al. 1999; Michalek et al. 2016).

In north Europe the distribution of the Mediterranean mussel overlaps with that of the Blue mussel (*Mytilus edulis*). In these areas a complex system of habitat and environmentally defined hybridisation occurs between these species. In simple terms, this results in a mixture of pure, hybrid and introgressed animals (Gosling *et al.* 2008).

No hybridisation has been recorded between Mediterranean mussels and mussels indigenous to South African.

7.10. PERSISTENCE AND INVASIVENESS

As shown in Section 7.7 the Mediterranean mussel is highly tolerant of extreme coastal conditions, which results in a high degree of persistence and invasiveness in suitable habitat types. This mussel has the characteristics of a successful invasive species, having a high tolerance to desiccation, fast growth, high reproductive output, larvae that can be distributed by sea currents, relatively low numbers of predators and can outcompete other species for habitat and food.

Mediterranean mussels first appeared in South Africa during the 1970's in the harbour town of Saldanha Bay (Boersma et al., 2006). They were first detected along the south coast in 1988 (McQuaid & Phillips 2000) following their introduction to the Port Elizabeth harbour for aquaculture. This population was subsequently removed and the small adjacent populations which had become established also died out. However, natural spread from the west coast continued and subsequent invasion now extends across the full extent of suitable coastal habitat in the country (Branch and Steffani 2004). No spat or mussels are currently imported into South Africa for aquaculture purposes, nor is it expected to become necessary for the import of any animals.

The Mediterranean mussel is already well established in South Africa and occupies at least 2050 km of coastline (Robinson et al. 2005) from the Namibian border in the north west to East London in the south east. Current distribution in South Africa is likely to be close to the full extent of invasion, which is only limited by sea temperature further east of East London. Were environmental conditions to remain the same, this alien species will persist regardless of efforts to effect control or limit aquaculture.

7.11. PROBABILITY OF NATURALISATION

Naturalised populations of Mediterranean mussels have been recorded in several localities around the world and no prospect exists of this global distribution being reversed. As indicated in the previous section, invasion in South Africa is likely to have already extended to virtually the entire range of environmental tolerance of the species. Wide-ranging naturalisation has already occurred in South Africa and is unlikely to be reversed in any way, regardless of the use of this species for aquaculture and/or unrestricted harvesting.

7.12. ABILITY TO CREATE ECOSYSTEM CHANGE

Generally, mussels are categorised as ecosystem engineers, as they can create complex, deep beds that change the structure of habitats and alter local communities. Mediterranean mussel beds can host diverse infaunal communities. Nevertheless, similar infaunal abundance has been noted from indigenous mussels (Griffiths et al. 1992), which means that the ability for complete ecosystem change (outside of affecting species composition by competition) is of a lower significance. Ecosystem change by the Mediterranean mussel is a consequence related mainly to biodiversity impacts (see next section).

In South Africa, the ecological effects of Mediterranean mussels are most noticeable on the West Coast, where the lower intertidal zones of rocky shores have become completely inundated with vast, dense beds of this species. Here, the composition of species has been affected (see next section).

Secondary ecological changes relate to matters such as the presence of a larger mussel species, which may result in greater difficulty for predators to use these mussels as food or in predators having to eat fewer mussels to gain the same energy intake (Anderson et al., 2002). Mussels also filter and clear the water of suspended phytoplankton, allowing greater sunlight penetration to benefit various species, including aquatic plants. However, these mussels have also been linked to mass mortalities of Swimming crabs (*Ovalipes trimaculatus*) as the larvae settle on the eyestalks and mouthparts of these crabs (Branch et al., 2004).

Insofar as the farming of mussels is concerned, this could lead to changes in food-web dynamics, water flows, nutrient availability and utilisation, oxygen and microbe levels. Mussels can also accumulate biological toxins and industrial pollutants, allowing them to move up the food web (Boersma et al., 2006). In Saldanha Bay, it was found that the macrobenthic communities under mussel production systems become disturbed in that the community structure changes from mostly suspension feeders to being dominated by deposit feeders (Stenton-Dozey *et al.* 2001). It was however found in Australia that the benthic effects of mussel farming do not extend more than 50 meters outside of the culture areas (McKinnon *et al*. 2003).

7.13. POSSIBLE IMPACTS ON BIODIVERSITY

Mediterranean mussels are more fecund, grow faster and show a greater tolerance to desiccation compared to the indigenous Ribbed mussel (*Aulacomya ater*), the Black mussel (*Choromytilus meridionalis*) and the Brown mussel (*Perna perna*) (Van Erkom, Schurink & Griffiths 1992; Hockey & Van Erkom Schurink 1992).

Mediterranean mussels can outcompete and displace these indigenous species, leading to a reduction in species related biodiversity. In such displacement, these exotic mussels can take up the limiting resource of hard substrate space in the intertidal zone and deeper areas. Mediterranean mussels can tolerate growth of other organisms in a secondary layer on their shells, but this does not adequately substitute available benthic space (Branch et al., 2004).

As seen elsewhere in the world, Mediterranean mussels have displaced indigenous species (Geller 1999) where they share similar habitats. The Ribbed mussel (*Aulacomya ater*) and large limpets such as the Bearded limpet (*Scutellastra argenvillei*) and Granular limpet (*Scutellastra granularis*) have been largely displaced in many intertidal shores in South Africa (Hanekom & Nel, 2002; Branch *et al*., 2004), but some smaller species flourish within the habitat that is created by these exotic mussels (Hanekom & Nel 2002; Branch et al. 2004).

The Ribbed mussel (*Aulacomya ater*) is the most severely affected indigenous species as it shares a preference with Mediterranean mussels for sediment-free waters in the rocky intertidal zone, but their distribution ranges overlap almost entirely (Branch & Steffani 2004). The higher sediment tolerance and ability to grow in sandy areas lowers competition with the Black mussel (*Choromytilus meridionalis*), while the distribution of the Brown mussel (*Perna perna*) only overlaps marginally with that of Mediterranean mussels due to different levels of water temperature tolerance (Branch & Steffani, 2004).

Dense beds of Mediterranean mussels consist of multiple layers and can therefore support a higher biomass per unit area as opposed to indigenous species that form single layers. Consequently, there is an increase in total mussel biomass (Griffiths *et al.*

1992) and an increase in the density of mussel bed infauna (Hammond & Griffiths, 2004).

The invasion of Mediterranean mussels has significantly benefited mussel predators such as the whelk (*Nucella cingulata)* and the Black oyster catcher (*Haematopus moquini*), leading to a greater abundance of these species (Van Erkom Schurink and Griffiths 1990; Branch and Steffani, 2004).

Mediterranean mussels could affect biodiversity through indirect genetic impacts. As a result of competition and displacement the population size of native species decline, which could result in the loss of genetic diversity in areas where it has not already spread.

7.14. POSSIBLE IMPACTS ON OTHER NATURAL RESOURCES

By removing particulates and excess nitrogen from the marine environment, Mediterranean mussels influence water quality. In areas where water displacement is limited, this could lead to a reduction in turbidity, which may allow for greater levels of photosynthesis and algal or plant biomass coupled to increased sunlight penetration (Shumway *et al*. 2003).

The remaining lifecycle processes of Mediterranean mussels 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 they benefit some coastal communities that depend on these mussels as a source of food and income.

7.15. ACTING AS VECTOR OF OTHER SPECIES

The uncontrolled import of Mediterranean mussels may result in the introduction of other species, if care is not taken with regards to ensuring that other species are excluded. This is unlikely to happen as there is no dependence in South Africa on imported stock for aquaculture, given the presence of adequate quantities of larvae and spat in the surrounding environment.

In a previous study (Calvo-Ugarteburu and McQuaid 1998) it was found that Mediterranean mussels from South Africa was free of trematode parasites. In contrast, the indigenous Brown mussel (*Perna perna*) was found to be infested by 4 trematode species.

An endolithic cyanophyte (*Mastigocoleus sp*.) and a lichen (*Pyrenocolema sp*.) bore into the shells of mussels and seem to affect Mediterranean mussels more severely than other indigenous mussel species (Webb & Korrubel 1994). These parasites reduced body condition and growth (Calvo-Ugarteburu and McQuaid, 1998), which may negatively affect aquaculture.

8. HISTORY OF TRANSLOCATION AND CULTIVATION

Active modern-day farming of mussels started in Spain; at first by means of simple techniques in which mussels where controlled within the environment, and later by more advanced means in which growing rafts, platforms and ropes systems were developed. Today the farming of mussels entails the collection of young spat from the standing stocks in the environment and are arranged for culture purposes on suspended ropes that are suspended either from rafts, wooden frames or from longlines of floating buoys (FAO, 2018).

Mainly through the increased movement of ships from the late twentieth century, and specifically hull fouling and the exchange of ballast waters, the Mediterranean mussel has become a globally distributed species. Other pathways of distribution include translocation for aquaculture purposes (Anderson *et al*., 2002).

Mediterranean mussels have established fully naturalised populations in countries such as Hong Kong, Japan, Korea, Australia, America, Mexico, Canada, Great Britain, Ireland and South Africa (Branch and Steffani, 2004), and is now recognised as one of the world's 100 worst invasive alien species (GISD 2012).

In South Africa, Mediterranean mussel is now abundantly distributed along the entire west coast, while on the south coast they form mixed beds with the indigenous Brown mussel (*Perna perna*) (Picker & Griffiths, 2011). The current scale of Mediterranean mussel farming in South Africa is focused mainly in the Saldanha Bay area, as well as other designated aquaculture areas in and around Port Elizabeth and East London.

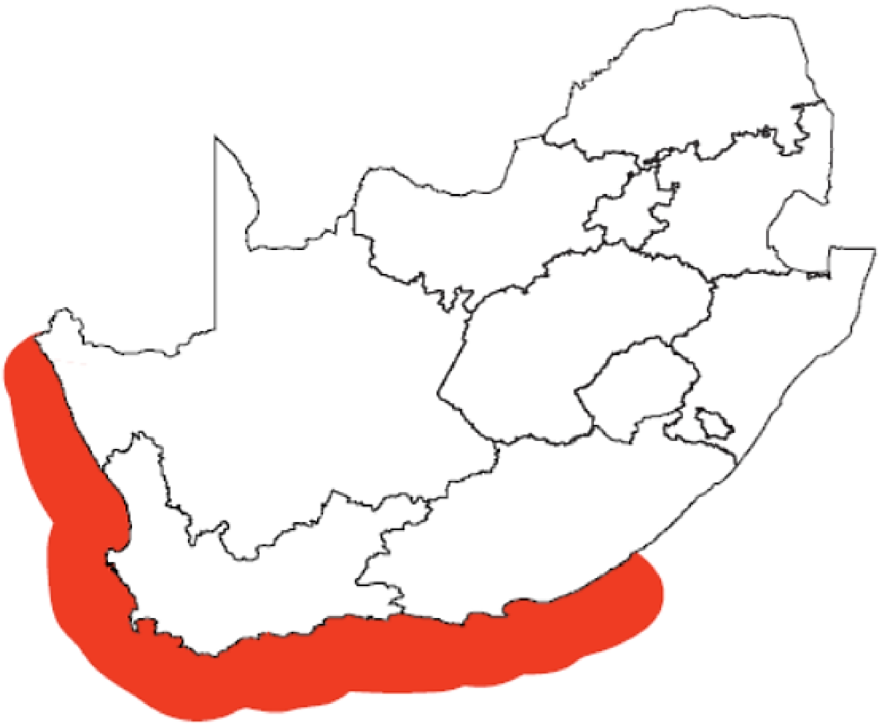

Figure 2: Introduced range (in red) of M. galloprovincialis along the South African coast (Source: M. Picker and C. Griffiths)

9. THE RECEIVING ENVIRONMENT

As a national framework document, this risk assessment cannot report on the receiving environment for specific areas, and on specific Mediterranean mussel projects or restricted activities. Notably however is that a large section of the South African coastline is within the lethal temperature tolerance range of Mediterranean mussels, which has led to invasion across virtually all areas of suitable habitat along the West Coast and South Coast, eastwards to East London.

9.1. CLIMATE AND HABITAT MATCH

In South Africa, a vast area of coastline is suitable to the naturalisation of Mediterranean mussels. As temperature is a primary determinant for the distribution of Mediterranean mussels, its range correlates closely with known changes in sea temperature.

For this BRBA 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 Mediterranean mussels (van Erkom Schurink & Griffiths 1992). 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

Mediterranean mussels demonstrate optimal growth between 10 and 20°C (van Erkom Schurink & Griffiths 1992) meaning that the farming of this species would be possible in at least 2 of the regions above; being the West Coast and South Coast.

With reference to the six South African marine ecoregions (Sink et al. 2011) as shown in the figure below, Mediterranean mussels have naturalised in the following 6 of 22 ecozones:

- Namaqua Inshore
- Namaqua Inner Shelf
- Southwestern Cape Inshore
- Southwester Cape Inner Shelf
- Agulhas Inshore

- Agulhas Inner Shelf

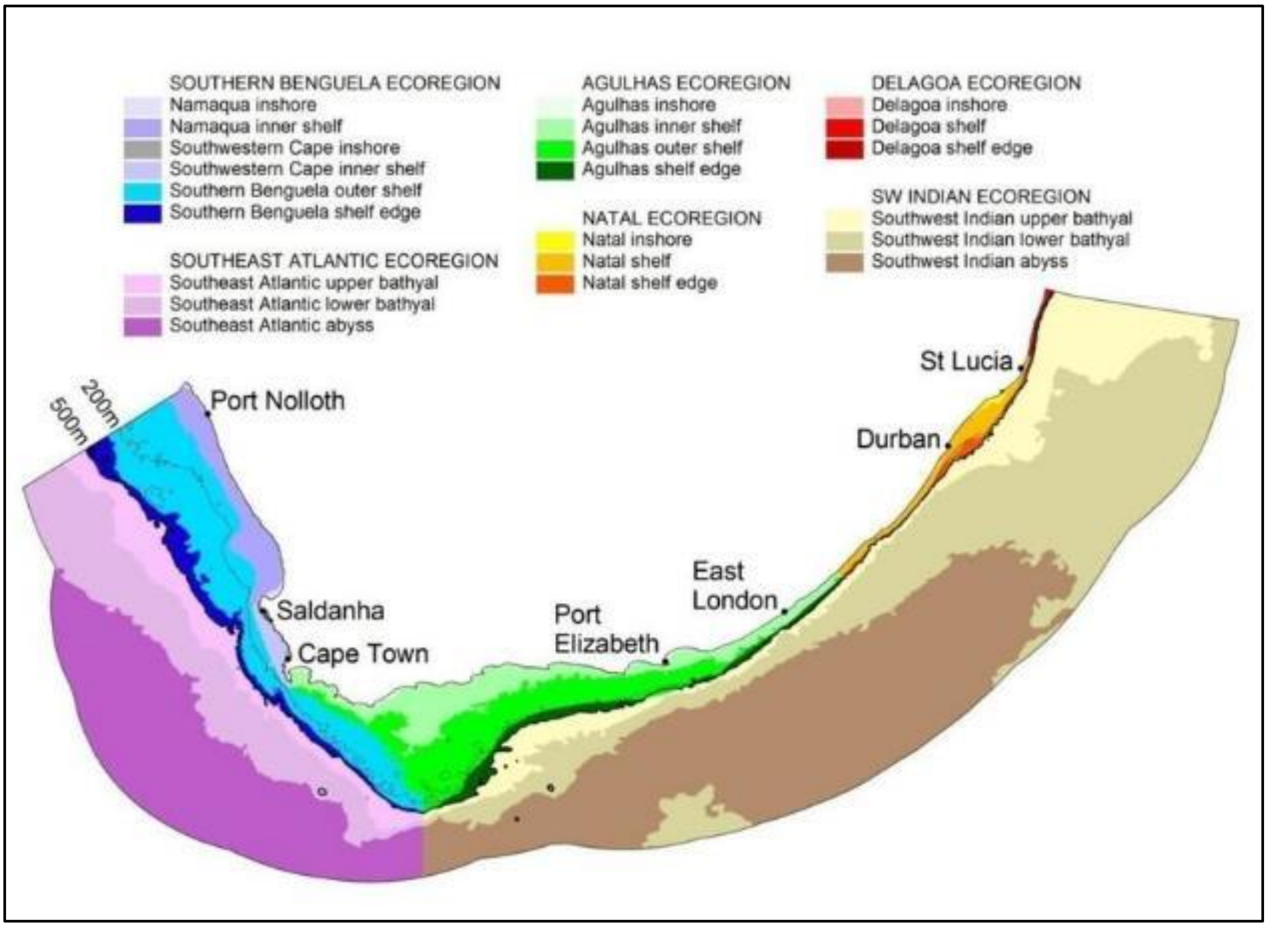

Figure 2: The six marine ecoregions with 22 ecozones incorporating biogeographic and depth divisions in the South African marine environment (Sink et al. 2011).

The habitat requirements for Mediterranean mussels (specifically nutrient rich waters with low silt levels and a solid substrate) are met intermittently along the entire South African coastline.

9.2. TOOLS TO IDENTIFY SENSITIVE AREAS

Although Mediterranean mussels have invaded virtually all the suitable habitat along the South African coastline that falls within its tolerance range for temperature, many national and provincial conservation plans, biodiversity frameworks and mapped marine zones can be used to determine sensitive areas in which Mediterranean mussel pose a biodiversity risk. These include, but are not limited to:

- A range of geographic mapping tools are published by the South African National Biodiversity Institute (SANBI), through which proclaimed conservation areas, critical biodiversity areas and other sensitive habitats can be identified.
- The South African Institute of Aquatic Biodiversity (SAIAB) conducts research and provides data on aquatic (marine and freshwater) biodiversity.
- Apart from general information that can be accessed from the National Department of Environmental Affairs (DEA), the Oceans and Coasts Branch of DEA, local and provincial conservation authorities, and mandated provincial biodiversity authorities can provide local information of relevance.

10. THEORY BEHIND ECOLOGICAL RISK ASSESSMENT

Ecological Risk Assessment provides an effective tool for assessing environmental effects or actions, and aids in resource based and environmental decision making. The risk assessment approach is widely recognized and much of this document is based on internationally researched risk assessment principals. To this end, the process is well suited to the establishment of the BRBA framework for the propagation and grow out of Mediterranean mussels, 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 growing out and propagating Mediterranean mussel, 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).

10.1. THE PRECAUTIONARY AND OTHER PRINCIPALS

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

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

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

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

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

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

10.2. METHODOLOGY IN THE RISK ASSESSMENT

In aquaculture, several risk assessment methodologies are used, each of which depict different levels of complexity and subjectivity (Burgman, 2005; Kapuscinski et al. 2007; Vose 2008; FAO, 2015). However, the interplay between likelihood and consequence to determine acceptability and management 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) outline several ways to help maintain the scientific credibility of risk assessment (FAO, 2015).

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

Risk analysis provides an objective, repeatable, and documented assessment of risks posed by a particular course of actions or hazards. This BRBA depicts a step-by-step process expanded and modified from the aquaculture risk assessment work by Fletcher et al. (2002 and 2003), in which an inventory of potential risks is characterized and scored for probability, severity, scope, permanence, confidence, monitoring and mitigation; and

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

- Identification of risks and determination of endpoints (consequences). This is also referred to as problem formulation in risk assessment and determines what is at risk.
- Determination of the endpoints and the acceptability in endpoint levels (the level of acceptable change if a risk or stressor were to occur).

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

10.3. 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 Mediterranean mussels, 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 Mediterranean mussels, 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 the case with Mediterranean mussels).

Some confusion is caused by the fact that both the pathway (escape in the case of aquaculture with Mediterranean mussel) 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.

10.4. 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 are 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 are 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 propagation and grow out of Mediterranean mussels in South Africa.

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

Risk / Stressor	As example: the escape of Mediterranean mussel				
Endpoint	As example: displacement on an indigenous species				
Probability	High	Moderate	Low	Extremely low	Negligible
Severity	Catastrophic	High	Moderate	Low	Negligible
Scope	Extensive	Regional	Local	Project based	Negligible

Permanence	Permanent	Long-lasting	Moderate	Temporary (Periodic)*	Short term (Periodic)*
Confidence	Doubtful	Low	Moderate	High	Very high
Monitoring	Zero	Low	Moderate	High	Very high
Mitigation	Irreversible	Low	Moderate	High	Very high

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

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

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

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

10.5. PERCEPTION OF RISK

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

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

10.6. RISK COMMUNICATION

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

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

11. SPECIFIC ASSESSMENT FOR MEDITERRANEAN MUSSEL

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

11.1. NATURALISED IMPACTS OF MEDITERRANEAN MUSSELS

Mediterranean mussels have invaded virtually all areas that are suitable to this species along the South African coastline. Elevated concentrations of larvae occur in the coastal waters, while recruitment and settlement rates are high. This means that control methods for this species, and any measures implemented to manage the potential biodiversity impacts associated with aquaculture, will have no effect on the distribution, invasion, naturalisation and impact of this species in South Africa.

Assessment of the ecological risks of Mediterranean mussels must be considered against the already invaded marine environment, meaning that the scores allocated to the pathways of risk and the endpoints (impacts) must be seen in light of the status of invasion, the current abundance of this species in the environment, and the nature of the receiving environment.

11.2. INVENTORY OF POTENTIAL PATHWAYS AND RISKS

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

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

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

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.

11.3. 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.

11.3.1. 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
- 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

Escape during handling, seeding, harvesting and transport

Mediterranean mussel farming entails extensive handling of the animals, which includes the handling and sorting of newly settled spat, the seeding of these spat onto production ropes, the thinning out of mussels on production ropes and harvesting. Much of these actions take place offshore where the mussels are farmed, leading to the reintroduction of mussels into the environment, some of which will survive.

From the above it is concluded that the probability of escape from these actions is absolute, but that this has no effect on the already naturalised populations of Mediterranean mussels that occur in the areas that are suitable to farming in South Africa. 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 mussels 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 mussels will become detached from the production ropes in the normal run of production. These could become detached due to poor adhesion to the production ropes, due to the feeding of fish and other predators and spontaneously, given the ability of mussels to detach from its byssal thread.

Apart from the escape by individual animals, mussels will spawn on the production ropes depending on their age, condition and the environment. The results in the release of millions of gametes, contributing to the existing larval population in the surrounding waters.

From the above it is concluded that the probability of escape directly from the production ropes (individual animals) and through spawning is absolute, but that this has no effect on the already naturalised populations of Mediterranean mussels that occur in the areas that are suitable to farming in South Africa. Little 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 mussels will not change the ecological risk profile.

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 mussel production infrastructure. The design of any system should ensure that rafts, ropes, platforms, anchors, buoys and other equipment is sturdy. Likewise, regular maintenance is required to prevent malfunction and breakage.

The collision of boats and ships with mussel production system 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 mussel production systems, some degree of breakage and system failure is normal under severe conditions. In such instances the probability of escape is absolute, but that will have no effect on the already naturalised populations of Mediterranean mussels that occur in the areas that are suitable to farming in South Africa. Mitigation measures include the use of tried and tested production system design, regular maintenance of all equipment and ensuring that production rope systems are not overburdened with too many mussels.

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 mussels. 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 no effect on the already naturalised populations of Mediterranean mussels that occur in the areas that are suitable to farming in South Africa. A range of measures exist to mitigate theft and human error.

Escape due to adverse weather and sea conditions

Directly linked to design, maintenance and human error, is the fact that mussels are most often farmed in high-energy offshore environmental that 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 has no effect on the already naturalised populations of Mediterranean mussels that occur in the areas that are suitable to farming in South Africa. 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.

11.3.2. 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 mussels, 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 Mediterranean mussels in South Africa, the potential for the introduction of novel diseases as a result of aquaculture activities is absent, given that no new stock is currently imported for culture purposes. Pathways for new and novel diseases thus rest mainly on the potential for international movement of the disease-causing organisms by shipping.

If a need ever arises to import Mediterranean mussels from elsewhere, it should be noted that this will be subject to veterinary clearance from the Directorate of Animal Health in the Department of Environment, Forestry and Fisheries (DEFF). In addition to this, the disease protocols and screening for certain notifiable diseases, in terms of the protocols of the World Organisation for Animal Health (OIE), is mandatory and should be applied.

Were novel diseases to be detected in South African Mediterranean mussel stocks, the extent of mussel invasion in local marine waters is likely to lead to a spread thereof throughout their southern African range. Such novel diseases may or may not affect other indigenous mussel species depending on host specificity. It should be noted that Mediterranean mussels are susceptible to a range of shell-boring parasites that occur in indigenous mussel stocks (Webb & Korrubel 1994).

11.4. DISCUSSION OF RISK ENDPOINTS

Although the farming of Mediterranean mussels in South African waters is not without the potential for environmental impacts, the biodiversity risks (endpoints), regardless of the scale of farming, is nullified by the fact that these mussels have already invaded through the entire extent of their tolerable range, and they exhibit a high degree of re-settlement and persistence. For this reason, the biodiversity impact will 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.

11.4.1. PHYSICAL ABIOTIC IMPACT TO THE ENVIRONMENT

Mediterranean mussels can cause some degree of physical impact to the environment through the establishment of very dense and extended mussel beds in intertidal rocky areas. Although these beds tend to be denser and larger than those created by indigenous mussel species, they possess similar physical characteristics in terms of evaluating the impact of Mediterranean mussel on the abiotic environment. Shells of dead mussels 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.

11.4.2. SPECIES DISPLACEMENT

Sections 7.13 speaks to the ability of Mediterranean mussels to displace both indigenous mussel and other molluscan species, especially the Ribbed mussel (*Aulacomya ater*). Such displacement has led to a significant decline in this species on the South African coastline.

Although the potential ecological risk of species displacement is of concern, it will continue despite the presence of aquaculture activities, given the invasion and naturalisation of Mediterranean mussels.

11.4.3. COMPETITION - FOOD, HABITAT & OTHER RESOURCES

The displacement of species indicated in the previous section relaters to competition for habitat, which will not be repeated here. Mediterranean mussels however also compete for food resources in that they feed on the same phytoplankton and organic particles that serve as a food resource for other mussels and marine species. Where these food resources are abundant, the impact is likely to be less severe, but in marginal habitats that are invaded by these exotic mussels, the competition for food could lead to the suppression of other indigenous species.

Although the potential ecological risk of competition for food is of concern, it will continue despite the presence of aquaculture activities, given the invasion and naturalisation of Mediterranean mussels.

11.4.4. HYBRIDIZATION

Although hybridisation is known to occur between Mediterranean mussels and Blue mussel (*Mytilus edulis*), both of the genus *Mytilus*, no intergeneric hybridisation has been recorded with indigenous mussel species along the South African coast [Ribbed mussel (*Aulacomya ater*), Black mussel (*Choromytilus meridionalis*) and Brown mussel (*Perna perna*)]

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

11.4.5. EFFECTS OF DISEASE

Assemblage of new stock and high stocking densities commonly found in aquaculture, can lead to disease related issues. The potential impacts of novel diseases introduced into an area through aquaculture can be wide-ranging and severe. Nevertheless, Mediterranean mussel stocks used in South Africa are taken from the already occurring populations of larvae and spat, which would expose any aquaculture facility to the disease causing organisms that already occur in the surrounding environment, unless the production and husbandry practices facilitate the outbreak of diseased through modifying the behaviour and condition of either the mussels or the disease causing organisms.

Internationally some diseases and a range of parasites (Ahmet 2014) have been reported for Mediterranean mussels, but little information is available around their presence or effects on South African Mediterranean mussel stock, or the possible effects on indigenous mussel species.

Harmful algal blooms (know as “red tide”) is not a mussel 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 mussels and other marine life. Due to the feeding habits of mussels the toxins from the algal blooms may periodically accumulate in the flesh of the mussels, rendering them toxic for human consultation. The mussel producers along the South Africa coastline (specifically Saldanha Bay) monitor for these toxins continuously. These algal blooms are however an environmental (and biodiversity) impact on marine life and not a biodiversity risk caused by the Mediterranean mussels.

11.5. ASSESSMENT SCORING OF RISK LEVELS

With reference to the pathways and risk inventory in Section 11.2, the flowing 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 Mediterranean mussels is 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 assessment, the biodiversity risks that are posed by the farming of Mediterranean mussels must be considered in context to the fully invaded marine environment in which this species has already become naturalised from the Namibian border to East London. Any degree of aquaculture will not change the biodiversity risk that is already posed by this feral population, except in instances where the import of mussels creates a pathway for novel diseases – an unlikely scenario given no reliance on the import of stock.

11.5.1. RISK PATHWAYS

The relationship between a risk pathway and the endpoint has been discussed in Section 10.3. It should be noted that the probably of a pathway such as escape refers specifically to the probability (chance) of escape, and not to the probability of the escape event leading to an impact or endpoint. Likewise, the severity refers to the severity (quantity) of escape, the scope to the distribution of escapees and permanence to the survival and propagation of the escapees. These aspects should not be confused with the characterisation of the endpoints or impacts.

The scoring of the biodiversity risk pathways associated with the farming of Mediterranean mussels creates a false impression, given that the farming systems are by their very nature prone to escape, and given that these exotic mussels have already fully invaded the marine environment in which they are farmed. The tables hereafter depict an aggregate score for South Africa in general.

a. The risk of Mediterranean mussels 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 9: Risk pathway characterisation related to escape during handling, seeding, harvesting and transport.

b. The risk of Mediterranean mussels 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 10: Risk pathway characterisation related to escape from the aquaculture infrastructure.

c. The risk of Mediterranean mussels 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 11: Risk pathway characterisation related to escape through poor design, system malfunction and/or poor maintenance.

d. The risk of Mediterranean mussels 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 12: Risk pathway characterisation related to escape through deliberate or accidental human actions, including theft.

e. The risk of Mediterranean mussels 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 13: Risk pathway characterisation related to escape through adverse weather and sea conditions.

f. The risk of Mediterranean mussels 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 14: Risk pathway characterisation related to spread of novel diseases.

11.5.2. 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 Mediterranean mussels creates a false impression, given that the surrounding environment to any South African farming operations are already fully invaded. The biodiversity risks have therefor already occurred and there is no prospect of reversal. The tables hereafter depict an aggregate score for South Africa in general.

a. The risk of Mediterranean mussels causing physical (abiotic) impacts to the environment.

Risk	Life history characteristics of Mediterranean mussels				
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 15: Risk endpoint characterisation related to physical damage to the environment.

b. The risk of Mediterranean mussels causing species displacement.

Risk	Life history characteristics of Mediterranean mussels				
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 16: Risk endpoint characterisation related to species displacement.

c. The risk of Mediterranean mussels causing competition for food, habitat niches and other resources.

Risk	Life history characteristics of Mediterranean mussels				
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 17: 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 Mediterranean mussels.

Risk	Life history characteristics of Mediterranean mussels				
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 18: Risk endpoint characterisation related to impact of diseases and pathogens.

11.6. SUMMARY OF RISK PROFILE

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

Table 19: 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	High	Moderate	High	Low	Moderate	High	High	Low
Severity	High	High	High	High	High	Catastrophic	Moderate	High	Moderate	Catastrophic
Scope	Extensive	Extensive	Extensive	Extensive	Extensive	Extensive	Regional	Regional	Local	Extensive
Permanence	Permanent	Permanent	Permanent	Permanent	Permanent	Long-lasting	Permanent	Permanent	Long-lasting	Long-lasting
Confidence	Very high	Very high	Very high	Very high	Very high	Very high	Very high	Very high	High	High
Monitoring	Very high	Very high	High	Moderate	Very high	Moderate	Very high	High	Low	Moderate
Mitigation	Irreversible	Irreversible	Irreversible	Irreversible	Irreversible	Moderate	Irreversible	Irreversible	Irreversible	Low

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

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

Table 20: 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 Mediterranean mussels is as follows (table next page):

Table 21: Score allocation to the risk profile.

	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	1	1	4	5	1	12	6	2	4	12
Severity	5	5	6	6	5	4	12	5	12	4
Scope	1	1	1	1	1	1	4	4	7	1
Permanence	1	1	1	1	1	4	3	2	4	4
Confidence	10	10	9	9	10	9	10	9	8	7
Monitoring	9	9	7	6	9	5	9	8	4	5
Mitigation	1	1	1	1	1	5	2	2	2	3
Total Score	28	28	29	29	28	40	46	32	41	36

The score allocation, although subjective and debatable, has been done based on information 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 Mediterranean mussels have already fully invaded the marine environment results in a skewed scoring. Escape from farming operations is absolute, while the farming activities, whether mitigated or not, makes virtually no difference to the ecological endpoints or impacts. The scoring therefor is of very limited value in this risk assessment.

Notwithstanding the information in the paragraph above, the pathway related risks for escape through handling, seeding, harvesting, transport, escape directly from the production ropes (including spawning), and escape facilitated by adverse weather and sea conditions is highest. These pathways pose an absolute probability of escape, yet the score is somewhat mitigated by the high confidence in the assessment. These escapes can be monitored and mitigated to some extent, but this will make no difference to the endpoint impact. The management of these risk pathways has no ecological value, apart from managing the pathway of disease introduction through prohibiting the import of additional stock for aquaculture purposes.

With due consideration to the existing invasion biology of Mediterranean mussels in South Africa, the score for the ecological endpoint of species displacement is most relevant. This is a biodiversity concern, but no means of monitoring or mitigation on account of the current and future aquaculture facilities will change this existing impact.

Note that this scoring methodology has been used to grade the potential negative biodiversity risks and impacts only. The potential positive ecological impacts of Mediterranean mussels include the creation of habitat niches for a range of smaller molluscs and other marine species, while providing food for sea stars, birds such as the Africa black oystercatcher (*Haematopus moquini*) and a range of other marine species (Hockey & van Erkom Schurink 1992). Mediterranean mussels 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 (Shumway *et al*. 2003). Mussel farms can also serve as sheltered areas for certain fish species and other marine life.

12. 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 Mediterranean mussels 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 the South African coastline has already been invaded by this exotic species.

The mussel 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 Mediterranean mussels being processed for export from South Africa.

In terms of the mussel production reported to the FAO, South Africa produced 1804 tons in 2017, valued at approximately U$ 3,8 million. This figure is set to grow with new farms that have since been established.

Mediterranean mussel farming is currently limited to 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 to the surrounding environment has already occurred and will continue to occur despite the expansion of mussel aquaculture.

The mussel 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 Mediterranean mussel aquaculture has already resulted in several socio-economic advantages, which include:

- The creation of rare 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 up the socio-economic consequences that may result from the manifestation of any of the ecological impacts related to these mussels. In this case the socio-economic benefits from aquaculture should be encouraged, as no degree of farming will change the biodiversity risk profile. In addition to this, the feral populations of Mediterranean mussels support a significant recreational and semi-commercial / small scale fishery.

The continued presence of Mediterranean mussels holds no direct threat to humans or any human livelihoods.

13. BALANCED COST OF ERADICATION

There are no examples of Mediterranean mussels having been eradicated successfully.

A balanced view must be taken to the potential ecological cost of Mediterranean mussel invasion 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 invasion that has already taken place and the insignificant effects that could manifest towards human beings and their livelihoods, the cost of eradicating Mediterranean mussels 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.

14. RISK MONITORING

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

Threshold limits 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 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 invasion of Mediterranean mussels in South African marine waters already, 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 Mediterranean mussels 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.
- An annual review of operational procedures.
- A monthly inspection of all maintenance, as well as integrity and seaworthiness of production facilities.

15. 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 Mediterranean mussel farming, no level of on-farm mitigation will stem the biodiversity related impacts of the naturalised 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 Mediterranean mussels in aquaculture:

To prevent the introduction of novel diseases:

- Prohibit the import of Mediterranean stock, as local stocks are sufficient. In the event that any imports are considered, stick disease control and biosecurity measures must be applied.

Precautions against inclement weather and severe sea conditions:

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

16. RESEARCH NEEDS

The invasion of Mediterranean mussels into South African waters, its distribution and impacts (ecological and socio-economic) have been well studied. However, it is important to continue with biological research on the species with a focus on incidence of parasites, mussel mortalities, biofouling and benthic impacts, phytoplankton stripping and condition index. Furthermore, continual evaluation of the distribution range, mariculture efforts and impacts of these mussels on the environment and on other commercial species, needs to be maintained.

17. BENEFIT / RISK TRADE-OFF

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

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 tradeoff can become a highly-complicated exercise when assigning objective and comparable values to these. Although this tradeoff is not being pursued in this assessment report, considering the risk profile indicated above in conjunction with the advantages and benefits from the use of Mediterranean mussels for aquaculture, one can arrive at an acceptable risk tradeoff in which the use of this species should be permitted in areas where invasion has already taken place.

18. RECOMMENDATIONS

Risk assessment techniques have been applied to all the major biodiversity risk components related to the use of Mediterranean mussels for aquaculture in South Africa. Mediterranean mussels are already distributed to the full extent of their physiological tolerance limits along the South African coastline, and the use of this species in aquaculture operations will not result in further expansion of its range, or in any increase in the density of animals within this range. Culture of this species should thus be allowed to continue in any coastal area, provided that the non-biodiversity related environmental impacts have been adequately assessed.

19. CONCLUSION

This BRBA has illustrated that the use of Mediterranean mussels in aquaculture in South Africa harbours no greater a biodiversity risk than the existing feral population does. Only the import of new mussel stocks may pose a limited disease related risk.

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