Mediterranean mussel *Mytilus galloprovincialis*

1 Taxonomy

Species: *Mytilus galloprovincialis*

Family: Mytilidae

Order: Mytiloida

Class: Bivalvia

The Mediterranean mussel *Mytilus galloprovincialis* is a large blue-black mussel which often aggregates in dense beds. It is easily confused with the indigenous black mussel *Choromytilus meridionalis*, but can be distinguished by the presence of pits in the resilial ridge (narrow white band alongside the hinge ligament on the inner surface of the shell, Figure 1 below). On average, the length of the shell is approximately 5 cm, but it can grow up to 12 cm (Picker & Griffiths 2011).

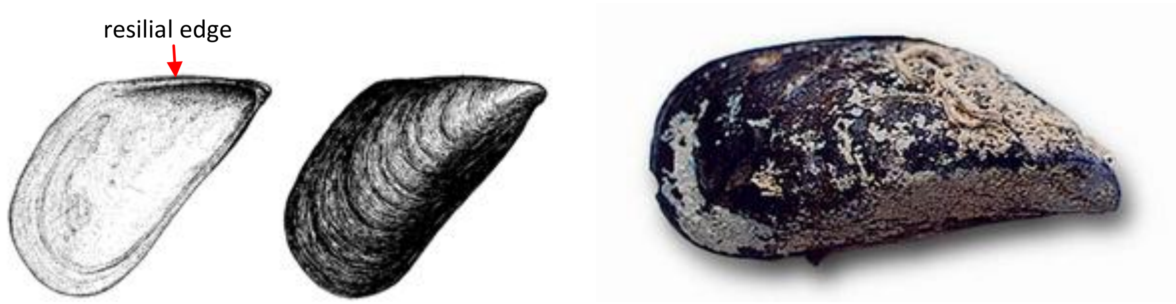

Figure 1. Images of *Mytilus galloprovincialis* (Source: FAO 2012)

2 Natural distribution and habitat

Native to the Mediterranean coastline (Figure 2), the earliest record of *M. galloprovincialis* is in the Galicia region in North West Spain. Globally it is found on temperate sheltered and exposed rocky shores but is generally absent from heavily silted or sandy areas. It does not extend its distribution on benthic substrata seaward of the intertidal fringe – although it grows well on suspended mussel ropes (Hockey & van Erkom Schurink, 1992, Branch & Steffani, 2004).

M. galloprovincialis attaches firmly to rocks by means of strong byssal threads which are secreted by a mobile foot. In South Africa, peak biomass, maximum size and greatest percentage cover and depth of mussel beds are attained at intermediate levels of wave exposure (Hammond & Griffiths 2004).

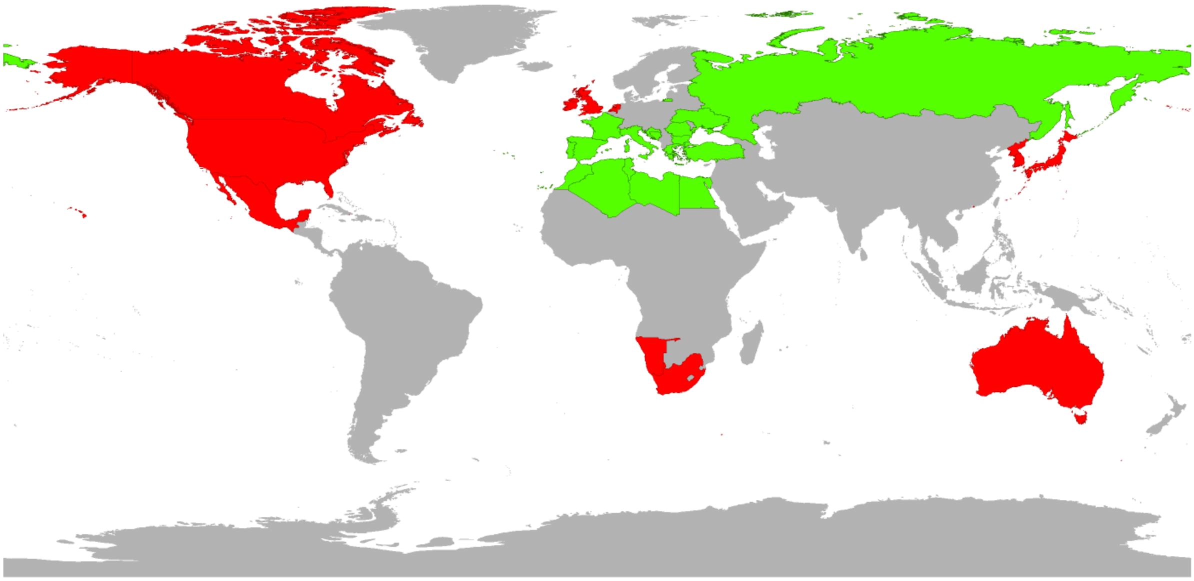

Figure 2. **Native (green) and introduced (red) ranges of *M. galloprovincialis* globally (Data source: GISD 2012). Please note this map does not indicate country wide presence, but merely that the species is categorised as an alien within that country.**

3 Biology

3.1 Diet and mode of feeding

M. galloprovincialis is a filter feeder and feeds by pumping water through enlarged sieve-like gills. Food particles are accumulated on the gill lamellae and are then transported by cilia towards the mouth whilst continually being sorted according to size. Fine particles are ingested and travel into the oesophagus and stomach where further sorting takes place.

Stable isotope ratios from a study by Bustamante and Branch (1996) indicate that on the west coast of South Africa, *M. Galloprovincialis* obtains 60-70% of its nitrogen and carbon requirements from kelp-derived particles introduced into the intertidal from subtidal kelp beds. Phytoplankton constitutes the majority of the remaining 30-40%. In Saldanha Bay, the farmed mussels feed primarily on phytoplankton (comprising approximately 80% of the diet) (A. Tonin, Saldanha Bay Oyster Company, pers. comm.).

3.2 Growth

M. galloprovincialis grows rapidly and can attain 70 mm within its first year at favourable sites (Picker & Griffiths 2011). Results from a study conducted by Steffani and Branch (2003) show that greatest recruitment and growth rates are achieved at exposed sites in comparison to sites sheltered from direct wave action or at sites exposed to extreme wave action. It has been suggested that better growth rates and condition at moderately exposed sites relative to sheltered sites can be attributed to greater food supply. Furthermore, larval supply may increase with greater water flux at exposed sites. However, opportunities for attachment may diminish at extremely exposed sites

(Branch & Steffani 2004). Colony sizes reach in the order of millions of individuals. On the West Coast of South Africa dense multilayered beds extend for several hundred metres along the rocky shore (A. Biccard, Anchor Environmental, pers. obs.).

3.3 Reproduction

M. galloprovincialis are gonochoristic broadcast spawners. The gonads extend throughout the body and are cream coloured in males and pink in females. Millions of gametes are released during spawning events with fertilised eggs developing into free swimming planktotrophic larvae capable of dispersing large distances (Picker & Griffiths 2011).

Upon reaching sexual maturity (1-2 years as reported by MarLIN 2009) reproduction takes place more than once each year with annual reproductive output, expressed as a percentage of body mass, known to exceed 120% (Van Erkom, Schurink & Griffiths 1991). The total reproductive output of *M. galloprovincialis* ranges between 20% and 200% greater than that of any of the indigenous mussel species in South Africa.

3.4 Environmental tolerance ranges

Relative to indigenous mussel species, *M. galloprovincialis* displays great tolerance to environmental variability – a characteristic which makes it an aggressive invasive species on South African shores. Most significant are its rapid growth rate at differing water temperatures and resistance to desiccation. *M. galloprovincialis* is exclusively a marine species. It has not yet been reported to have penetrated any estuaries in South Africa, which suggests it has a fairly low tolerance to environments of decreased salinity.

Anestis *et al.* (2007) have shown significant mortality rates of *M. galloprovincialis* at temperatures greater than 24°C with the upper limit (i.e. 100% mortality) occurring within 20 days of exposure to water at 30°C. It is not clear what the minimum temperature tolerance limit of this species is, yet it is known to exist in vast beds on the west coast of South Africa where temperatures can drop to a minimum of approximately 7°C during peak upwelling season. Fastest ingestion, absorption rates and largest growth rates were found to occur between water temperatures of 10°C and 20°C (van Erkom Schurink & Griffiths 1992).

Survivorship and tolerance to air exposure and desiccation in *M. galloprovincialis* is reported to be double that of any of the indigenous species in South Africa (Branch & Steffani 2004). 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% survivorship in *M. galloprovincialis* compared to 78% for *Perna perna*, 37-46% for *C. meridionalis* and only 0-10% for *Aulacomya ater*.

M. galloprovincialis is inferior in respect of its siltation tolerance when compared to the indigenous South African mussel species (Branch & Steffani 2004). Like *A. ater* and *P. perna*, *M. galloprovincialis* is excluded from sandy areas where siltation takes place, whereas *C. meridionalis* thrives in these conditions (Hockey & van Erkom Schurink 1992).

4 History of domestication

In the early 1900s, mussel culture in Spain became popular, with the first trials in Tarragona and Barcelona utilising poles on which to grow mussels. This was an adequate technique to meet the low demand (at the time, mussels were used primarily as agricultural manure and also as a source of seed for the few bottom culture facilities). Culture techniques developed (as demand increased) in the 1940s and soon the primary methods incorporated floating mussel rafts. Initially these consisted of wooden frames which had a float in the centre and from which grass ropes with mussel seed attached hung. Nowadays most rafts used internationally consist of a eucalyptus wood frame (FAO 2012).

International grow-out techniques include i) bottom culture; ii) off-bottom culture; iii) suspended culture; iv) floating culture; v) hardening (in conjunction with suspended culture) (FAO 2012).

5 Introduction and spread (South Africa)

M. galloprovincialis was first discovered in South Africa in 1979, in Saldanha Bay (Branch & Steffani 2004) where it was most likely introduced as a result of shipping. Given that this species is a broadcast spawner and has a planktotrophic larval stage, it was expected to disperse rapidly along the coast of South Africa shortly after its discovery. Indeed, by 1984 it was the dominant intertidal mussel along parts of the west coast. A study by Pfaff *et al.* (2011) shows that recruitment of mussel larvae on the west coast of South Africa is entirely influenced by prevailing nearshore ocean currents and that upwelling, together with wave exposure, was positively correlated with the settlement of mussel larvae on the rocky shore.

M. galloprovincialis first appeared on the south coast of the country in 1988 (McQuaid & Phillips, 2000) following its introduction to 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 the distribution range now extends from central Namibia (west coast) to just beyond East London on the east coast (Robinson *et al.* 2005, Mead *et al.* 2011) (Figure 3).

This mussel species has invaded most estuaries (with suitable substratum) in the Southern Cape. For example, in the Breede River, *M. galloprovincialis* can be found up to 7 km from the river mouth (A. Tonin, Saldanha Bay Oyster Company, pers. comm.).

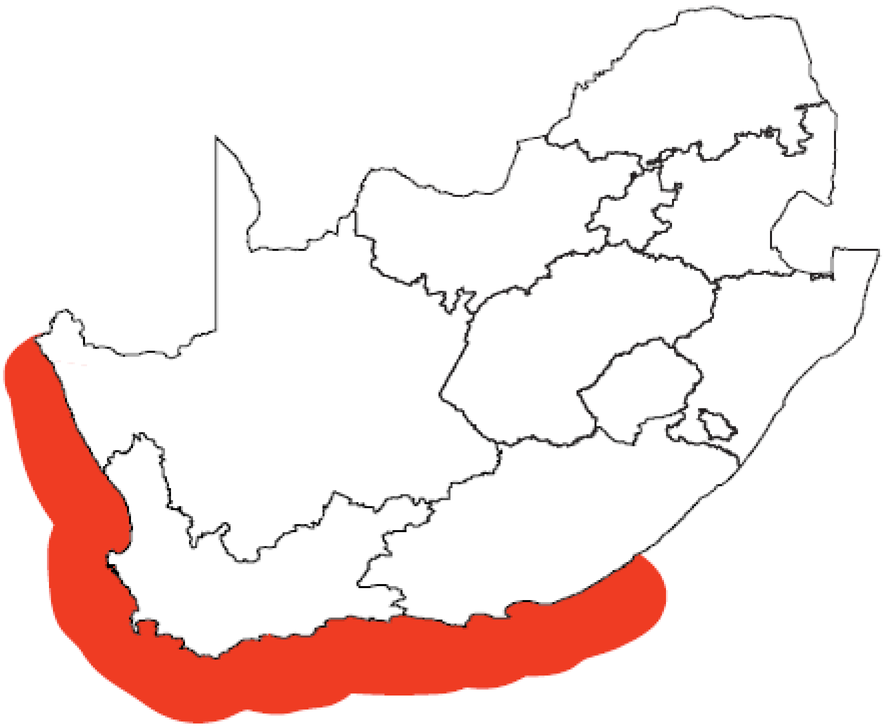

Figure 3. **Introduced range (red) of *M. galloprovincialis* within South Africa (Source: M. Picker & C. Griffiths)**

6 Introduction and spread (International)

M. galloprovincialis has colonised and formed naturalised populations at nine localities outside of its native range. These include Hong Kong, Japan, Korea, Australia, America, Mexico, Canada, Great Britain and Ireland (Branch & Steffani 2004) (Figure 2). Due to its association with large shipping ports, it is likely that the mussel is transported via ballast water or hull fouling. In addition, there is a visible range expansion from these ports along the coast at most sites of introduction (Branch & Steffani 2004).

Due to its widespread distribution, *M. galloprovincialis* has been listed as one of the World's Worst 100 Invasive Alien Species (GISD 2012). This list has been compiled by the Global Invasive Species Database and La Fondation TOTAL d' Enterprise in collaboration with the International Union for Conservation of Nature (IUCN) Invasive Species Specialist Group (ISSG). Due to the complexity of interactions between a species and its environment, certain assumptions were made in creating this list. Species were selected based on the severity of their impact on biodiversity and/or human activities, as well as "their illustration of important issues surrounding biological invasion."

7 Compatibility with local environmental conditions

Compatibility of this species to local environmental conditions was evaluated by comparing the water temperature ranges of the South Africa to the known environmental tolerance ranges for *M.*

galloprovincialis (van Erkom Schurink & Griffiths 1992). The water temperatures of the South African coast can be broadly grouped as follows (Field & Griffiths 1991):

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

Given that *M. galloprovincialis* demonstrates optimal growth rates between 10 and 20°C (van Erkom Schurink & Griffiths 1992), it is clear that culture of *M. galloprovincialis* is possible in at least 2 of these regions; the West and South coast. These temperature zones correspond to the five marine inshore ecozones which comprise South Africa's 3100 km length coastline – the Namaqua, the Southwestern Cape, Agulhas, Natal and Delagoa (Sink *et al.* 2012) (Figure 4). The 2011 National coastal and marine habitat classification incorporate the following key drivers of marine biodiversity patterns:

- Terrestrial and benthic-pelagic connectivity
- Substrate (consolidated or unconsolidated)
- Depth and slope
- Geology, grain size and wave exposure (which interact in the case of beaches)
- Biogeography

The current distribution of *M. galloprovincialis* lies in the Namaqua, Southwestern Cape and Agulhas ecozones (Picker & Griffiths 2011).

7.1 Culture techniques

In South Africa, mussel seed (from the offshore larval pool) naturally settles on culture ropes and the mussels are then cultivated in suspension. There is currently no import of mussel seed required in South Africa. Both long-line and raft culture methods have been trialled, however, due to the high energy waves which hit most of the coastline, rafts are now the preferred option. During harvesting, immature mussels are collected and reseeded onto ropes to allow for further growth. In Saldanha Bay, the original square mussel rafts are being gradually replaced by a linear design, which allows increased water flow beneath the rafts (S. Jackson, Stellenbosch University, pers. comm.).

8 Research requirements

The introduction of *M. galloprovincialis* to South African waters, its distribution and impacts (ecological and socio-economic) have been well studied in South Africa. However, it is important to continue doing biological research on the species with a focus on incidence of parasites, mussel mortalities and condition index (FAO 2012).

Furthermore, continual evaluation of the distribution range, mariculture efforts and impact of *M. galloprovincialis* on the environment and on other commercial species, needs to be maintained.

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

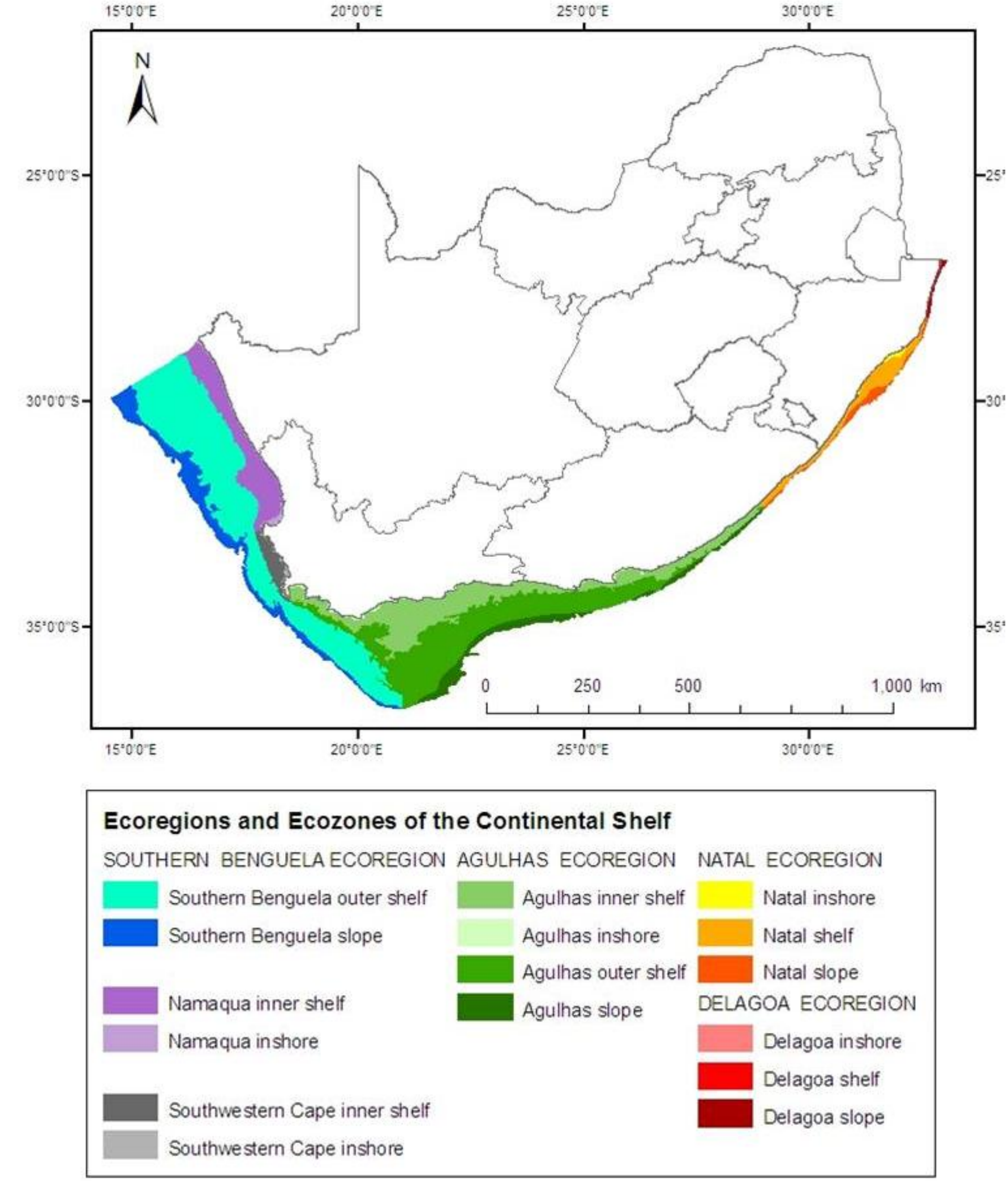

Figure 4. **Map highlighting the five marine inshore ecozones of South Africa (Sink *et al.* 2012).**

9 Benefit assessment

9.1 Potential ecological benefits

M. galloprovincialis can improve water quality by removing particulates and excess Nitrogen from the aquatic environment, reducing turbidity (and thus allowing vegetation to photosynthesise more efficiently) and converting nutrients into an accessible form (Shumway *et al*. 2003).

Mussels can act as water quality indicators, due to their ability to filter toxins and microbes from the surrounding environment. In South Africa, shellfish farmers are required to sample animal tissues and water in the culture area, to be tested by external laboratories, as part of the South African Molluscan Shellfish Monitoring and Control Program. The results of these analyses can assist in ensuring human health, while providing a quantitative indication of ecosystem health. The programme demonstrates that farmers are operating responsibly and can provide guarantees of safety to consumers both locally and internationally.

The invasion of *M. galloprovincialis* has also benefited *Haematopus moquini*, the African black oystercatcher. This native species is classed as near-threatened on the IUCN Red List. Since the arrival of the mussel on South African shorelines, this bird has shifted its diet so that it is now primarily consuming *M. galloprovincialis*. Following this increase in food availability, the breeding success of the oystercatcher has increased (Hockey & van Erkom Schurink 1992). In addition, aquaculture facilities can provide refuge for fish species or even function as a nursery ground for juvenile fish and other crustaceans (Shumway *et al*. 2003).

9.2 Socio-economic benefits

The international production of *M. galloprovincialis* in aquaculture increased from the 1950s (initiation of statistic collections by the FAO) until the mid 1980s when production reached a plateau (Figure 5). The current worldwide annual production of *M. galloprovincialis* is estimated to be around 107 488 tonnes. The international value of *M. galloprovincialis* has followed this increase (although the recording of value data was only initiated in the early 1980s) and is currently valued at USD0.106 billion (Figure 6).

In 2008, there were three mussel farms in South Africa, employing 26 full time staff and no part time staff (Britz *et al.* 2009). The production in South Africa over the last twelve years has fluctuated in both directions, however, since production peaked in 2008 at 736 tonnes and has gradually decreased since (Figure 7). The total 2011 production of *M. galloprovincialis* in South Africa was 570 tonnes (A. Nakani, pers. comm.). Mussel farming in South Africa was valued at ZAR9.1 million in 2010 (with an export value of ZAR0.8 million) (DAFF 2012).

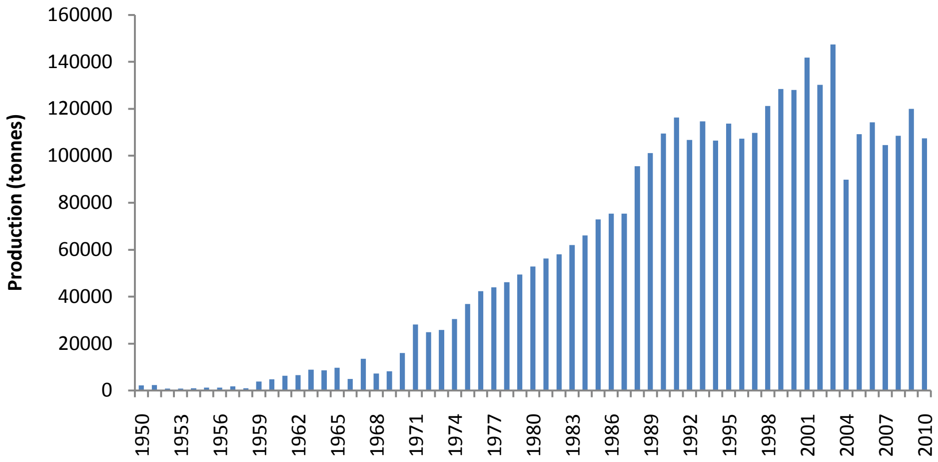

Figure 5. **International production of *M. galloprovincialis* from 1950-2010 (Modified from FAO - Fisheries and Aquaculture Information and Statistics Service - 10/09/2012)**

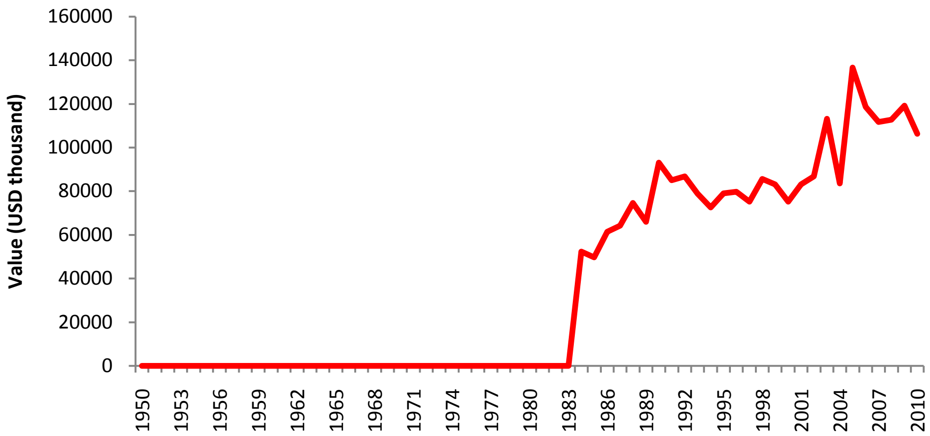

Figure 6. **International value (in USD thousand) of *M. galloprovincialis* from 1950-2010 (Modified from FAO - Fisheries and Aquaculture Information and Statistics Service - 10/09/2012)**

South African mussel farms in 2011 were employing 79 full time and 64 part time staff. Of these full time employees, the majority (n=66) were male and 13 were female (A. Nakani, pers. comm.).

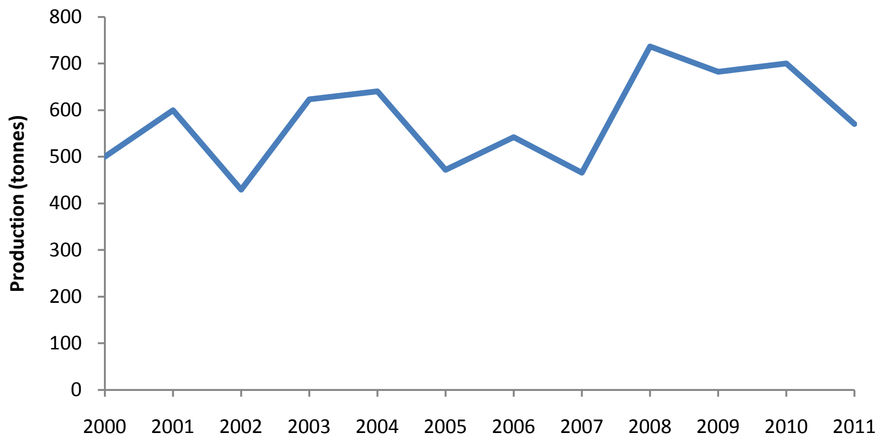

Figure 7. **Mussel aquaculture production (tonnes) in South Africa 2000-2010 (Data supplied by DAFF 2012 and A. Nakani, pers. comm.)**

A recent study by Olivier *et al.* (in press) investigated the ecological carrying capacity of Saldanha Bay with regards to bivalve farming. The findings indicate that the sector could increase 10 to 28 fold, potentially creating an additional 940 to 2500 jobs for the region without compromising the environment.

A study undertaken on the West coast of South Africa (in the communities of Port Nolloth and Hondeklipbaai) demonstrated that there is potential for a small scale commercial *M. galloprovincialis* fishery. In order for the fishery to be biologically sustainable, harvesting could only occur over two seasons: March–April and September–October. The total annual harvest would have to be restricted to between 69 and 287.5 tonnes (Robinson *et al.* 2007).

There is a significant recreational fishery sustained by mussels (indigenous species and *M. galloprovincialis*) in South Africa (Hockey *et al.* 1988, Rius *et al.* 2006). A review by Sowman (2006) recommended the following fisheries for *M. galloprovincialis*: West coast - recreational, subsistence and small scale commercials fisheries; South and East coasts – recreational and subsistence.

According to the Marine Living Resources Act of South Africa (Act No. 18 of 1998), the recreational limit for *M. galloprovincialis* is 30 per day although restrictions apply within Marine Protected Areas, National Parks and in some wetlands and river mouths. In 2011, 41,446 mollusc recreational permits were issued for South Africa and an additional 5,527 mussel permits in KwaZulu-Natal (all species) (DAFF unpublished data). This means that in 2011, there were potentially close to 47,000 mussel collectors in South Africa.

10 Risk assessment

10.1 Likelihood of this species becoming established in South Africa

The Mediterranean mussel is already well established in South Africa and currently occupies 2050 km of coastline with an estimated standing stock of 35 403.7 ±9099.6 tons SD (Robinson *et al.* 2005). Most of the existing favourable habitat available to this species in South Africa has been occupied and it is unlikely that the range distribution will extend further eastward as the water temperature increases beyond that which is favourable for optimum growth of the species.

In the case of other alien species, risk assessment profiles have been compiled, in which the species have been assessed in accordance with the European Non-Native Species Risk Analysis Scheme (ENSARS) (Copp *et al.* 2008) developed by CEFAS (UK Centre for Environment, Fisheries & Aquaculture Science). ENSARS provides a structured framework (Crown Copyright 2007-2008) for evaluating the risks of escape, introduction to and establishment in open waters, of any non-native aquatic organism being used (or associated with those used) in aquaculture. In the case of *M. galloprovincialis* which has established self sustaining populations along the coastline from the Namibian border to East London, further culturing of this species anywhere in this region is unlikely to significantly affect the size of the current populations in any way. Aquaculture operations primarily rely on natural seeding from the offshore larval pool. Where this is not the case, spat is collected from local populations of the species. Currently no spat is imported into South Africa. As a result of these culture techniques and the current distribution of the species, *M. galloprovincialis* has not been assessed using a risk scoring framework.

10.2 Potential ecological impacts

The ecological effects following the invasion of *M. galloprovincialis* are most noticeable on the west coast of South Africa where the lower intertidal zones of rocky shores have become inundated with vast, dense beds of the species. In comparison with the indigenous mussels, *C. meridionalis, A. ater* and *P. perna, M. galloprovincialis* displays greater fecundity, growth rates and tolerance to desiccation (van Erkom Schurink & Griffiths 1992, Hockey & van Erkom Schurink 1992).

Of the three indigenous species, *A. ater* is most severely affected by *M. galloprovincialis* as not only do they occupy similar sediment-free positions on the rocky shore, but their distribution ranges overlap almost entirely (Branch & Steffani 2004). The impacts of this species on the abundance of *C. meridionalis* is thought to be much lower, as it is tolerant of sedimentation, occupying sandy areas where *M. galloprovincialis* is excluded. Similarly, effects on *P. perna* are thought to be minimal as the overlap in their distribution ranges is small (South Coast only). Interactions between these two species are also supposedly more balanced, but should favour *M. galloprovincialis* owing to its higher growth and reproductive performance, and the fact that *P. perna* is not a competitively dominant species (Branch & Steffani 2004).

Given that *M. galloprovincialis* mussel beds consist of multiple layers and can therefore support a higher biomass per unit area than the indigenous species that only form single layers, a significant increase in mussel biomass on West Coast has been noted following its introduction (Griffiths *et al.* 1992). As a result, a simultaneous rise in the density of associated mussel bed infauna has also occurred (Hammond & Griffiths 2004). Furthermore, predators such as the whelk *Nucella cingulata* and the black oyster catcher *Haematopus moquini* (once a near-threatened species) have benefited significantly from the increased food availability (Branch and Steffani 2004). The presence and high rate of recruitment of *M. galloprovincialis* in South Africa has also resulted in a loss of habitat for the competitively inferior native limpet *Scutellastra granularis* (Hockey & van Erkom-Schurink 1992, in

Morton 1996). In Australia, the benthic effects of the blue mussel have been reported to not extend more than 50 m outside culture areas (McKinnon *et al*. 2003).

Regarding the farming of *M. galloprovincialis,* Stenton-Dozey *et al.* (2001) found disturbed macrobenthic communities under 78% of mussel rafts surveyed in Saldanha Bay. The community structure has changed from mostly suspension feeders to being dominated by deposit feeders.

10.3 Potential socio-economic impacts

M. galloprovincialis has out-competed the limpet *S. granularis* on semi-exposed and exposed rocky shores on the West Coast (Hockey & van Erkom-Schurink 1992). It is likely that this has had a negative impact on the traditional harvest of this limpet species by artisanal fishers for use as lobster bait. This appears to be the only known negative socio-economic impact for this species. On the other hand, higher growth rates for this species relative to the local mussel species, has almost certainly contributed significantly to the success of the local mussel culture operations.

10.4 Risk summary

There is reasonable likelihood that:

- Naturalised mussel populations will compete with and/or predate on indigenous species and will pose a risk to the continued survival of native species especially those that occupy a similar habitat;
- No hybridisation will occur with indigenous species; and
- Diseases or parasites could be transferred to populations of indigenous molluscs if new stock is introduced to the country or specimens are translocated within the country without the application of best management practises, including having these individuals certified disease free by qualified veterinarians.

11 Control and prevention options

Control of invasive mussel populations is thought to be impossible given its extensive distribution to date, in addition to high fecundity and easily dispersed larvae (Picker & Griffiths 2011). It is likely that any attempt to control *M. galloprovincialis* in South Africa will be unsuccessful as a result of recruitment from a vast offshore larval pool, as well as potential introduction through pathways such as shipping.

12 Recommendations regarding suitability for use in aquaculture in South Africa

M. galloprovincialis is already widely distributed in South Africa, most likely to the full extent of its physiological tolerance limits, and the use of this species in aquaculture operations is unlikely to result in further expansion of this range or any increase in density within the existing range. Culture of this species should thus be allowed to continue in those regions where it already exists.

In addition, a number of area-specific recommendations are proposed, based on the presence of an existing population and climatic suitability, the elements of which are outlined in Error! Reference source not found.. The culture of *M. galloprovincialis* within a Marine Protected Area (MPA) should be prohibited. Similarly, culture of the species in estuarine areas with a suitable climate for *M. galloprovincialis* should be prohibited. In marine bays and estuaries where there is an existing introduced population or the species is non-existent (but climatically unsuitable for reproduction), culture should be permitted under medium level biosecurity measures, including best management practises. If in the unlikely event that an import of spat is required in future, this must be sourced from a hatchery that is certified biosecure. Following the import of spat, any fouling material accumulated on the mussel ropes should not be released back into the sea (given the potential for the further introduction of alien species associated with mussel culture).

Table 1. Recommendations for *M. galloprovincialis* culture in South Africa, depending on the category of area proposed for farming. Red blocks indicate 'No culture" and green blocks indicate "low biosecurity". White blocks represent "Non-applicability", i.e. in this case, *M. galloprovincialis* has no native distribution within South Africa and has already become established in all areas where it is climatically suitable.

Area category	Native distribution	Existing introduced population	Species not present (climatically suitable)	Species not present (climatically unsuitable)
MPA				
All other areas (estuarine)				
All other areas (marine)				

Established populations represent a vast stock of individuals for stocking any future aquaculture operations. Introduction of fresh spat or stock from other countries is unnecessary and is not recommended as it carries with it a risk of introducing new parasites or pathogens to existing wild and farmed stocks and/or other native species. If in future, it becomes necessary to translocate spat within South Africa or to import fresh spat from abroad, further risk assessment is recommended.

13 References

Anestis, A., Lazou, A., Portner, H.O. & Michaelidis, B. 2007. Behavioral and metabolic, and molecular stress responses of marine bivalve *Mytilus galloprovincialis* during long-term acclimation at increasing ambient temperature. American Journal Of Physiology-Regulatory Integrative And Comparative Physiology 293: R911–R921

Branch, G.M. & Steffani, N.C., 2004. Can we predict the effects of alien species? A case-history of the invasion of South Africa by *Mytilus galloprovincialis* (Lamarck). Journal of Experimental Marine Biology and Ecology 300: 189– 215.

Britz, P.J., Lee, B. & Botes, L. 2009. AISA 2009 Aquaculture Benchmarking Survey: Primary Production and Markets. AISA report produced by Enviro-Fish Africa (Pty) Ltd. 117 pp.

Bustamante, R.H. & Branch, G.M., 1996. The dependence of intertidal consumers on kelp-derived organic matter on the west coast of South Africa. Journal of Experimental Marine Biology and Ecology 196: 1– 28.

Copp, G.H., Britton, J.R., Cowx, I.G., Jeney, G., Joly, J-P., Gherardi, F., Gollasch, S., Gozlan, R.E., Jones, G., MacLeod, A., Midtlyng, P.J., Miossec, L., Nunn, A.D., Occhipinti-Ambrogi, A., Oidtmann, B., Olenin, S., Peeler, E., Russell, I.C., Savini, D., Tricarico, E. & Thrush, M. 2008. Risk assessment protocols and decision making tools for use of alien species in aquaculture and stock enhancement. EU Co-ordination Action Project: IMPASSE Environmental impacts of alien species in aquaculture, Deliverable report 3.2.

DAFF 2012. Department of Agriculture, Forestry and Fisheries Aquaculture Annual Report 2011 South Africa. ISBN: 973-1-868-71-355-4.

FAO 2005-2012. Cultured Aquatic Species Information Programme. *Mytilus galloprovincialis*. Cultured Aquatic Species Information Programme . Text by Figueras, A. In: FAO Fisheries and Aquaculture Department [online]. Rome. Updated 1 January 2004. [Cited 17 October 2012].

Field, J.G. & Griffiths, C.L., 1991. Littoral and sublittoral ecosystems of southern Africa. In: Mathieson, A.C. and Nienhuis, P.H., Editors, 1991. Ecosystems of the World 24. Intertidal and Littoral Ecosystems, Elsevier, Amsterdam, pp. 323–346.

GISD. 2012. Global Invasive Species Database – *Mytilus galloprovincialis* – Available from http://www.issg.org/database/species/ecology.asp?si=102&fr=1&sts=sss&lang=EN

Griffiths, C.L., Hockey, P.A.R., Van Erkom Schurink, C. & Roux, P.J.L., 1992. Marine invasive aliens on South African shores: implications for community structure and trophic functioning. South African Journal of Marine Science 12: 713–722.

Hammond, W. & Griffiths, C.L. 2004. Influence of wave exposure on South African mussel beds and their associated infaunal communities. Marine Biology 144: 547–552.

Heasman, K.G., Pitcher, G.C., Mcquaid, C.D. & Hecht, T. 1998. Shellfish mariculture in the Benguela system: Raft culture of *Mytilus galloprovincialis* and the effect of rope spacing on food extraction, growth rate, production and condition of mussels. Journal of Shellfish Research 17: 33-39.

Hockey, P.A.R., Bosman, A.L. & Siegfried, W.R. 1988. Patterns and correlates of shellfish exploitation by coastal people in Transkei: an enigma of protein production. Journal of Applied Ecology 25: 353–363.

Hockey, P.A.R. & van Erkom Schurink, C. 1992. The invasive biology of the mussel *Mytilus galloprovincialis* on the southern African coast. Transactions of the Royal Society of South Africa 48: 123–139.

Kulhanek, S.A., Ricciardi, A. & Leung, B. 2011. Is invasion history a useful tool for predicting the impacts of the world's worst aquatic invasive species? Ecological Applications 21: 189–202.

Leung, B., Lodge, D.M., Finnoff, D., Shogren, J.F., Lewis, M.A. & Lamberti, G. 2002. An ounce of prevention or a pound of cure: bioeconomic risk analysis of invasive species. Proceedings of the Royal Society of London B 269: 2407-2413.

MarLIN (Marine Life Information Network), 2009. *Marine Life Information Network*. Plymouth: Marine Biological Association of the United Kingdom. [cited 13/09/12]. Available from: www.marlin.ac.uk

McKinnon, LJ., Parry G.D., Leporati, S.C., Heisler, S.,Werner, G.F., Gason, A.S.H., Fabris, G. & O'Mahony, N. 2003. The environmental effects of the blue mussel (*Mytilus edulis*) aquaculture in Port Phillip Bay. Fisheries Victoria, Research Report Series No.1, Department of Primary Industires, Queenscliff, Victoria, Australia.

McQuaid, C.D. & Phillips, T.E., 2000. Limited wind-driven dispersal of intertidal mussel larvae: in situ evidence from the plankton and the spread of the invasive species *Mytilus galloprovincialis* in South Africa. Marine Ecology Progress Series 201: 211–220.

Mead, A., Carlton, J. T., Griffiths, C. L. & Rius, M., 2011. Introduced and cryptogenic marine and estuarine species in South Africa. Journal of Natural History 45: 2463-2524.

Morton, B. 1996. The Aquatic Nuisance Species Problem: A Global Perspective and Review, University of Hong Kong.

Olivier, D., Heinecken, L., & Jackson, S. In press. Mussel and oyster and culture in Saldanha Bay, South Africa: potential for sustainable growth, development and employment creation. Journal of Food Security.

Pfaff, M.C., Branch, G.M., Wieters, E.A., Branch, R.A. & Broitman, B.R. 2011. Upwelling intensity and wave exposure determine recruitment of intertidal mussels and barnacles in the southern Benguela upwelling region. Marine Ecology Progress Series 425: 141-152

Picker, M.D. & Griffiths, C.L. 2011. Alien and Invasive Animals – A South African Perspective. Randomhouse/Struik Cape Town. 240pp.

Rius, M., Kaehler, S., & McQuaid, C.D. 2006. The relationship between human exploitation pressure and condition of mussel populations along the south coast of South Africa. South African Journal of Science 102: 130-136.

Robinson, T.A., Griffiths, C.L., McQuaid, C.D. & Rius, M. 2005. Marine alien species of South Africa – status and impacts. African Journal of Marine Science 27: 297–306.

Robinson, T.B., Govender, A., Griffiths, C.L. & Branch, G.M. 2007. Experimental harvesting of *Mytilus galloprovincialis*: Can an alien mussel support a small-scale fishery? Fisheries Research 88: 33–41.

Shumway, S.E., Davis, R., Downey, R., Karney, J., Kraeuter, J. Parsons, Rheault, R & Wikfors, G. 2003. Shellfish aquaculture – in praise of sustainable economies and environments. World Aquaculture 34: 8-10.

Sink, K., Holness, S., Harris, L., Majiedt, P., Atkinson, L., Robinson, T., Kirkman, S., Hutchings, L., Leslie, R., Lamberth, S., Kerwath, S., von der Heyden, S., Lombard, A., Attwood ,C., Branch, G., Fairweather, T., Taljaard, S., Weerts, S., Cowley, P., Awad, A., Halpern, B., Grantham, H. & Wolf, T. 2012. National Biodiversity Assessment 2011: Technical Report. Volume 4: Marine and Coastal Component. South African National Biodiversity Institute, Pretoria. Pp 325.

Sowman, M. 2006. Subsistence and small-scale fisheries in South Africa: A ten-year review. Marine Policy 30: 60–73.

Steffani, C.N. & Branch, G.M. 2003. Growth rate, condition, and shell shape of *Mytilus galloprovincialis*: responses to wave exposure. Marine Ecology Progress Series 246: 197–209.

Stenton-Dozey, J.M.E., Jackson, L.F. & Busby, A.J. 1999. Impact of Mussel Culture on Macrobenthic Community Structure in Saldanha Bay, South Africa. Marine Pollution Bulletin 39: 357-366.

Van Erkom Schurink, C. & Griffiths, C.L. 1991. A comparison of reproductive cycles and reproductive output in four southern African mussel species. Marine Ecology Progress Series 76: 123–134.

Van Erkom Schurink, C. & Griffiths, C. L. 1992. Physiological energetics of four South African mussel species in relation to size, ration and temperature. Comparative Biochemistry and Physiology 101: 779–789.