Bering Sea Marine Invasive Species Assessment

Alaska Center for Conservation Science

Scientific Name: *Mytilus galloprovincialis*

Common Name *Mediterranean mussel*

Phylum	Mollusca
Class	Bivalvia
Order	Mytiloida
Family	Mytilidae

Final Rank 67.75

Data Deficiency: 0.00

Species Occurrence by Ecoregion

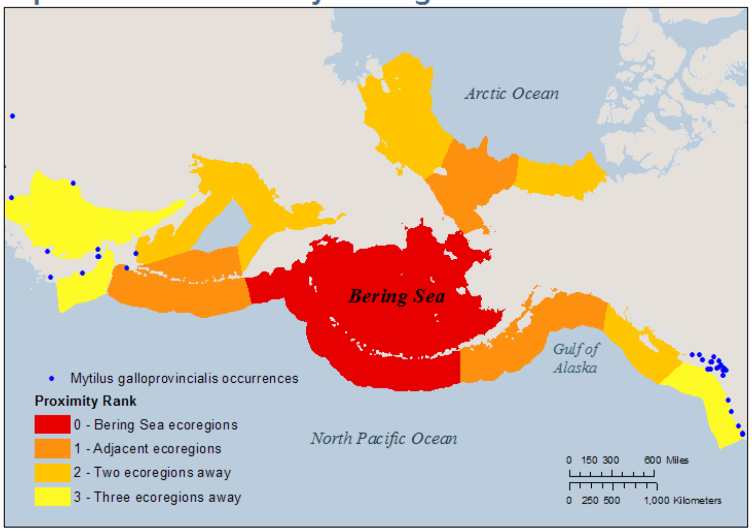

Figure 1. Occurrence records for non-native species, and their geographic proximity to the Bering Sea. Ecoregions are based on the classification system by Spalding et al. (2007). Occurrence record data source(s): NEMESIS and NAS databases.

Category Scores and Data Deficiencies

Category	Score	Total Possible	Data Deficient Points
Distribution and Habitat:	21.25	30	0
Anthropogenic Influence:	10	10	0
Biological Characteristics:	23.75	30	0
Impacts:	12.75	30	0
Totals:	67.75	100.00	0.00

General Biological Information

Tolerances and Thresholds

Minimum Temperature (°C)	7	Minimum Salinity (ppt)	10
Maximum Temperature (°C)	31	Maximum Salinity (ppt)	38
Minimum Reproductive Temperature (°C)	15	Minimum Reproductive Salinity (ppt)	20
Maximum Reproductive Temperature (°C)	25	Maximum Reproductive Salinity (ppt)	38

Additional Notes

Mytilus galloprovincialis (the Mediterranean Mussel) is native to the Mediterranean Sea and has been intentionally and accidentally introduced worldwide. It is an important aquaculture species due to its high growth rate and reproductive output.

Reviewed by Nora R. Foster, NRF Taxonomic Services, Fairbanks AK

Review Date: 9/27/2017

1. Distribution and Habitat

1.1 Survival requirements - Water temperature

Choice: D No overlap – Temperatures required for survival do not exist in the Bering Sea

Score: 0 of 3.75

Ranking Rationale:
Year-round temperature requirements do not exist in the Bering Sea.

Background Information:
M. galloprovincialis is a cold-temperate to warm-temperate species. It can tolerate temperatures up to 31°C for short periods of time (< 1 month), but exhibits stress responses above 24°C (Anestis et al. 2007; Schneider 2008). A minimum threshold of ~7°C has been suggested based on experiments and geographic distribution (DAFF 2016).

Sources:
NEMESIS; Fofonoff et al. 2003 Schneider 2008 DAFF 2016 Anestis et al. 2007

1.2 Survival requirements - Water salinity

Choice: A Considerable overlap – A large area (>75%) of the Bering Sea has salinities suitable for year-round survival

Score: 3.75 of 3.75

Ranking Rationale:
Salinities required for year-round survival occur over a large (>75%) area of the Bering Sea.

Background Information:
The salinity range for survival is 10 ppt to 38 ppt (Shurova 2001; Fofonoff et al. 2003).

Sources:
NEMESIS; Fofonoff et al. 2003 Shurova 2001

1.3 Establishment requirements - Water temperature

Choice: D No overlap – Temperatures required for reproduction do not exist in the Bering Sea

Score: 0 of 3.75

Ranking Rationale:
Temperatures required for reproduction do not exist in the Bering Sea.

Background Information:
The reproductive temperature range for M. galloprovincialis is 15°C to 26°C (His et al. 1989).

Sources:
NEMESIS; Fofonoff et al. 2003 His et al. 1989

1.4 Establishment requirements - Water salinity

Choice: A Considerable overlap – A large area (>75%) of the Bering Sea has salinities suitable for reproduction

Score: 3.75 of 3.75

Ranking Rationale:
Salinities required for reproduction occur over a large (>75%) area of the Bering Sea.

Background Information:
The salinity profile for reproduction of M. galloprovinicialis is 20 PSU to 38 PSU (His et al. 1989).

Sources:
NEMESIS; Fofonoff et al. 2003 His et al. 1989

1.5 Local ecoregional distribution

Choice: B Present in an ecoregion adjacent to the Bering Sea

Score: 3.75 of 5

Ranking Rationale:
Found in the Sea of Okhotsk.

Background Information:
Found in the Sea of Okhotsk, Japan, Hong Kong, and Korea. In North America, it occurs in California, Washington, Oregon, and British Columbia.

Sources:
Branch and Steffani 2004

1.6 Global ecoregional distribution

Choice: A In many ecoregions globally

Score: 5 of 5

Ranking Rationale:
Found in ecoregions worldwide, but restricted to temperate regions.

Background Information:
Its native range is the Mediterranean Sea, mainly on the northern shore. Introduced populations occur from Morocco to the U.K. (McDonald et al. 1991 as qtd. in Fofonoff et al. 2003; Hilbish et al. 2000; Smietanka et al. 2004), South Africa, New Zealand, Japan, Hong Kong, northeastern Russia, southwest South America, and the West Coast of North America (Fofonoff et al. 2003). M. galloprovinicialis is cryptogenic in southern South America, Australia, and New Zealand (Fofonoff et al. 2003).

Sources:
Hilbish et al. 2000   NEMESIS; Fofonoff et al. 2003   Smietanka et al. 2004

1.7 Current distribution trends

Choice: A Recent rapid range expansion and/or long-distance dispersal (within the last ten years)

Score: 5 of 5

Ranking Rationale:
Rapid colonization and long-distance dispersal have been documented.

Background Information:
Rapid colonization and long-distance dispersal have been documented (Branch and Steffani 2004). All introductions so far have been in temperate regions and at localities where there are large shipping ports (Branch and Steffani 2004).

Sources:
Branch and Steffani 2004

Section Total - Scored Points:	21.25
Section Total - Possible Points:	30
Section Total -Data Deficient Points:	0

2. Anthropogenic Transportation and Establishment

2.1 Transport requirements: relies on use of shipping lanes (hull fouling, ballast water), fisheries, recreation, mariculture, etc. for transport

Choice: A — Has been observed using anthropogenic vectors for transport and transports independent of any anthropogenic vector once introduced

Score: 4 of 4

Ranking Rationale:
Transported by numerous anthropogenic vectors and capable of transporting during the larval stage on their own.

Background Information:
Can be introduced via ship hull fouling and transport of ballast water (Geller et al., 1994 as qtd. in Branch and Steffani 2004). In Japan and in China, where it is widely cultivated, it has spread as a result of larval dispersal from mussel farms.

Sources:
Branch and Steffani 2004   GISD 2016b   NEMESIS; Fofonoff et al. 2003

2.2 Establishment requirements: relies on marine infrastructure, (e.g. harbors, ports) to establish

Choice: A — Readily establishes in areas with anthropogenic disturbance/infrastructure and in natural, undisturbed areas

Score: 4 of 4

Ranking Rationale:
Can establish in anthropogenic areas (e.g. in cultivation) and in undisturbed areas.

Background Information:
Larvae can escape from farms and establish wild populations. Areas of introduction are associated with large shipping ports, but once introduced, readily expands its range (Branch and Steffani 2004).

Sources:
Branch and Steffani 2004   GISD 2016b

2.3 Is this species currently or potentially farmed or otherwise intentionally cultivated?

Choice: A — Yes

Score: 2 of 2

Ranking Rationale:

Background Information:
Widely cultivated in China, Japan, South Africa, Australia, and from California to British Columbia.

Sources:
GISD 2016b   NEMESIS; Fofonoff et al. 2003

Section Total - Scored Points:	10
Section Total - Possible Points:	10
Section Total -Data Deficient Points:	0

3. Biological Characteristics

3.1 Dietary specialization

Choice: A Generalist at all life stages and/or foods are readily available in the study area

Score: 5 of 5

Ranking Rationale:
Consumes numerous taxa, many of which exist in the Bering Sea.

Background Information:
Filter feeder, feeds on a wide range of planktonic organisms. Shown to be a generalist and adaptive feeder over a wide range of plankton concentrations and water flow velocities (Denis et al. 1999).

Sources:
Denis et al. 1999   GISD 2016b

3.2 Habitat specialization and water tolerances

Does the species use a variety of habitats or tolerate a wide range of temperatures, salinity regimes, dissolved oxygen levels, calcium concentrations, hydrodynamics, pollution, etc?

Choice: B Requires specialized habitat for some life stages (e.g., reproduction)

Score: 3.25 of 5

Ranking Rationale:
Current distribution mostly restricted to temperate regions. Habitat and food is likely available in the Bering Sea, but reproduction and growth cycles require water temperatures not readily found in the Bering Sea.

Background Information:
Low tolerance to siltation and low salinity (below 18PSU). Prefers semi-exposed or exposed habitats with a high rate of water flow; in South Africa, rarely became established at sheltered sites in spite of rapid colonization and spread (Branch and Steffani 2004). In South Africa, known to exist where temperatures can drop to a minimum of approximately 7°C during peak upwelling season. However, optimal water temperature for larval growth occurred at 20°C (His et al. 1988). Low tolerance for warm waters limits its expansion into subtropical areas, where water temperatures are between 22-27°C (Assis et al. 2015). An ecotoxicology study conducted in a heavily industrial area found that M. galloprovincialis showed signs of stress in response to anthropogenic pollution (Cappello et al. 2013).

Sources:
Assis et al. 2015   Branch and Steffani 2004   Cappello et al. 2013   GISD 2016b   His et al. 1989   NEMESIS; Fofonoff et al. 2003

3.3 Desiccation tolerance

Choice: A Highly tolerant (>7 days) of desiccation at one or more stages during its life cycle

Score: 5 of 5

Ranking Rationale:
High dessication tolerance.

Background Information:
Very high desiccation tolerance. Individuals that were continuously exposed to air for up to 7 days exhibited 92% survivorship (Branch and Steffani 2004).

Sources:
Branch and Steffani 2004   GISD 2016b

3.4 Likelihood of success for reproductive strategy

i. Asexual or hermaphroditic ii. High fecundity (e.g. >10,000 eggs/kg) iii. Low parental investment and/or external fertilization iv. Short generation time

Choice: A High – Exhibits three or four of the above characteristics

Score: 5 of 5

Ranking Rationale:
Sexual reproduction, high fecundity, external fertilization, short generation time.

Background Information:
Sexual reproduction with external fertilization. High fecundity, with millions of gametes released during spawning events (DAFF 2016). Long spawning season. In some regions, can spawn year-round (Seed 1969). Individuals reach maturity within one year.

Sources:
Branch and Steffani 2004 DAFF 2016 GISD 2016b NEMESIS; Fofonoff et al. 2003 Seed 1969

3.5 Likelihood of long-distance dispersal or movements

Consider dispersal by more than one method and/or numerous opportunities for long or short distance dispersal e.g. broadcast, float, swim, carried in currents; vs. sessile or sink.

Choice: A Disperses long (>10 km) distances

Score: 2.5 of 2.5

Ranking Rationale:
M. galloprovincialis disperses an average of 35 km.

Background Information:
Larvae can disperse passively via surface currents generated by wind (Branch and Steffani 2004). On the coast of San Diego County, larvae dispersed an average of 35 km, though a large proportion settled more locally. A few (1.5%) dispersed for more than 125 km. There was extensive genetic exchange between bays and between open-coast and bay populations (Lopez-Duarte et al. 2012). In South Africa, M. galloprovincialis had spread along 223km of coastline within three years of its introduction (Branch and Steffani 2004).

Sources:
Branch and Steffani 2004 Lopez-Duarte et al. 2012 NEMESIS; Fofonoff et al. 2003

3.6 Likelihood of dispersal or movement events during multiple life stages

i. Can disperse at more than one life stage and/or highly mobile ii. Larval viability window is long (days v. hours) iii. Different modes of dispersal are achieved at different life stages (e.g. unintentional spread of eggs, migration of adults)

Choice: B Moderate – Exhibits one of the above characteristics

Score: 1.75 of 2.5

Ranking Rationale:
M. galloprovincialis has a relatively long planktonic larval stage and limited dispersal ability as an adult.

Background Information:
Adults are mostly sessile (though they do have a muscular foot which allows them to crawl if microhabitat is unfavourable; Cáceres-Martínez et al. 1994). Adults can potentially be transported overland if attached to fishing or shipping gear. Larvae are suspended in the water column and can disperse via wind-generated water currents (Branch and Steffani 2004). For three Mytilus spp. in western North America: Temporal variability in recruitment rates, dependent on peak reproduction period: in Oregon, this peak occurred in late summer-early fall, but switched to wintertime in northern and central California (Broitman et al. 2008).

Sources:
Branch and Steffani 2004 Broitman et al. 2008 Caceres-Martinez et al. 1994

3.7 Vulnerability to predators

Choice: **D**

Multiple predators present in the Bering Sea or neighboring regions

Score: 1.25 **of** 5

Ranking Rationale:

Numerous predators, many of which exist in the Bering Sea.

Background Information:

In South Africa, where it was introduced, whelk and oystercatchers were important predators that readily exploited M. galloprovincialis as a food resource (Branch and Steffani 2004). In California, common intertidal predators include seastars, crabs, and dog whelk (Shinen 2007).

Sources:

Branch and Steffani 2004 Shinen 2007

Section Total - Scored Points:	23.75
Section Total - Possible Points:	30
Section Total -Data Deficient Points:	0

4. Ecological and Socioeconomic Impacts

4.1 Impact on community composition

Choice: A High – Entire community and/or may cause extirpation or extinction at the species or trophic level

Score: 2.5 of 2.5

Ranking Rationale:
Competes with similar species for food and space.

Background Information:
In California and in Japan, has replaced the closely related native mussel M. trossulus and Septifer virgatus (Geller 1999). In South Africa, competes with 3 native mussel species, but only competition with A. atar is considered to be of serious concern (DAFF 2016). Invasion by M. galloprovincialis led to an 80% reduction in A. atar at monitored sites near Saldanha Bay (Branch and Steffani 2004). Replacement of M. trossulus by M. galloprovincialis may not have severe impacts, as the two species support similar levels of species richness and diversity, indicating functional redundancy (Shinen 2007).

In Japan, outcompetes many other native species, including the Pacific oyster, a small barnacle, and an edible seaweed species (Chavanich et al. 2010). Competes for space with shore species including limpets, anemones, and seaweeds (Fofonoff et al. 2003; Branch and Steffani 2004).

In Langebaan Lagoon, South Africa, mussel beds of M. galloprovincialis replaces naturally-occurring sandbank communities with communities more typical of rocky shores (Robinson and Griffiths 2002).

Provides habitat to species small enough to live and reproduce on mussels and mussel beds. Provides an additional source of food for predators (Branch and Steffani 2004).

Sources:
Branch and Steffani 2004   Chavanich et al. 2010   DAFF 2016   Shinen 2007   Geller 1999   NEMESIS; Fofonoff et al. 2003   Robinson and Griffiths 2002

4.2 Impact on habitat for other species

Choice: B Moderate – Causes or has potential to cause changes to one or more habitats

Score: 1.75 of 2.5

Ranking Rationale:

Background Information:
By creating mussel beds, provides habitat for infaunal species, increasing overall infaunal biomass and abundance (Branch and Steffani 2004).

Sources:
Branch and Steffani 2004

4.3 Impact on ecosystem function and processes

Choice: **C**

Limited – Causes or potentially causes changes to food webs and/or ecosystem functions, with limited impact and/or within a very limited region

Score: **0.75** **of** **2.5**

Ranking Rationale:

M. galloprovinicialis usually replaces very similar native organisms in function. Effects on ecosystems is likely to be most pronounced in areas with no native mussel species.

Background Information:

Impacts seem most pronounced in ecosystems where no native mussel species were present. For example, in central and southern Japan, invasion of M. galloprovincialis resulted in the mass deposition of pseudofeces in the sediment, creating hypoxic conditions (Chavanich et al. 2010). A study of mussel farms in the Iberian Peninsula showed that production of biodeposits increased natural sedimentation rates in the area, but this effect was partially counteracted by swift water currents (Zúñiga et al. 2014). Mussel biodeposits are high in nutrients and an important part of nutrient cycling in marine environments. Indeed, a study by Jansen et al. (2012) found that 1/3 of organic nutrients in biodeposits can be mineralized and thereby become available for primary producers. Through filter feeding, improves water quality.

Sources:

Jansen et al. 2012   NEMESIS; Fofonoff et al. 2003   Zuniga et al. 2014

4.4 Impact on high-value, rare, or sensitive species and/or communities

Choice: **D**

No impact

Score: **0** **of** **2.5**

Ranking Rationale:

To date, no impacts on high-value, rare, or sensitive species have been reported for M. galloprovincialis.

Background Information:

No information found.

Sources:

None listed

4.5 Introduction of diseases, parasites, or travelers

What level of impact could the species' associated diseases, parasites, or travelers have on other species in the assessment area? Is it a host and/or vector for recognized pests or pathogens, particularly other nonnative organisms?)

Choice: **C**

Limited – Has limited potential to spread one or more organisms, with limited impact and/or within a very limited region

Score: **0.75** **of** **2.5**

High uncertainty? ☑

Ranking Rationale:

Has been shown to host parasites in other locations. Unsure as to whether these parasites would survive or propagate in the Bering Sea.

Background Information:

Experimentally cultured mussels were found to host the parasites Marteilia refringens and the trematode Proctoeces maculatus (Villalba et al. 1997). M. refringens can also infect the blue mussel M. edulis. While mussels are usually not adversely affected by this parasite, in France mortalities up to 100% were associated with heavy infection rates.

Sources:

Villalba et al. 1997   Culloty et al. 1999

4.6 Level of genetic impact on native species

Can this invasive species hybridize with native species?

Choice: **B**

Moderate – Causes or has potential to cause genetic changes in one or more species, with moderate impact and/or within only a portion of the region

Score: 1.75 **of** 2.5

Ranking Rationale:

Has been known to hybridize with numerous Mytilus species.

Background Information:

In Britain and Ireland, hybridizes with M. edilus. In western North America and in the northwest Pacific, hybridizes with M. trossulus, sometimes at very high frequencies (up to 70%). Although rates of F1 (first-generation hybrids) are often high, frequency of F2 hybrids is small, indicating that little genetic exchange is occurring between the two species (Rawson et al. 1999; Brannock and Hilbish 2010). This result could indicate poor survival or reduced fertility of hybrids, due to genetic incompatibility (Rawson et al. 1999). However, introgression between M. galloprovincialis and M. trossulus has been quite limited, and effects of hybridization with M. trossulus and M. edilus do not seem to go beyond the hybrid zone (Rawson et al. 1999; Hilbish et al. 2002). Hybridization has also been observed between native Southern Hemisphere M. galloprovincialis and introduced Northeast Atlantic lineages at several locations near ports in New Zealand. This introgression is considered a threat to the genetic biodiversity of native mussel populations, particularly on remote southern ocean islands, which harbors unique genetic lineages (Gardner et al. 2016).
In South Africa, hybridization with indigenous species is deemed unlikely (DAFF 2016).

Sources:

Branch and Steffani 2004   Brannock and Hilbish 2010   DAFF 2016   Gardner et al. 2016   Hilbish et al. 2002

4.7 Infrastructure

Choice: **A**

High – Is known to cause degradation to infrastructure and/or is expected to have severe impacts and/or will impact the entire region

Score: 3 **of** 3

Ranking Rationale:

Fouling organism found on ships, docks, jetties, pipes, and industrial water systems.

Background Information:

Mytilus spp. are abundant and common fouling organisms on ships, docks, jetties, pipes, and industrial water systems (Woods Hole 1952). M. galloprovincialis has been found in Japanese power plants causing major expenses due to damage and cleaning (Iwasaki 2006). Its impacts on infrastructure may be difficult to recognize in areas where it has replaced M. trossulus.

Sources:

Woods Hole 1952   Iwasaki 2006   NEMESIS; Fofonoff et al. 2003

4.8 Commercial fisheries and aquaculture

Choice: C — Limited – Has limited potential to cause degradation to fisheries and aquaculture, and/or is restricted to a limited region

Score: 0.75 of 3

Ranking Rationale:
Can cause a decrease in the abundance of other aquaculture species.

Background Information:
Interferes with aquaculture of other species, such as oysters (Chavanich et al. 2010). In Japan, growth of M. galloprovincialis led to a 35% reduction of oyster aquaculture (worth about 500 million Japanese yen). At the same time, cultivation of M. galloprovincialis is extensive in Japan. No negative impacts on commercial fisheries have been reported in South Africa (DAFF 2016). Introduction is usually positive from an economic perspective, because of its higher growth rates compared to native mussels (Fofonoff et al. 2003; DAFF 2016).

Sources:
Chavanich et al. 2010 DAFF 2016 NEMESIS; Fofonoff et al. 2003

4.9 Subsistence

Choice: C — Limited – Has limited potential to cause degradation to subsistence resources, with limited impact and/or within a very limited region

Score: 0.75 of 3

Ranking Rationale:
Linked to declines of bait species.

Background Information:
In South Africa, M. galloprovincialis has had a negative impact on the limpet S. granularis, a bait species employed by traditional artisanal fishers (DAFF 2016). Higher growth rates of M. galloprovincialis relative to the local mussel species, has almost certainly contributed significantly to the success of the local mussel culture operations.

Sources:
DAFF 2016

4.101 Recreation

Choice: D — No impact

Score: 0 of 3

Ranking Rationale:
To date, no impacts on recreation have been reported.

Background Information:
No information available in the literature.

Sources:
None listed

4.11 Human health and water quality

Choice: **C**	Limited – Has limited potential to pose a threat to human health, with limited impact and/or within a very limited region	**Score:** **0.75** **of** **3**

Ranking Rationale:

Cases of PSP and other shellfish syndromes are rare in Alaska. Current regulations and safety procedures greatly reduce the risk of bacterial transmission, especially in cultivated mussels. Recreational harvesting of shellfish in the Bering Sea is limited.

Background Information:

All bivalves can bioaccumulate toxins in their tissues as a result of consuming toxic dinoflagellates. Consuming raw or cooked bivalves can lead to Paralytic Shellfish Poisoning (PSP), which can cause health issues and even death (NIMPIS 2009). The state of Alaska discourages harvesting on untested beaches (ADEC 2013).

Sources:

NIMPIS 2009 ADEC 2013

Section Total - Scored Points:	12.75
Section Total - Possible Points:	30
Section Total -Data Deficient Points:	0

5. Feasibility of prevention, detection and control

5.1 *History of management, containment, and eradication*

Choice: **C** Attempted; control methods are currently in development/being studied

Score: of

Ranking Rationale:
Controlling the spread of invasive species that use anthropogenic vectors for transport is an active area of research (e.g. Ruiz and Reid 2007, Hagan et al. 2014).

Background Information:
Mussels populations are hard to control for due to their large distributions, high fecundity and easily dispersed larvae (Picker and Griffiths 2011 as qtd. in DAFF 2016). Difficulty differentiating between M. galloprovinicialis and native Mytilus species may complicate control efforts. There is also the potential of further introductions through pathways such as ballast water. In areas where M. galloprovincialis is farmed, the use of sterile triploid and tetraploid mussels, which have been recently developed by the aquaculture industry, helps prevent the spread of larvae into the wild.

Sources:
DAFF 2016   Ruiz and Reid 2007   Hagan et al. 2014

5.2 *Cost and methods of management, containment, and eradication*

Choice: **A** Major long-term investment, or is not feasible at this time

Score: of

Ranking Rationale:
Methods to control the spread of marine invasive species (e.g. through ballast water treatment or vessel cleaning) are being studied, and currently necessitate major long-term investments (Zagdan 2010; Hagan et al. 2014).

Background Information:
Treatment of ballast water and anti-fouling methods would help prevent spread.

Sources:
GISD 2016b   Zagdan 2010   Hagan et al. 2014

5.3 *Regulatory barriers to prevent introductions and transport*

Choice: **B** Regulatory oversight, but compliance is voluntary

Score: of

Ranking Rationale:
This species can be transported by several anthropogenic vectors. Currently, compliance with hull fouling regulations are largely voluntary.

Background Information:
Regulations exist regarding the transport and introduction of shellfish in water bodies. Under Alaska law, a permit must be obtained from the Alaska Department of Fish and Game (ADF&G) in order to collect, possess, or transport shellfish for educational, scientific, or propagative uses. Ballast water management is mandatory and regulated by the U.S. Coast Guard (CFR 33 § 151.2). However, compliance with ship fouling regulations are largely voluntary (Hagan et al. 2014).

Sources:
Hagan et al. 2014   CFR 2017

5.4 Presence and frequency of monitoring programs

Choice: **A** No surveillance takes place

Score: of

Ranking Rationale:

Background Information:
No informations available in the literature.

Sources:
None listed

5.5 Current efforts for outreach and education

Choice: **A** No education or outreach takes place

Score: of

Ranking Rationale:

Background Information:
No education or outreach material found. Not on the list of 50 priority species by the Washington Invasive Species Council. Not listed on the Oregon Department of Fish and Wildlife website or on the Invasive Species Council of British Columbia website. This species often co-occurs with native mussels and is hard to differentiate from other Mytilus species.

Sources:
NEMESIS; Fofonoff et al. 2003

Section Total - Scored Points:

Section Total - Possible Points:

Section Total -Data Deficient Points:

Literature Cited for *Mytilus galloprovincialis*

- NIMPIS. 2009. National Introduced Marine Pest Information System. Available from: http://www.marinepests.gov.au/nimpis
- ADEC. 2013. Paralytic Shellfish Poisoning Fact Sheet. Alaska Department of Environmental Conservation. Available from: http://dec.alaska.gov/eh/fss/Food/Docs/fact_PST_6-4-2013_final%20(2).pdf. Accessed 02-Jan-2017.
- 33 CFR § 151.2050 Additional requirements - nonindigenous species reduction practices
- Hagan, P., Price, E., and D. King. 2014. Status of vessel biofouling regulations and compliance technologies – 2014. Maritime Environmental Resource Center (MERC) Economic Discussion Paper 14-HF-01.
- Iwasaki, K. 2006. Human-mediated introduction of marine organisms in Japan: A review. Pages 104-112 in Koike, F., Clout, M. N., Kawamichi, M., De Poorter, M., and K. Iwatsuki, editors. Assessment and control of biological invasion risks. Shoukadoh Book Se
- Fofonoff, P. W., G. M. Ruiz, B. Steves, C. Simkanin, and J. T. Carlton. 2017. National Exotic Marine and Estuarine Species Information System. http://invasions.si.edu/nemesis/. Accessed: 15-Sep-2017.
- Ruiz, G. M., and D. F. Reid. 2007. Current State of Understanding about the Effectiveness of Ballast Water Exchange (BWE) in Reducing Aquatic Nonindigenous Species (ANS) Introductions to the Great Lakes Basin and Chesapeake Bay, USA: Synthesis and Analysi
- Zagdan, T. 2010. Ballast water treatment market remains buoyant. Water and Wastewater International 25:14-16.
- His, E., Robert, R., and A. Dinet. 1989. Combined effects of temperature and salinity on fed and starved larvae of the mediterranean mussel Mytilus galloprovincialis and the Japanese oyster Crassostrea gigas. Marine Biology 100(4):455-463.
- Schneider, K. R. 2008. Heat stress in the intertidal: Comparing survival and growth of an invasive and native mussel under a variety of thermal conditions. Biological Bulletin 215(3):253-264.
- Shurova, N. M. 2001. Influence of salinity on the structure and the state of bivalve Mytilus galloprovincialis populations. Russian Journal of Marine Biology 27(3):151-155.
- Branch, G. M., and C. N. Steffani. 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.
- Hilbish, T. J., Mullinax, A., Dolven, S. I., Meyer, A., Koehn, R. K. and P. D. Rawson. 2000. Origin of the antitropical distribution pattern in marine mussels (Mytilus spp.): Routes and timing of transequatorial migration. Marine Biology 136:69-77.
- Smietanka, B., Zbawicka, M., Wolowicz, M., and R. Wenne. 2004. Mitochondrial DNA lineages in the European populations of mussels (Mytilus spp.). Marine Biology 146:79-92.
- Global Invasive Species Database. 2016. Species profile: Mytilus galloprovincialis. IUCN/SSC Invasive Species Specialist Group. Available from: http://www.iucngisd.org/gisd/species.php?sc=102 Accessed 20-Oct-2017.
- Denis, L., Alliot, E., and D. Grzebyk. 1999. Clearance rate responses of Mediterranean mussels, Mytilus galloprovincialis to variations in the flow, water temperature, food quality and quantity. Aquatic Living Resources 12(4): 279-288.
- Assis, J., Zupan, M., Nicastro, K. R., Zardi, G. I., McQuaid, D., and E. A. Serrão. 2015. Oceanographic conditions limit the spread of a marine invader along southern African shores. PLoS ONE 10(6): e0128124. doi:10.1371/journal.pone.0128124.

- Cappello, T., Maisano, M., D'Agata, A., Natalotto, A., Mauceri, A., and S. Fasulo. 2013. Effects of environmental pollution in caged mussels (Mytilus galloprovincialis). Marine Environmental Research 91: 52-60.

- DAFF. 2016. Mediterranean mussel Mytilus galloprovincialis Fact Sheet. Deparment of Agriculture, Forestry and Fisheries, Pretoria, South Africa. Available from: http://www.nda.agric.za/doaDev/sideMenu/fisheries/03_areasofwork/Aquaculture/BIODIVERSITY/M.%2

- Seed, R. 1969. The ecology of Mytilus edulis L. (Lamellibranchiata) on exposed rocky shores. Oecologia 3(3-4):277-316. doi.org/10.1007/BF00390380

- Lopez-Duarte, P. C., Carson, H. S., Cook, G. S., Fodrie, F. J., Becker, B. J., DiBacco, C., and L. A. Levin. 2012. What controls connectivity? An empirical, multi-species approach. Integrative and Comparative Biology 52(4):511-524.

- Broitman, B. R., Blanchette, C. A., Menge, B. A., Lubchenco, J., Krenz, C., Foley, M., et al. 2008. Spatial and temporal patterns of invertebrate recruitment along the West Coast of the United States. Ecological Monographs 78(3): 403-421.

- Caceres-Martinez, J., Robledo, J. A. F., and A. Figueras. 1994. Settlement and post-larvae behaviour of Mytilus galloprovincialis: field and laboratory
 experiments. Marine Ecology Progress Series 112: 107-117.

- Shinen, J. L. 2007. Invasion ecology of Mytilus galloprovincialis: Competitor and predator effects regulating its establishment and its potential impact as an exotic foundation species. PhD Thesis, University of California, Davis, CA, U.S.A. 117 pp.

- Chavanich, S., Tan, L. T., Vallejo, B., and V. Viyakarn. 2010. Report on the current status of marine non-indigenous species in the Western Pacific region. Intergovernmental Oceanographic Commission Sub-Commission for the Western Pacific (IOC/WESTPAC), Ba

- Geller, J. B. 1999. Decline of a native mussel masked by sibling species invasion. Conservation Biology 13(3): 661-664.

- Robinson, T. B., and C. L. Griffiths. 2002. Invasion of Langebaan Lagoon, South Africa, by Mytilus galloprovincialis – effects on natural communities. African Zoology 37(2):151-158.

- Jansen, H. M., Verdegem, M. C. J., Strand, Ø., and A. C. Smaal. 2012. Seasonal variation in mineralization rates (C-N-P-Si) of mussel Mytilus edulis biodeposits. Marine Biology 159:1567-1580.

- Zuniga, D., Castro, C. G., Aguiar, E., Labarta, U., Figueiras, F. G., and M. J. Fernandez-Reiriz. 2014. Biodeposit contribution to natural sedimentation in a suspended Mytilus galloprovincialis Lmk mussel farm in a Galician Ría (NW Iberian Peninsula). Aqu

- Villalba, A., Mourelle, S. G., Carballal, M. J., and C. Lopez. 1997. Symbionts and diseases of farmed mussels Mytilus galloprovincialis throughout the culture process in the Rias of Galicia (NW Spain). Diseases of Aquatic Organisms 31:127-139.

- Culloty, S. C., Novoa, B., Pernas, M., Longshaw, M., Mulcahy, M. F., Feist, S. W., and A. Figueras. 1999. Susceptibility of a number of bivalve species to the protozoan parasite Bonamia ostreae and their ability to act as vectors for this parasite. Diseas

- Brannock, P. M., and T. J. Hilbish. 2010. Hybridization results in high levels of sterility and restricted introgression between invasive and endemic marine blue mussels. Marine Ecology Progress Series 406: 161-171.

- Gardner, J. P. A., Zbawicka, M., Westfall, K. M., and R. Wenne. 2016. Invasive blue mussels threaten regional scale genetic diversity in mainland and remote offshore locations: The need for baseline data and enhanced protection in the Southern Ocean. Glob

- Hilbish, T. J., Carson, E. W., Plante, J. R., Weaver, L. A., and M. R. Gilg. 2002. Distribution of Mytilus edulis, M. galloprovincialis, and their hybrids in open-coast populations of mussels in southwestern England. Marine Biology 140:137-142.

- Woods Hole Oceanographic Institution. 1952. Marine fouling and its prevention. Prepared for the Bureau of Ships, U.S. Navy Department. Contribution No. 580. George Banta Publishing, Menasha, WI, U.S.A. 388 pp.

- Anestis, A., Lazou, A., Portner, H .O, and B. Michaelidis. 2007. Behavioral, metabolic, and molecular stress responses of marine bivalve Mytilus galloprovincialis during long-term acclimation at increasing ambient temperature. American Journal of Physiolo