



Monterey Bay Aquarium Seafood Watch®

Farmed Mussels

Mytilus spp., *Perna* spp.

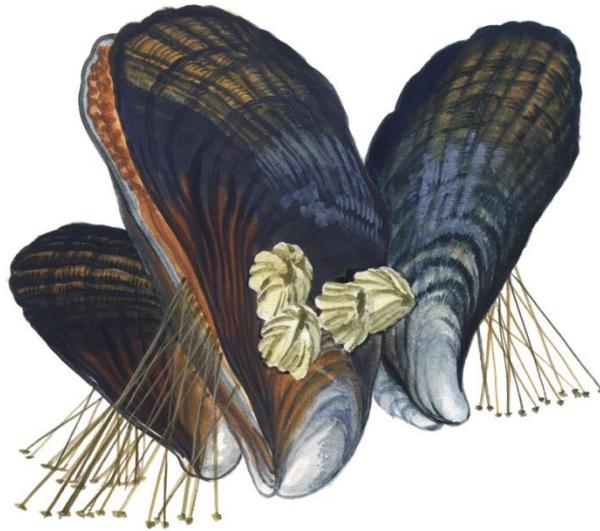


Image ©Monterey Bay Aquarium

Worldwide

On Bottom (Seafloor), Suspended Culture (Intertidal/Shallow and Deep Water)

October 2014

Kari Heinonen, Consulting Researcher

Disclaimer

Seafood Watch® strives to have all Seafood Reports reviewed for accuracy and completeness by external scientists with expertise in ecology, fisheries science and aquaculture. Scientific review, however, does not constitute an endorsement of the Seafood Watch® program or its recommendations on the part of the reviewing scientists. Seafood Watch® is solely responsible for the conclusions reached in this report.

About Seafood Watch®

Monterey Bay Aquarium's Seafood Watch® program evaluates the ecological sustainability of wild-caught and farmed seafood commonly found in the United States marketplace. Seafood Watch® defines sustainable seafood as originating from sources, whether wild-caught or farmed, which can maintain or increase production in the long-term without jeopardizing the structure or function of affected ecosystems. Seafood Watch® makes its science-based recommendations available to the public in the form of regional pocket guides that can be downloaded from www.seafoodwatch.org. The program's goals are to raise awareness of important ocean conservation issues and empower seafood consumers and businesses to make choices for healthy oceans.

Each sustainability recommendation on the regional pocket guides is supported by a Seafood Report. Each report synthesizes and analyzes the most current ecological, fisheries and ecosystem science on a species, then evaluates this information against the program's conservation ethic to arrive at a recommendation of "Best Choices," "Good Alternatives" or "Avoid." The detailed evaluation methodology is available upon request. In producing the Seafood Reports, Seafood Watch® seeks out research published in academic, peer-reviewed journals whenever possible. Other sources of information include government technical publications, fishery management plans and supporting documents, and other scientific reviews of ecological sustainability. Seafood Watch® Research Analysts also communicate regularly with ecologists, fisheries and aquaculture scientists, and members of industry and conservation organizations when evaluating fisheries and aquaculture practices. Capture fisheries and aquaculture practices are highly dynamic; as the scientific information on each species changes, Seafood Watch®'s sustainability recommendations and the underlying Seafood Reports will be updated to reflect these changes.

Parties interested in capture fisheries, aquaculture practices and the sustainability of ocean ecosystems are welcome to use Seafood Reports in any way they find useful. For more information about Seafood Watch® and Seafood Reports, please contact the Seafood Watch® program at Monterey Bay Aquarium by calling 1-877-229-9990.

Guiding Principles

Seafood Watch™ defines sustainable seafood as originating from sources, whether fished¹ or farmed, that can maintain or increase production in the long-term without jeopardizing the structure or function of affected ecosystems.

The following **guiding principles** illustrate the qualities that aquaculture must possess to be considered sustainable by the Seafood Watch program:

Seafood Watch will:

- Support data transparency and therefore aquaculture producers or industries that make information and data on production practices and their impacts available to relevant stakeholders.
- Promote aquaculture production that minimizes or avoids the discharge of wastes at the farm level in combination with an effective management or regulatory system to control the location, scale and cumulative impacts of the industry's waste discharges beyond the immediate vicinity of the farm.
- Promote aquaculture production at locations, scales and intensities that cumulatively maintain the functionality of ecologically valuable habitats without unreasonably penalizing historic habitat damage.
- Promote aquaculture production that by design, management or regulation avoids the use and discharge of chemicals toxic to aquatic life, and/or effectively controls the frequency, risk of environmental impact and risk to human health of their use.
- Within the typically limited data availability, use understandable quantitative and relative indicators to recognize the global impacts of feed production and the efficiency of conversion of feed ingredients to farmed seafood.
- Promote aquaculture operations that pose no substantial risk of deleterious effects to wild fish or shellfish populations through competition, habitat damage, genetic introgression, hybridization, spawning disruption, changes in trophic structure or other impacts associated with the escape of farmed fish or other unintentionally introduced species.
- Promote aquaculture operations that pose no substantial risk of deleterious effects to wild populations through the amplification and retransmission of pathogens or parasites.
- Promote the use of eggs, larvae, or juvenile fish produced in hatcheries using domesticated broodstocks thereby avoiding the need for wild capture.

¹ "Fish" is used throughout this document to refer to finfish, shellfish and other invertebrates.

- Recognize that energy use varies greatly among different production systems and can be a major impact category for some aquaculture operations, and also recognize that improving practices for some criteria may lead to more energy-intensive production systems (e.g. promoting more energy-intensive closed recirculation systems).

Once a score and rank has been assigned to each criterion, an overall seafood recommendation is developed on additional evaluation guidelines. Criteria ranks and the overall recommendation are color-coded to correspond to the categories on the Seafood Watch pocket guide:

Best Choices/Green: Are well managed and caught or farmed in environmentally friendly ways.

Good Alternatives/Yellow: Buy, but be aware there are concerns with how they're caught or farmed.

Avoid/Red: Take a pass on these. These items are overfished or caught or farmed in ways that harm other marine life or the environment.

Final Seafood Recommendation

Farmed Mussels

Mytilus spp., *Perna* spp.

Cultured worldwide via on bottom and suspended culture methods in intertidal and subtidal areas

Criterion	Score (0-10)	Rank	Critical?
C1 Data	8.75	GREEN	
C2 Effluent	10.00	GREEN	NO
C3 Habitat	8.13	GREEN	NO
C4 Chemicals	10.00	GREEN	NO
C5 Feed	10.00	GREEN	YES
C6 Escapes	4.00	YELLOW	NO
C7 Disease	8.00	GREEN	NO
C8 Source	9.00	GREEN	
9X Wildlife mortalities	-2.00	GREEN	NO
10X Introduced species escape	-1.00	GREEN	
Total	64.80		
Final score	8.11		

OVERALL RANKING

Final Score	8.11
Initial rank	GREEN
Red criteria	0
Interim rank	GREEN
Critical Criteria?	NO

FINAL RANK
GREEN

Scoring note – scores range from zero to ten where zero indicates very poor performance and ten indicates the aquaculture operations have no significant impact.

Global farmed mussel production has a final numerical score of 8.11. With no red criteria, the final recommendation is a green “Best Choice.”

Executive Summary

Mussels are cultured in many countries using a variety of methods. The most common cultured species are *Mytilus* spp. (blue mussels) and *Perna* spp., such as *P. canaliculus* (Greenshell).

There are few data shortages regarding mussel farming and relevant environmental impacts. Most of the data are of moderate to high quality, and reasonably up-to-date and complete, so as to enable the assessor to obtain a full understanding or reliable representation of mussel farm operations and impacts.

Farmed mussels are not provided external feed or nutrient fertilization and from this vantage point there is no effluent concern, but there can be a concern over changes in the sedimentary environment of mussel farms due to biodeposition and sediment trapping. These changes are limited to the farm site and are not considered to extend beyond the immediate vicinity of farms. Furthermore, mussel farming has been shown to increase water quality at the farm site through removal of excess nutrients and phytoplankton. Overall, re-eutrophication benefits may outweigh the minor risk of sedimentary changes.

Farmed mussel culture operations are located in intertidal and shallow subtidal environments, as well as in waters greater than or equal to 20 m deep. These habitats are considered to have moderate to high value; however, the impact of farmed mussel operations on habitat is considered to be minimal, with the main concerns stemming from biodeposition and mechanical harvest, such as dredging. The content of habitat regulations surrounding mussel culture or aquaculture generally takes into account environmental impacts and ecosystem function and services. Enforcement organizations are identifiable, permitting processes are based on zoning plans, and the process appears relatively transparent. The caveat to this is that it is not clear if all the regulations in all the locations are effective or well-enforced. Although there are some variations in the effectiveness of the management regimes, the fundamental nature of the production system means that mussel farming is unlikely to have substantial habitat impacts.

Recent mussel culture generally does not entail the application of chemicals (i.e., antibiotics, pesticides, herbicides, fertilizers) to control fouling and predators or to prevent disease. The amount of chemicals used in mussel culture (whether in an open system or hatchery) would be minute, if at all. Further, the water in which chemicals would be used generally is not released to the marine environment. Thus, there is no threat of chemical contamination to adjacent waters or organisms.

The risk of escape is directly related to the degree of connection to the natural ecosystem and whether the mussels are native to that ecosystem. Typical production systems for farmed mussels include on-bottom or suspended culture in open systems (e.g., intertidal and subtidal coastal areas) without effective best management practices for design, construction, and management of escapes; and there are no safeguards for larval escape due to unrestricted

broadcast spawning. While some mussels are cultured within their native ranges, others are cultured in areas where they were introduced by various means (i.e., shipping) more than 10 years ago and are now fully established. Data suggest that recipient ecosystems have been impacted by such introductions, due to competition for resources and habitat modification.

Few mass mortality events due to parasite and pathogen infection have been reported in farmed mussels. Despite the fact that mussel growout systems are open to the natural environment, increasing the possibility of pathogen exchange, the low or infrequent occurrence of mussel diseases, coupled with biosecurity measures that have been put in place at farm, government, and international levels reduce the risk of parasite and pathogen infection to a low level. This is further reinforced by the fact that production practices (especially those of natural settlement) do not increase the likelihood of pathogen amplification compared to natural populations.

The source of stock for farmed mussels comes from active collection (via dredging) and natural or passive settlement. Dredging is usually employed in areas of bottom growout and has the potential to impact wild mussels through dislodgement of individuals and the substrate they were once attached to, or through direct mortality. A passive collection of mussel spat is much more common and not expected to have any negative impacts on the wild stock. There are very few hatcheries that supply seed to mussel culture around the world, but hatchery methods have been employed in China since the 1970s and more recently in the Pacific Northwest of the United States. Mussels cultured in hatcheries are from the same environment as growout.

The use of passive, non-harmful barriers yields no evidence of direct or accidental mortality of predators or wildlife, while the use of visual, acoustic, or biological deterrents result in behavioral changes only. Some physical and chemical forms of fouling control may result in direct or accidental mortality of fouling organisms, but no population level effects would be expected from either method. Most off-bottom harvest techniques result in low levels of mortality of those organisms associated with mussels (mostly fouling organisms). Mortality can occur during the cleaning of ropes, poles, and stakes. In contrast, dredge harvest techniques result in mortality of wildlife beyond exceptional cases, but due to rapid recovery and some potential benefit to predators, there is no expectation of long term significant impact to the affected species' population size. Furthermore, suspension culture is more common than on-bottom culture, reducing the risk of impact.

The majority of mussel culture relies on the natural settlement of planktonic spat, but in some instances the movement of larger mussel seed from collection areas to farm locations has been associated with the introduction of non-native species. Since the movement of mussel seed is only conducted in a small proportion of global mussel production, the reliance on animal movements is considered low for the international or trans-waterbody movement of live animals. Both the source and destination of these movements have low biosecurity (i.e., the source collection bed and the destination farmed mussel beds are "open" to the collection or release of non-native species). The risk associated with such movements are considered low—

taking into account the minor trans-waterbody movement of mussel seed at the global level, but acknowledging the risk of introducing non-native species where it does occur.

Overall, farmed mussels available on the U.S. market get a high numerical score of 8.11 out of 10. The analysis of farmed mussels has no critical criteria, and the overall ranking is “green.” Therefore, the final recommendation is “Best Choice.”

Table of Contents

About Seafood Watch®	2
Guiding Principles	3
Final Seafood Recommendation.....	5
Executive Summary.....	1
Introduction	5
Scope of the analysis and ensuing recommendation.....	5
Analysis	12
Scoring guide.....	12
Criterion 1: Data quality and availability	12
Criterion 2: Effluents.....	14
Criterion 3: Habitat	16
Criterion 4: Evidence or Risk of Chemical Use.....	23
Criterion 5: Feed	26
Criterion 6: Escapes	27
Criterion 7: Disease; pathogen and parasite interactions.....	29
Criterion 8: Source of Stock – independence from wild fisheries	33
Criterion 9X: Wildlife and predator mortalities.....	35
Criterion 10X: Escape of unintentionally introduced species.....	38
Acknowledgements	39
References	40
Appendix 1: Data points and all scoring calculations	48

Introduction

Scope of the analysis and ensuing recommendation

Species: Farmed mussels available worldwide (*Mytilus* spp. and *Perna* spp.)

Geographic Coverage: Worldwide (major production countries are China, Spain, Canada, United States, Brazil, Ecuador, New Zealand, Norway)

Production Methods: Bottom and suspended culture in intertidal and subtidal plots

Species Overview

Production statistics

Aquaculture is the fastest growing sector of food production and provides half of the seafood products consumed worldwide (Shumway 2011). Mussel farming has become an increasingly important global aquaculture activity, accounting for the third greatest proportion of molluscan aquaculture production by quantity (Figure 1). Figure 2 depicts the overwhelming contribution of China and Spain to global mussel production. In the United States, the market is dominated by imported mussels (Figure 3).

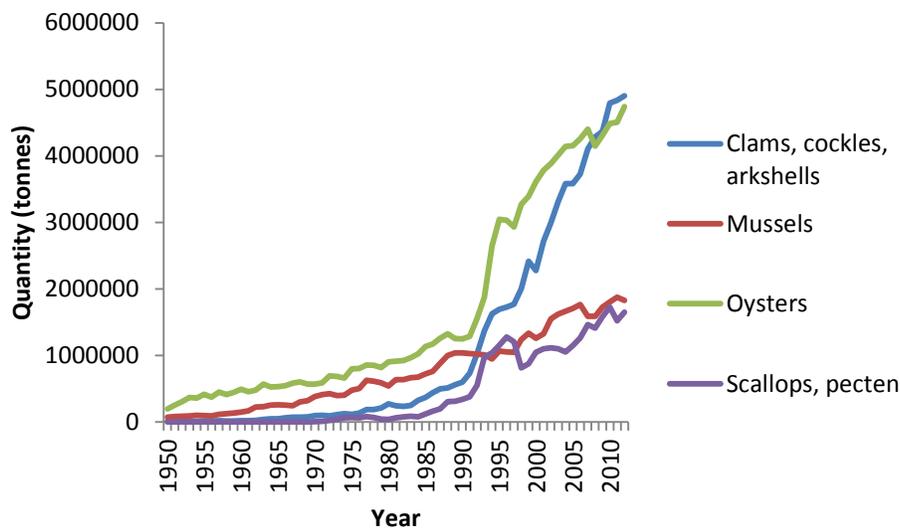


Figure 1. The quantity of global bivalve mollusc production in the marine environment (FAO 2014).

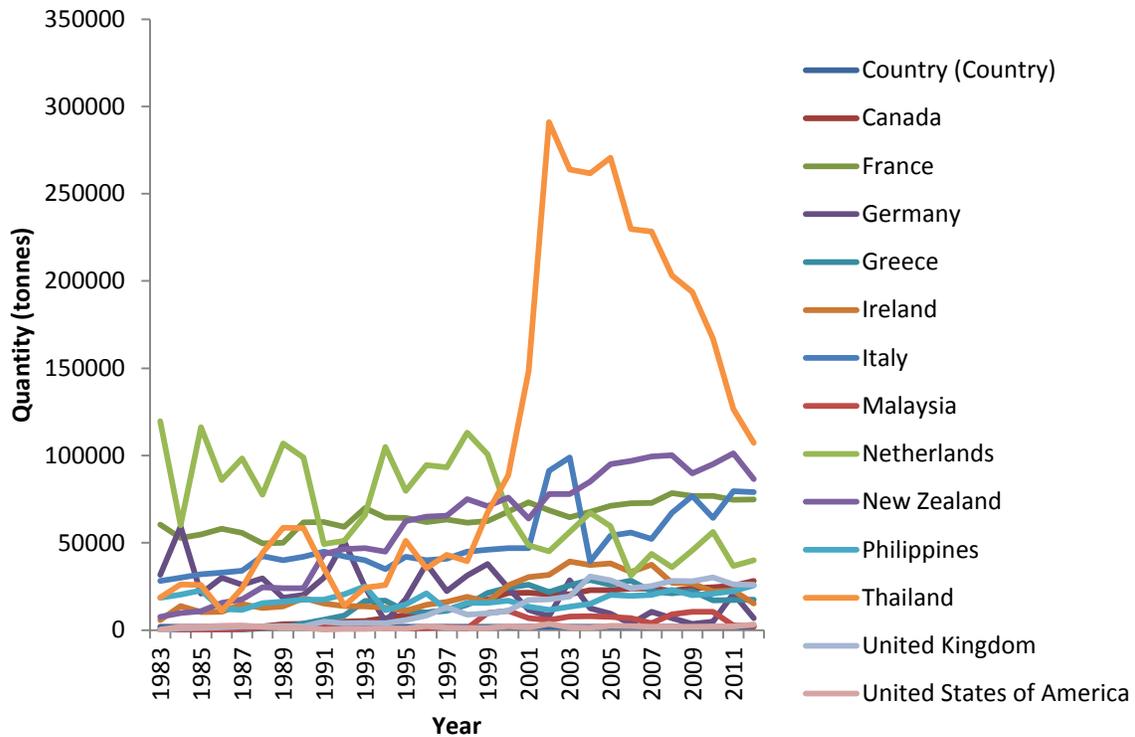


Figure 2. The quantity of global production in tonnes for *Mytilus* spp. and *Perna* spp. (FAO 2014). FAO data are dependent upon self-report methodology. Lack of a country's contribution in this figure may be due to no report or the manner in which FAO aggregated the data.

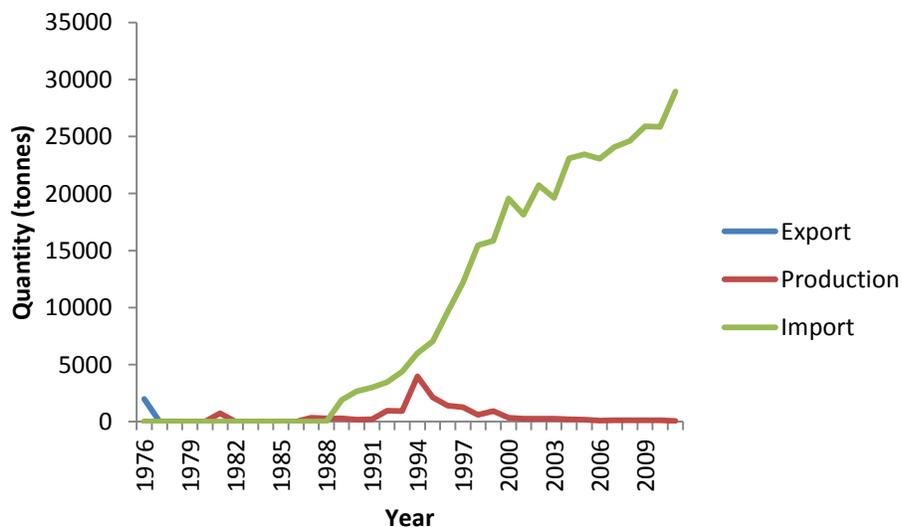


Figure 3. Production and trade of mussels in the United States (FAO 2014). Commodity types are aggregated.

Production systems

Mussels are cultured in many countries using a variety of methods based on the prevailing hydrographic, social and economic conditions. There are two main types of culture, including suspension culture and bottom culture. These methods are discussed in more detail below (as reviewed in Aypa 1990 and Morse and Rice 2010). Additionally and in some countries, young mussels are transplanted from natural spawning grounds to sites with favorable conditions for growth.

Description of Culture Methods:

Bottom Culture

Bottom culture consists of growing mussels directly on the seafloor, and is associated with low cost and lower meat yields relative to suspended culture. Firm substrate with adequate tidal flow are required for bottom culture, but turbidity, food supply and predators are also considered in choosing the location. Small mussels are seeded to the substrate or an existing bed is used to grow a marketable-sized product (Morse and Rice 2010). Bottom culture is extensively practiced in some geographic areas (i.e., the Netherlands), where the source of seeds is relies on natural settlement (Aypa 1990). Bottom culture is also employed in Ireland and the U.S., but is not considered sustainable because of challenges associated with adequate spat supply the Pacific Northwest of the United States and in China in the 1970s, and is based upon conditioning of adult mussels. Spawning is induced by thermal shock or stripping and the resultant larvae are allowed to feed and grown until ready to settle on ropes. 1 mm mussels are moved from setting tanks to a nursery, where they grow to 6-10 mm before being transferred to growout systems (FAO 2004-2014).

Product forms

A common trend among all regions is the presence of two different markets for aquaculture mussels: a fresh market (before or after depuration²) and a processed market. Depuration stations may sell their mussels to central markets, from which they are then sold to individual or bulk consumers. Processed forms of mussels include canned (boiled and jarred), preserved (boiled and soaked in brine), and frozen products; however, the mussels that are of the poorest quality and size are canned. For the Greenshell™ (*Perna canaliculus*), a number of factories specialize in alternative or derivative mussel products (i.e., smoked mussel meat, mussel chowder, crumbed/coated or stuffed mussels, marinated mussels, mussel powder and vacuum packed-mussels) (FAO 2004-2013, 2005-2013a,b, 2013).

² “Depuration (purification) is a process by which shellfish are held in tanks of clean seawater under conditions which maximize the natural filtering activity which results in expulsion of intestinal contents, which enhances separation of the expelled contaminants from the bivalves, and which prevents their recontamination.” (Lee et al. 2008)

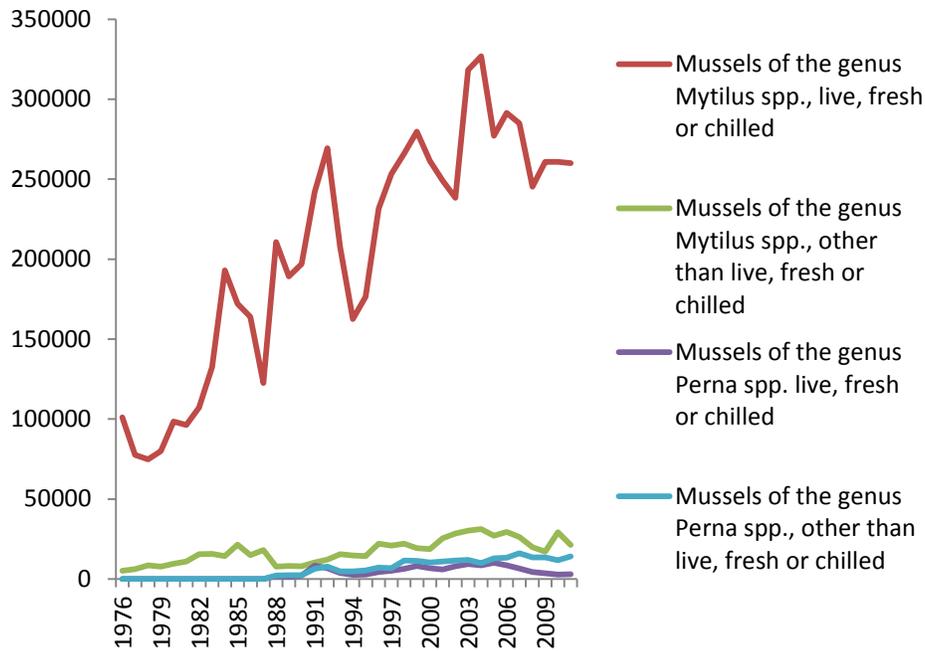


Figure 4. Quantity of product forms of cultured mussels (*Mytilus* spp. and *Perna* spp.) available on the global market (FAO 2014).

Common Market Names

Farmed mussels are available on the U.S. market as “mussels”. Species include:

Mytilus edulis— blue mussel (farmed along the Northeast Coast of North America and the Pacific Northwest)

Mytilus galloprovincialis—*Gallo or Mediterranean mussel* (farmed in the Pacific Northwest)

Perna viridis—Asian green mussel

Perna canaliculus— green-lipped mussel, New Zealand mussel or Greenshell™

Species

Mytilus edulis. The blue mussel has a wide geographical distribution. The blue mussel has been harvested from wild beds and cultured plots for centuries. Intertidal wooden pole culture in France dates back to the 13th century. Global production of the blue mussels has been variable over time, but production from most of the mature, large-scale producing nations (i.e., France and the Netherlands) has stabilized. Forecasts for the mussel industry show the greater emphasis on value added products (i.e., prepared dishes) rather than on the live on-shell market, and that higher competition for raw material might be the limiting factor in the short term (FAO 2004-2013).

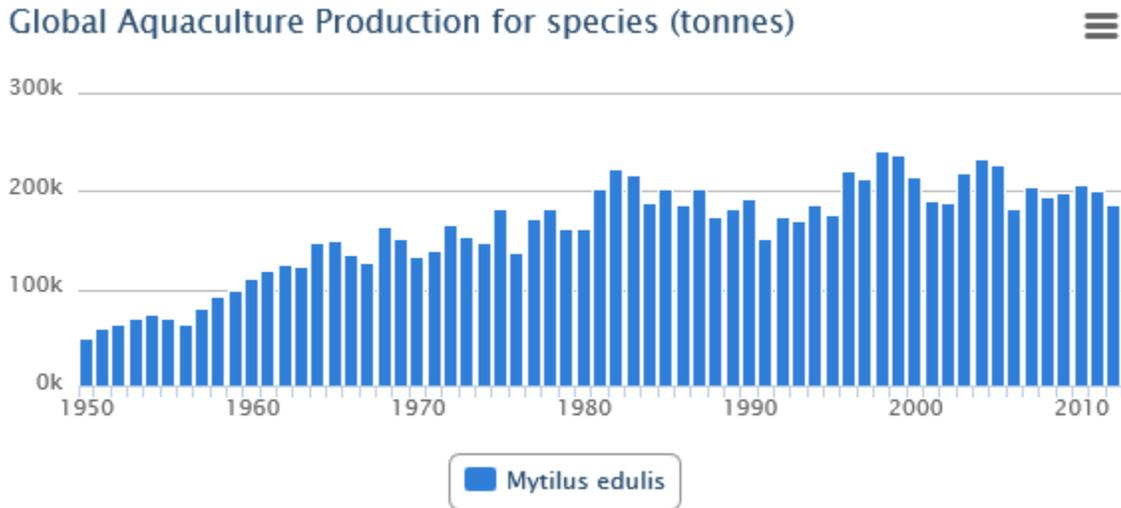


Figure 5. Global aquaculture production of *Mytilus edulis* (FAO 2004-2014).

Mytilus galloprovincialis. The country with the highest production of *M. galloprovincialis* is China, but information regarding mussel culture in China is lacking. Aside from China, the species is mainly cultured in coastal waters from northwest Spain and the north shores of the Mediterranean Sea, but production has also been reported from southern Mediterranean countries, Russian Federation, Ukraine, and South Africa. Production reports of *M. galloprovincialis* are confounded by the fact that until the early 1990s, all mussels from Western Europe were considered to be *M. edulis*, and limited information about Chinese mussel culture practices make analysis difficult. There are two mussel markets in the Mediterranean region: a fresh market before depuration and a processed market. Larger quantities of mussels are marketed fresh, but the canning market has expanded since 1984 (FAO 2006-2013).

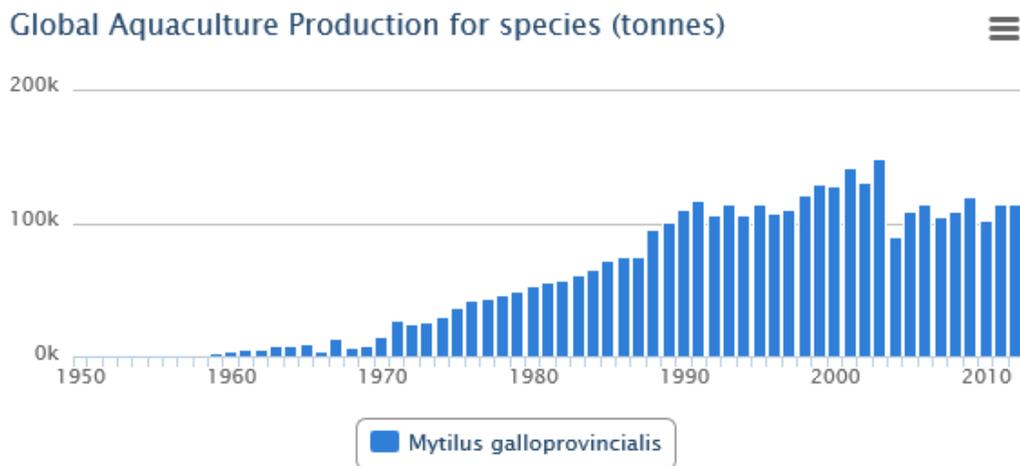


Figure 6. Global aquaculture production of the *Mytilus galloprovincialis* (FAO 2005-2014).

Perna viridis. The Asian green mussel is widely distributed in the Indo-Pacific region, extending from Japan to New Guinea and from the Persian Gulf to South Pacific Islands (Siddall 1980). The green mussel is a popular food item that is harvested in the wild and grown in aquaculture facilities in its native area.

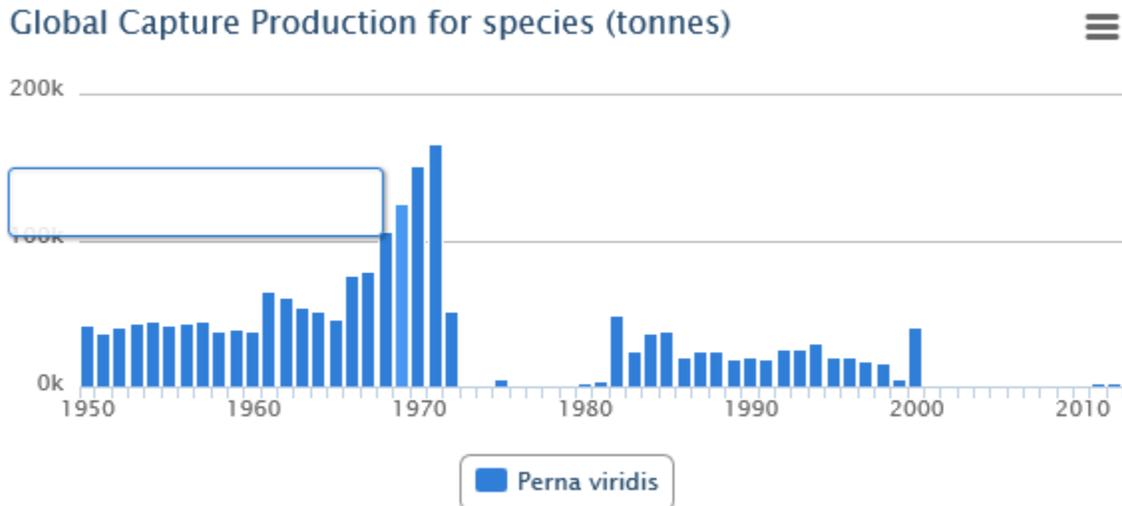


Figure 7. Global aquaculture production of *Perna viridis* (FAO 2014).

Perna canaliculus. The Greenshell™ has been harvested for consumption since the beginning of human habitation in New Zealand, but culture practices were not initiated until the mid-1960s. *Perna canaliculus* is endemic to New Zealand, but farms are limited to areas that are suitable for growth (high subtidal and sheltered inshore areas). The domestic market takes a small portion of the product. New Zealand mussels are currently exported to about 60 countries, the major importers being Japan, Australia, USA, and Europe. Depending on the specific market destination, New Zealand mussels are sold on the half shell, whole out of shell, live in shell, frozen in shell, or individually quick frozen. Those frozen in the half shell make up over 70 percent of total export sales, making New Zealand the world's leading exporter of half-shell mussels. Research efforts continue to build upon the environmental and production aspects of the mussel industry. One initiative is focused on a selective breeding program and the technology for small scale hatchery seed production. Commercial-scale hatchery seed production and off-shore farming are expected within five years (FAO 2005-2013).

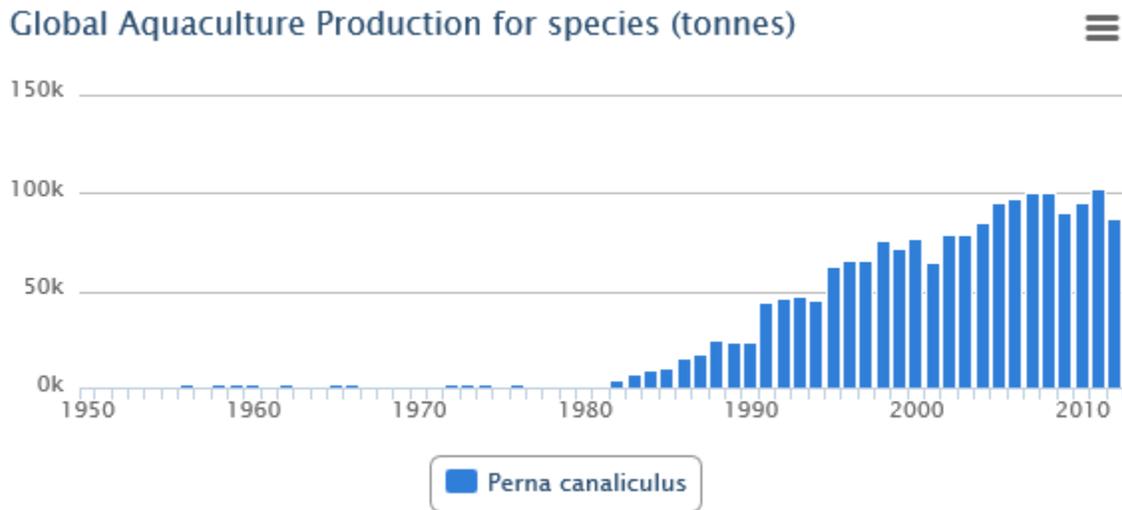


Figure 8. Global aquaculture production of *Perna canaliculus* (FAO 2005-2014).

Analysis

Scoring guide

- With the exception of the exceptional factors (3.3x and 6.2X), all scores result in a zero to ten final score for each criterion and the overall final rank. A zero score indicates lowest performance, while a score of ten indicates highest performance. In contrast, the two exceptional factors result in negative scores from zero to minus ten, and in these cases zero indicates no negative impact.
- The full Seafood Watch Aquaculture Criteria to which the following scores relate are available [here](#)
- The full data values and scoring calculations are available in Appendix 1

Criterion 1: Data quality and availability

Impact, unit of sustainability and principle

- *Impact: poor data quality and availability limits the ability to assess and understand the impacts of aquaculture production. It also does not enable informed choices for seafood purchasers, nor enable businesses to be held accountable for their impacts.*
- *Sustainability unit: the ability to make a robust sustainability assessment.*
Principle: robust and up-to-date information on production practices and their impacts is available to relevant stakeholders.

Data Category	Relevance (Y/N)	Data Quality	Score (0-10)
Industry or production statistics	Yes	7.5	7.5
Effluent	Yes	10	10
Locations/habitats	Yes	7.5	7.5
Predators and wildlife	Yes	10	10
Chemical use	Yes	7.5	7.5
Feed	No	Not relevant	n/a
Escapes, animal movements	Yes	10	10
Disease	Yes	10	10
Source of stock	Yes	7.5	7.5
Other – (e.g., GHG emissions)	No	Not relevant	n/a
Total			70

C1 Data Final Score	8.75	GREEN
----------------------------	-------------	--------------

Brief Summary

There are few data shortages regarding mussel farming and relevant environmental impacts. Most of the data are of moderate to high quality, reasonably up-to-date and complete, so as to

enable the assessor to obtain a full understanding or reliable representation of mussel farm operations and impacts.

Justification of Ranking

There are few data shortages regarding industry or production statistics relevant to mussel culture. Industry and production statistics available through the FAO (2014) are fairly up-to-date and the data are considered to give a reliable representation of the industry, but there may be some noncritical gaps in the data or data may have been aggregated in a noncritical manner. FAO data are also dependent upon self-reports. For this reason, the data quality and availability of industry and production statistics are considered moderate to high, scoring 7.5 out of 10.

There is sufficient information on effluent, predator and wildlife mortalities, escapes and disease to make relevant assessments. The majority of the available data in effluent, predator and wildlife mortalities, escapes and disease categories are complete, up-to-date within reason and have been peer-reviewed. For this reason, data associated with these categories are considered high quality and receive a score of 10 out of 10.

Data on feed is not relevant as farmed mussels are not provided external feed or nutrients.

The data available for location and habitats, chemical use, and source of stock are complete and accurate in relevance to this assessment, but may not meet all of the “high” requirements thus scoring 7.5 out of 10. For example, there has been a lack of studies focusing on the impacts of collection of spat on wild stocks (Beveridge 2001). More recent studies have focused on the impact of active collection (i.e., dredging) on wild stock, but there has not been a focus on passive collection of spat. This is most likely due to the fact that passive collection is not anticipated to have any negative impacts. Another example is the general gap in data on effective management of mussel farms and enforcement of regulations on a global basis. The available country-specific data suggest the appropriate framework exists to enable informed environmental decisions and planning, but not all data can be verified.

Overall, data quality and availability are considered moderate to high. The final score is 8.75 (out of 10).

Criterion 2: Effluents

Impact, unit of sustainability and principle

- *Impact: aquaculture species, production systems and management methods vary in the amount of waste produced and discharged per unit of production. The combined discharge of farms, groups of farms or industries contributes to local and regional nutrient loads.*
- *Sustainability unit: the carrying or assimilative capacity of the local and regional receiving waters beyond the farm or its allowable zone of effect.*
- *Principle: aquaculture operations minimize or avoid the production and discharge of wastes at the farm level in combination with an effective management or regulatory system to control the location, scale and cumulative impacts of the industry's waste discharges beyond the immediate vicinity of the farm.*

Effluent Evidence-Based Assessment

C2 Effluent Final Score	10.00	GREEN
--------------------------------	--------------	--------------

Evidence-Based Assessment – used when good quality data clearly defines an appropriate score

Brief Summary

Farmed mussels are not provided external feed or nutrient fertilization and from this vantage point there is no effluent concern, but there can be a concern over changes in the sedimentary environment of mussel farms due to biodeposition and sediment trapping. These changes are limited to the farm site and are not considered to extend beyond the immediate vicinity of farms. Furthermore, mussel farming has been shown to increase water quality at the farm site through removal of excess nutrients and phytoplankton. Overall, impacts of mussel farming are likely to be minor and unlikely to reach beyond the immediate vicinity of the farm; and because re-eutrophication benefits may outweigh such risks, there is no concern regarding resultant effluent or waste impacts. The score for the effluent criterion is 10 (out of 10).

Justification of ranking

For all production methods, mussels feed exclusively on the material in the natural seawater (Aypa 1990). They are not provided external feed or nutrient fertilization and from this vantage point there is no effluent concern; however, there is some effluent concern regarding the direct and indirect impact of mussel culture on the sedimentary environment of the farm.

Active filter feeding by mussels results in the excretion of undigested material (feces or pseudofeces), which increases biodeposition in areas where mussels occur in high densities, such as farms (Dame 1993, Norkko et al. 2001). Mussel beds and off-bottom culture also trap sediments that have become suspended in the water column (Ysebaert et al. 2008). Mussel farms can lead to high sedimentation rates when considering both sediment trapping and biodeposition. In a study by Ysebaert et al. (2008), bottom and suspended mussel culture resulted in changes in the sedimentary environment at the culture sites. In areas surrounding mussel beds at bottom culture sites, and in areas underneath suspended culture sites, grain size was smaller and particulate organic carbon, nitrogen and phosphorous concentrations were

higher than in nearby locations free of mussel culture. Similar findings have been reported for naturally occurring mussel beds and commercially cultured mussels (Ragnarsson and Raffaelli 1999, Chamberlain et al. 2001, Smith and Shackley 2004); however, the effects were limited to the mussel beds themselves or direct surroundings. Results from other studies have shown that mussel farm impacts are confined to less than 50 m from the farm boundary (as reviewed in Ysebaert et al. 2008).

Alternatively, mussel farming can be used as a tool for re-eutrophication of coastal waters (Lindahl 2011). The concept of re-eutrophication is that mussels could be the means by which increased nutrients and phytoplankton in coastal waters are recycled to land and reused. Specifically, the excess nutrients in coastal waters are assimilated into mussel biomass, which can be used as seafood, feedstuff, or fertilizer (instead of causing negative environmental effects). From this perspective, mussel farming increases water clarity and the overall quality of the water column.

There is also some concern regarding the production of wastewater and waste material from land-based facilities where mussels are cleaned or depurated. Regulations may dictate that liquid waste be discharged to a local sewer system, discharged to the estuary or sea, or disposed of in a landfill. In addition, depuration system recommendations include the siting of intake and discharge points being separate. There may also be requirements by relevant authorities for licensing for the discharge of used seawater and the disinfection of discharged seawater (Lee et al. 2008). While regulations and requirements vary by country, the fact that such principles exist reduce the risk for impacts from effluent. For this reason, effluent from land-based facilities is considered negligible.

Overall, data show no evidence that discharges from mussel culture cause or contribute to cumulative impacts beyond the immediate vicinity of the farm. Furthermore, mussel farming may provide increased benefits through reduced eutrophication (Ferreira et al. 2007, 2011). All impacts considered, the benefits of mussel farming generally outweigh any minimal impacts from effluent. Therefore, the Effluent Criterion is considered of no concern, and the criterion receives a score of 10 (out of 10).

Criterion 3: Habitat

Impact, unit of sustainability and principle

- *Impact: Aquaculture farms can be located in a wide variety of aquatic and terrestrial habitat types and have greatly varying levels of impact to both pristine and previously modified habitats and to the critical “ecosystem services” they provide.*
- *Sustainability unit: The ability to maintain the critical ecosystem services relevant to the habitat type.*
- *Principle: aquaculture operations are located at sites, scales and intensities that cumulatively maintain the functionality of ecologically valuable habitats.*

Habitat parameters	Value	Score	
F3.1 Habitat conversion and function		9.00	
F3.2a Content of habitat regulations	4.25		
F3.2b Enforcement of habitat regulations	3.75		
F3.2 Regulatory or management effectiveness score		6.375	
C3 Habitat Final Score		8.13	GREEN
Critical?	NO		

Brief Summary

Mussel culture generally occurs on bottom or in suspension, in coastal intertidal areas or in coastal inshore subtidal areas, which are generally considered to be of moderate to high habitat value; however, the impact of farmed mussel operations on habitat functionality is considered to be minimal, with the main concerns stemming from biodeposition and harvest. Minimal habitat impact, coupled with reasonable regulation and enforcement regarding licensing and site selection result in an overall high score (8.13).

Justification of Ranking

Factor 3.1. Habitat conversion and function

Habitat conversion is measured by the effect of aquaculture on ecosystem functionality and services. Mussel farming, and shellfish farming as a whole, provide valuable ecosystem goods and services, with few negative impacts. The greatest concerns raised about the effects of mussel culture on habitat are related to enhanced and localized biodeposition, filtration of the water column, and alteration of nutrient exchanges; but there are other broader ecological effects to consider such as the creation of novel habitat (as reviewed in McKindsey et al. 2011).

Pelagic effects

It is recognized that mussel farms remove phytoplankton and organic detritus from the water column through filtration. Filtration by mussels has the capacity to deplete or significantly reduce the water column concentration of suspended particles; however, depletion is only a concern if phytoplankton are cleared from the water column faster than they can be replaced by tidal exchange and primary production (Cranford et al. 2013). A benefit to reducing the amount of phytoplankton or other suspended particles available to other organisms and

potentially stimulating trophic cascades, is the reduction of primary symptoms of eutrophication (Burkholder and Shumway 2011). This key ecosystem service may result in recognized benefits such as an increase in the amount of underwater light, extending the euphotic zone and potentially enabling the recovery of submerged aquatic vegetation (SAV) and macroalgae (McKindsey et al. 2011). Submerged aquatic vegetation provides further ecosystem services, such as a refuge and nursery for juvenile fish and increased sediment stability (Yamamuro et al. 2006). In addition, reduction of eutrophication symptoms decreases the cycling time of suspended organic matter by removing the opportunity for bacterial remineralization, and therefore the onset of hypoxia and anoxia.

Habitat concerns resulting from the physical (infra) structure associated with suspended mussel culture include the alteration of hydrodynamics and current velocities, as well as reduced flow rates (as reviewed in McKindsey et al. 2011). Reduced currents may increase sedimentation, with the potential for resuspension during flood tides (Nikodic 1981, McKindsey et al. 2011). Given the dynamic nature of the system, and that pelagic effects are dependent upon the specifics of each study site, it is difficult to compare findings among studies, and linking different pelagic effects (removal of phytoplankton and organic detritus versus increased sedimentation and turbidity) will not be considered further.

Benthic effects

Mussels growing in suspended culture often create a food resource as well as favorable structures/habitats for other invertebrates and fishes by providing refuges from predation and adverse environmental conditions (Brooks 2000, Gutierrez et al. 2003, Coen et al. 2011, McKindsey et al. 2011). Mussel fall-off (as well as shells) and associated organisms from suspended culture have the potential to create benthic structure that would not normally occur on soft sediment bottoms, similar to that of hard-bottom reefs (Carbines 1993, McKindsey et al. 2011). Mussel fall-off enhances the amount of food available to benthic predators and scavengers and several studies have correlated an increase in abundance of benthic predators (e.g., sea stars, crabs, other macroinvertebrates, benthic fishes, and sea ducks) with mussel culture sites (as reviewed in McKindsey et al. 2011, Varennes et al. 2013).

Mussels (particularly in the genera *Mytilus*) are reef-forming shellfish that significantly enhance the vertical structure and habitat complexity in which other organisms live on or near, and from which they seek shelter or food (Coen et al. 2011). Thus, mussel culture may increase benthic species richness and diversity.

Biodeposition of fecal matter from mussel culture is a habitat concern because biodeposition from mussels in suspension may be substantial. Increased biodeposition may result in increased organic content load, affecting the biogeochemical properties of benthic sediments (i.e., benthic respiration and nutrient fluxes at the sediment-water interface) and the communities that live associated with such sediments (McKindsey et al. 2011). Increased organic content load is also a contributing factor of eutrophication. An additional factor to consider is the fact that organisms associated with mussel matrices (e.g., tunicates) may also contribute to the deposition of organic matter. While some sources state that organic content

of feces and pseudofeces varies based on food quality in the aquaculture region (Barnes 2006), McKindsey et al. (2011) state there is a general lack of information regarding the organic content of feces and pseudofeces from mussels that feed on a natural diet. Habitat concerns resulting from biodeposition are minimized by the fact that mussel farming can be used as a tool for re-eutrophication of coastal waters (Lindahl 2011, see Criterion 2 Effluent); whereby (instead of causing negative environmental effects) the excess nutrients in coastal waters are assimilated into mussel biomass, which can then be used as seafood, feedstuff, or fertilizer.

Additionally, mussel beds and off-bottom culture also trap sediments that have become suspended in the water column (Ysebaert et al. 2008). Mussel farms can lead to high sedimentation rates when considering both sediment trapping and biodeposition, but effects are generally limited to the mussel beds themselves or to the immediate surroundings (see Criterion 2 Effluent).

Overall, it is widely recognized that effects of shellfish culture are insignificant relative to other forms of culture because artificial feeds are not used (Giles et al. 2009, Weise et al. 2009, Ferreira et al. 2011).

Harvest

Mussels are harvested by a variety of methods dependent on the method of culture (Aypa 1990), and for the purposes of this section, the focus will be on the suspended or off-bottom culture. For example, mussels from suspended culture may be harvested by taking the lines out of the water and bringing them to shore, or by using mechanical methods directly on board a vessel whereby mussels are pulled up an escalator and stripped from the lines. Harvest by such methods is believed to have no significant impacts on habitat.

In today's large-scale mussel culture industry, harvesting of bottom cultured mussels requires the speed and high capacity associated with dredges. Dredges vary in size with wild harvest dredges being larger than culture harvest dredges. The harvest vessel may also be equipped with a tumbler to allow small mussels and other benthic organisms to be removed from the catch (Morse and Rice 2010). The overall impacts of dredges on seafloor habitat have been compared to "forest clear-cutting" and have been reviewed by numerous authors (Collie et al. 1997, Dorsey and Pederson 1998, Levy 1998, Auster and Langton 1999, Baulch 1999, Mercaldo-Allen and Goldberg 2011). Dredging has been shown to reduce habitat complexity and species diversity, cause shifts in community structure, cause loss of vertical structure, and reduce productivity or biomass. Dredging can also increase or decrease nutrient cycling, cause hypoxia, increase exposure of organisms to predation, and increase turbidity (Stokesbury et al. 2011).

There is, however, a difference between dredging for wild mussels and dredging for farmed mussels. Wild harvest fishermen often sample vast areas because they do not know the exact location and expanse of mussel density, and this practice can result in high mortality of non-target organisms. In contrast, mussel farmers know exactly where and when to dredge because they seeded the area. Tows for farmed mussels are generally much shorter, resulting in greatly reduced mortality of non-target organisms. Additionally, most shellfish farming takes place in

shallow coastal areas which can recover from major disturbances within a few weeks or months (Coen 1995). Species in these areas tend to be opportunists that tolerate highly turbid conditions and are capable of rapidly recolonizing disturbed seafloor habitats (Stokesbury et al. 2011). While dredging flattens the vertical structure and habitat provided by the mussels, the space created by harvesting adult shellfish provides space for new recruits. Furthermore, shellfish farmers often reseed their crops on an annual basis, which can restore vertical structure to the seafloor, enhances habitat for many additional species, and promotes resource sustainability (Mercaldo-Allen and Goldberg 2011, Stokesbury et al. 2011).

In Europe, mussel seed for bottom culture is collected by dredge from natural mussel beds, and is transplanted to bottom culture areas that support high growth rates and low mortality (Dolmer et al. 2012). In such regions, mussels may be dredged twice (i.e., once for collecting seed and once for collecting full-grown mussels for sale). Dredging for mussel seed has the potential to disrupt the seabed, resulting in increased burial of organic material and anoxic conditions. It might also dislodge sediment and increase turbidity, as well as dislodge non-target organisms, causing increased stress or mortality (Maguire et al. 2007, Creswell and McNevin 2008). While the effects of dredging for seed could be considered significant to the environment, the use of passive collection of seed dominates global mussel culture (see Criterion 8 Source of Stock). Therefore, the risk associated with dredging for mussel seed is considered minimal.

Habitats in which mussels are farmed may be improved through filtration and maintain full functionality if harvested by hand. Habitats in which mussels are farmed and then harvested by dredge are subject to increased turbidity, changes to sediment, and reduction in species diversity and biomass; however, these areas have been shown to recover quickly from all impacts.

Overall, the effects to habitat function and services from mussel culture are expected to be minimal and mitigated by the ecosystem services that mussels provide. The habitat remains functional and the score for this factor is 9 (out of 10).

Factor 3.2. Habitat and farm siting management effectiveness (appropriate to the scale of the industry)

Mussels are consumed in many forms (Figure 4), but are not imported live unless they have health certificates and meet water quality standards that are subject to convention and international agreements. Each country regulates aquaculture and enforces aquaculture policies differently, but often with the same goal of minimizing environmental impact. The following is an overview of habitat and farm management effectiveness in several countries with significant mussel aquaculture production.

In the U.S., the U.S. Army Corps of Engineers issues aquaculture permits before a farm can be established, which often require consultation with the National Marine Fisheries Service and the U.S. Fish and Wildlife Service, as well as approval by states confirming that the farm's practices are consistent with the coastal zone management programs. Additionally,

environmental best management practices (BMPs) are also employed to reduce, minimize, or mitigate the effects of farming practices on aquatic (or terrestrial) resources and interactions with other users of marine resources (Dewey et al. 2011, Getchis and Rose 2011).

In New Zealand, the amended Resource Management Act (RMA) provides most of the framework for managing aquaculture. Under the RMA, the Ministry of Conservation is responsible for preparing coastal policy statements, approving regional coastal plans and permits for coastal activities and other monitoring. The Ministry of Environment is responsible for making recommendations on issues for policy statements, and defining environmental standards. The Ministry of Fisheries keeps a national registry of fish farmers. Aquaculture is directly managed at the regional and territorial level using regional coastal plans that define zones for aquaculture and set limits on the character, scale and intensity of aquaculture and related industry activities. In terms of the shared use of the environment, the regulations governing the siting of marine farms, and the arrangement within them, ensure that they do not dominate the landscape. Precaution is made in all areas to provide ready access for all other marine users. The only issue with the regulatory framework in New Zealand is the need to clarify property rights for areas suitable for aquaculture so that mussel farmers can have a guaranteed tenure that is long enough to warrant investment (FAO 2006 to 2014).

Canada is party to international agreements with implications for the regulation of aquaculture, but all aspects of aquaculture in Canada are federally or provincially regulated, or both. The federal government has jurisdiction over the regulation of fish products marketed in export and inter-provincial trade, the conservation and protection of wild fish stocks and fish habitat and research and development. Federal authority to regulate the aquaculture industry is shared among 17 departments and agencies, with the Department of Fisheries and Oceans Canada (DFO) as the lead. Transport Canada grants authorizations for aquaculture facility plans affecting navigation under the Navigable Waters Protection Act. DFO or Transport Canada manages the environmental assessment process in coordination with Environment Canada and the Canadian Environmental Assessment Agency under the Canadian Environmental Assessment Act. Specific responsibilities for aquaculture have been delegated by the federal to the provincial level through memoranda of understanding. Provinces are responsible for aquaculture planning, site leasing, licenses and approvals for aquaculture sites, aquaculture training and education, the collection of statistics, the promotion of fish and aquaculture products, and the management of the industry's day-to-day operations. The provinces also regulate the food safety of aquaculture processing, while the regulation of food safety for export purposes remains under the exclusive jurisdiction of the federal government. All the provinces and territories have legislation to regulate aquaculture industries, either by way of proclaimed acts dealing with aquaculture or zoning bylaws (FAO 2007 to 2013).

In Spain, regulation of shellfish farming and aquaculture is managed by national and regional authorities. The General Secretariat for Maritime Fisheries (SGPM) provides information and coordination to these regional authorities on any issues related to aquaculture arising from Spain's involvement in multilateral organizations. Various producers' associations provide leadership for mussel culture at the regional level. Various laws and regulations at the national

and regional level apply to mussel culture. At the national level, applicable regulations include the Law on Marine Aquaculture and Law of the Coasts (FAO 2005-2014). Where regions have created their own regulations regarding marine aquaculture, these supersede the national legislation detailed above. In Galicia, the raft technology used for mussel farming is subject to certain regulatory limits in terms of size and density of mussel production. Permits for new shellfish aquaculture installations or leases are generally obtained within an average of one to two years after application. Applicants are generally granted a 10-year concession, which can be renewed in 10-year periods for a maximum of 50 years (as reviewed in Pinnell 2008).

In China, the use of the aquatic and terrestrial environment is regulated by different laws such as the Fisheries Law, the Regulation Law for Sea Area Usage, and the Environmental Impact Assessment Law, but site selection for aquaculture has no specific legislation (FAO 2004-2014, Chen et al. 2011). Use of state owned land and water areas is required to meet the local functional zoning scheme set by the Land Administration Law, including conservation areas, industry, aquaculture, etc. (FAO 2004-2014, Chen et al. 2011). Most farms are family operated and shellfish leases are managed by local communities (personal communication with X. Guo, November 29, 2012). Environmental Impact Assessments (EIAs) are required by different environmental laws, and while there is no specific referral to aquaculture, EIAs are required for construction projects that include large-scale aquaculture. Additionally, the Environmental Impact Assessment Law expands EIA requirements from individual construction projects to government planning for the development of agriculture, aquaculture, animal husbandry, forestry, water conservation and natural resources (FAO 2004-2014). At the local level, licenses may only be granted in state-owned waters if natural spawning, breeding and feeding grounds and migration pathways of fish, shrimp, crab, shellfish and algae are protected and not used as the aquaculture site. Licenses can be revoked if water surfaces and tidal flats are neglected for a period of 1 year (FAO 2004-2014). Water quality is monitored on lease grounds to ensure that it is suitable and remains suitable for aquaculture; however, monitoring may not be strictly enforced (personal communication with X. Guo, November 29, 2012). Overall, enforcement of aquaculture regulations is often weak as aquaculture is favored by the government as an important economic activity (Chen et al. 2011).

Overall, the content of habitat regulations surrounding mussel culture or aquaculture generally takes into account environmental impacts and ecosystem function and services and Criterion 3.2a receives a score of 4.25 out of 5. Similarly, enforcement organizations are identifiable, permitting processes are based on zoning plans, and the process appears relatively transparent and Criterion 3.2b receives a score of 3.75. The caveat to this is that the available information is not clear if all regulations in all locations are effective or well-enforced (see example of weak enforcement in China above). If general statements are available, they appear to rely on opinion rather than data, and therein lies uncertainty. As such, regulation and management of farm siting and licensing across all locations resulted in an overall habitat and farm siting management effectiveness score of 6.375 out of 10. When combined with the Factor 3.1 score, the final numerical score for Criterion 3 – Habitat is 8.13 out of 10, indicating that although there are some variations in the effectiveness of the management regimes, the fundamental

nature of the production system means that mussel farming is unlikely to have substantial habitat impacts.

Criterion 4: Evidence or Risk of Chemical Use

Impact, unit of sustainability and principle

- *Impact: Improper use of chemical treatments impacts non-target organisms and leads to production losses and human health concerns due to the development of chemical-resistant organisms.*
- *Sustainability unit: non-target organisms in the local or regional environment, presence of pathogens or parasites resistant to important treatments.*
- *Principle: aquaculture operations by design, management or regulation avoid the discharge of chemicals toxic to aquatic life, and/or effectively control the frequency, risk of environmental impact and risk to human health of their use.*

Chemical Use parameters	Score	
C4 Chemical Use Score	10.00	
C4 Chemical Use Final Score	10.00	GREEN
Critical?	NO	

Brief Summary

Recent mussel culture generally does not entail the application of chemicals (i.e., antibiotics, pesticides, herbicides, fertilizers) to control fouling and predators or prevent disease. The amount of chemicals used in mussel culture would be minute, if at all. Further, the water in which chemicals would be used generally is not released to the marine environment. Thus, there is no threat of chemical contamination to adjacent waters or organisms.

Justification of ranking

Chemical treatments in mussel farming could potentially be used to prevent predators, fouling organisms, and to treat infection by disease-causing bacteria in mussel hatcheries.

Predators

The use of chemical substances (i.e., copper sulfate, calcium oxide, sand coated with trichloroethylene, and insecticides) to control predators of molluscs was initiated in the 1930s in the U.S. (Loosanoff 1960, Jory et al. 1984, Shumway et al. 1988). While such chemicals proved effective, the concern for potential environmental and public health risks of copper sulfate, trichloroethylene, and insecticides far outweighed the benefits. The use of many chemicals (e.g., pesticides) in the marine environment for aquaculture, or otherwise, have been banned (Creswell and McNevin 2008, Sapkota 2008), hence the chemicals are no longer used to control predators at mussel farms. Furthermore, a review of predator controls in bivalve culture conducted by Jory et al. (1984) revealed that the installation of exclusionary devices (i.e., netting) was more successful than chemical treatment for control of bivalve predators.

Fouling

Fouling is a significant problem in suspended mussel culture. Physical structures in the marine environment provide substrate where sessile organisms can settle and begin fouling. Constant cleaning is required to remove fouling organisms. There have been many attempts to prevent fouling in bivalve culture through the use of chemicals such as Victoria Blue B, copper sulfate, quicklime, saturated salt solutions, chlorinated hydrocarbon insecticides, and other pesticides (Loosanoff 1960, MacKenzie 1979, Shumway et al. 1988, Brooks 1993); however, chemicals to control fouling may release potentially toxic constituents into the marine environment which pose a threat not only to the species being cultured, but also to other non-target organisms. Even antifoulants commonly used in finfish culture are not applied to shellfish gear. This is because the antifoulants approved for finfish culture have not been approved for shellfish culture, and the antifoulants currently available do not adhere to the plastics from which shellfish gear is made (Bishop 2004).

Promising experiments are being conducted on netting but they are inconclusive to date (personal communication with S. Shumway), and the East Coast Shellfish Growers Association Best Management Practices (Flimlin et al. 2010) caution the use of chemicals to control fouling. In British Columbia, the study of chemical methods to control fouling in mussel culture include the delivery of a lime solution to mussel socks; however, the application design incorporated a lime recovery system to reduce or prevent the amount of solution entering the environment, thus reducing or preventing effects to non-target species. While both physical and chemical methods can result in the mortality of fouling organisms, no population level effects were expected (DFO 2006); final results have not been published. Air drying, brine or freshwater dips, power washing, and manual control are not only more successful, but environmentally friendly antifouling methods (Creswell and McNevin 2008, Watson et al. 2009).

Antibiotics in mussel hatcheries

The use of antibiotics or therapeutics in U.S. aquaculture is overseen by the U.S. Food and Drug Administration (FDA) and regulations are quite stringent regarding use of unapproved chemicals. The U.S. Environmental Protection Agency (EPA) also regulates the use of non-pharmaceutical chemicals used in shellfish culture³; laws are strict and shellfish producers typically do not use unapproved chemicals. Bacteria that may cause disease in hatchery-reared larvae and spat can be controlled with antibiotics (Ford 2001); however, hatchery operators are concerned with the development of antibiotic resistance, and instead rely on improved animal husbandry and regular cleaning of hatchery equipment (Ford 2001, Creswell and McNevin 2008, Flimlin et al. 2010). Dilute hypochlorite (bleach) solutions often are used for disinfection of equipment, but they are disposed of in the municipal sewer system instead of the marine environment (Creswell and McNevin 2008, Flimlin et al. 2010). Furthermore, the use of hatcheries in mussel culture is fairly uncommon and antibiotics are not used in the natural environment where mussels are farmed (British Columbia Shellfish Growers Association 2012).

³ http://www.nmfs.noaa.gov/aquaculture/docs/policy/agency_fact_sheets/epa_regulatory_fact_sheet_updated.pdf

In New Zealand, chemicals (i.e., fertilizers, herbicides, pesticides) are not applied to mussel culture (Loyd 2003). In China, chemicals (including antibiotics) have been detected in aquatic products, but supervision and testing of chemicals in such products is improving and the use of most antibiotics for aquaculture is prohibited. Furthermore, references to the use of any chemical in aquaculture in China usually refers to fish farming (NBSO 2010). There is limited evidence for other countries, but chemicals are not generally used in mussel culture. Instead, farms commonly rely on sites with high water quality.

The amount of chemicals used in mussel culture would be minute, if at all. Further, the water in which chemicals would be used is not typically released into the marine environment. Thus, there is no threat of chemical contamination to adjacent waters. The most effective methods of treatment for predator and fouling control are manual removal, which do not entail discharge of active chemicals. Therefore, the chemical use score is 10 (out of 10).

Criterion 5: Feed

Impact, unit of sustainability and principle

- *Impact: feed consumption, feed type, ingredients used and the net nutritional gains or losses vary dramatically between farmed species and production systems. Producing feeds and their ingredients has complex global ecological impacts, and their efficiency of conversion can result in net food gains, or dramatic net losses of nutrients. Feed use is considered to be one of the defining factors of aquaculture sustainability.*
- *Sustainability unit: the amount and sustainability of wild fish caught for feeding to farmed fish, the global impacts of harvesting or cultivating feed ingredients, and the net nutritional gains or losses from the farming operation.*
- *Principle: aquaculture operations source only sustainable feed ingredients, convert them efficiently and responsibly, and minimize and utilize the non-edible portion of farmed fish.*

Feed parameters	Value	Score	
C5 Feed Final Score		10.00	GREEN
Critical?	NO		

Brief Summary

External feed is not provided to farmed mussels, therefore the feed criterion score is 10 (out of 10).

Criterion 6: Escapes

Impact, unit of sustainability and principle

- *Impact: competition, genetic loss, predation, habitat damage, spawning disruption, and other impacts on wild fish and ecosystems resulting from the escape of native, non-native and/or genetically distinct fish or other unintended species from aquaculture operations*
- *Sustainability unit: affected ecosystems and/or associated wild populations.*
- *Principle: aquaculture operations pose no substantial risk of deleterious effects to wild populations associated with the escape of farmed fish or other unintentionally introduced species.*

Escape parameters	Value	Score	
F6.1 Escape Risk		0	
F6.1a Recapture and mortality (%)	40		
F6.1b Invasiveness		5.5	
C6 Escape Final Score		4	YELLOW
Critical?	NO		

Brief Summary

Mussel culture poses a moderate risk of escape due to that fact that production systems are open to the environment without effective best management practices for design, construction, and management of escapes; and there are no safeguards for larval escape due to unrestricted broadcast spawning. While some mussels are cultured within their native ranges, others are cultured in areas where they were introduced by various means (i.e., shipping) more than 10 years ago and are now fully established. Data suggest that recipient ecosystems have been impacted by such introductions, due to competition for resources and habitat modification. The overall score for the escape criterion is low, but not critical.

Justification of Ranking

Factor 6.1a. Escape risk

The risk of escape is directly related to the degree of connection to the natural ecosystem. Typical production systems for farmed mussels include collection of spatfall and growout in the natural environment (i.e., open systems consisting of on-bottom, intertidal and shallow water, or deep water habitats).

Mussels undergo a planktonic larval phase that could be transported away from the farm sites. A single female can produce more than 20 million eggs, and spawning can be seen by cloudiness in local waters, usually in early summer. Fertilized by males, the larvae drift for some weeks, then settle as spat on the seafloor in near-shore areas, or on objects in the water column. In the adult phase, there is little chance of escape from farm sites since individuals live attached to substrates by byssal threads, or they are secured by nets or mesh. If a juvenile or adult mussel were to fall off, it would likely settle on the seafloor of the farm site and could be recaptured via collection methods.

Mussels are cultured in open systems without safeguards for escape prevention, and unrestricted broadcast spawning could result in larval escapes; therefore, mussel culture poses a high risk for escape (0 out of 10). The estimated percent of direct mortality at the escape site is 40%, which is an arbitrary acknowledgement of the mortality of larvae and accounts for the likelihood that large numbers of larvae will survive, resulting in a recapture and mortality score of 0.4 out of 1. The mortality score mitigates the high risk of escape and results in an overall moderate escape risk score of 4 out of 10 for Factor 6.1a.

Factor 6.1b. Invasiveness

For mussels cultured in their native regions (*M. edulis*), farmed stock is generally wild-caught or from passive settlement within the same body of water. Of the farmed mussel species analyzed in this report, *M. galloprovincialis*, *P. perna*, and *P. viridis* are all cultured outside of their native range in North America and several other countries (Padilla et al. 2011). *Perna* spp. were introduced through aquaculture both intentionally and accidentally, while *M. galloprovincialis* is documented as an accidental introduction or a species that “escaped” in regions outside of its native range. Under a worst case scenario approach for this analysis, farmed mussels are considered non-native, but already fully established in the production region. The score for Factor 6.1b Part B is 2.5.

The escape of native species is anticipated to have no environmental impact. For the culture of species beyond their native ranges (e.g., *M. galloprovincialis*), escape could be cause for concern. Impacts to ecosystems from the invasion of *M. galloprovincialis* include increased habitat for infaunal and other invertebrate species, increased recruitment and species richness, alteration of flow and sedimentation, increased food supply for intertidal predators, and competitive displacement of native species (including native mussels), as well as hybridization with native mussels (Branch and Steffani 2004, as reviewed in Padilla et al. 2011). The invasions of *Perna* spp. were also shown to increase habitat and alter flow and sedimentation. Additionally, these species served as a main source of fouling in water systems, on vessels, navigation buoys, crab traps and clam culture bags (Sousa et al. 2009, as reviewed in Padilla et al. 2011). Because non-native mussels have been shown to compete with native populations for food and habitat, and to some extent, modify those habitats and increase fouling, the ecosystem impact of ongoing escapes (6.1b Part C) score is 3. Combined with the non-native species score, the overall invasiveness score is 5.5 out of 10.

The moderate risk of escape (4 out of 10) coupled with the invasiveness score (5.5 out of 10) results in a final numerical score of 4 out of 10 for Criterion 6 – Escapes.

Criterion 7: Disease; pathogen and parasite interactions

Impact, unit of sustainability and principle

- *Impact: amplification of local pathogens and parasites on fish farms and their retransmission to local wild species that share the same water body.*
- *Sustainability unit: wild populations susceptible to elevated levels of pathogens and parasites.*
- *Principle: aquaculture operations pose no substantial risk of deleterious effects to wild populations through the amplification and retransmission of pathogens or parasites.*

Pathogen and parasite parameters	Score	
C7 Biosecurity	8.00	
C7 Disease; pathogen and parasite Final Score	8.00	GREEN
Critical?	NO	

Brief Summary

Few mass mortality events due to parasite and pathogen infection have been reported in farmed mussels. Despite the fact that mussel growout systems are open to the natural environment increasing the possibility of pathogen exchange, the low or infrequent occurrence of mussel diseases, coupled with biosecurity measures that have been put in place at farm, government, and international levels reduce the risk of parasite and pathogen infection to a low level. This is further reinforced by the fact that production practices (especially those of natural settlement) do not increase the likelihood of pathogen amplification compared to natural populations. Thus, the overall score is a low risk of 8 (out of 10).

Justification of Ranking

Diseases associated with mussels

There are few available data that demonstrate negative impacts on the environment as a result of shellfish aquaculture, except for the historical introduction of disease agents to new areas (Elston and Ford 2011). The diseases found in farmed mussels are presented in the table below. High mortalities caused by parasites or infectious diseases have yet to be recognized in *M. edulis*, but several parasites may be potentially harmful (FAO 2004-2014a). Similarly, neither of the diseases associated with *M. galloprovincialis* cause significant impairment to the culture of this species (FAO 2004-2014b); and high water quality in areas where *P. canaliculus* are grown eliminates the need for depuration (often used to treat mussels with low levels of microbial contamination; FAO 2005-2014).

Table 1. Diseases of Mussels (*Mytilus* spp. and *Perna* spp.) assimilated from (FAO 2004-2014a,b, 2005-2014).

DISEASE	AGENT	TYPE	EFFECTS	OCCURRENCE
Unnamed viral disease	Unknown	Virus	Epithelium of digestive tubules sloughs into lumen	<i>P. canaliculus</i>
	Picornidae-like virus	Virus	Heavy mortalities	<i>M. edulis</i>
Unnamed	Herpes-like virus	Bacteria	Occasional spat mortality	<i>P. canaliculus</i>
Vibriosis	Vibriosis	Bacteria	Occurs in larvae and spat; epithelial necrosis; mortality	<i>M. edulis</i>
Rickettsiosis	Rickettsia/Chlamydia	Bacteria	Gills and digestive gland	<i>M. edulis</i>
Parasitic infection	<i>Lichomolgus uncus</i> , <i>Pseudomyicola spinosus</i>	Copepods	No damage	<i>P. canaliculus</i> ,
	<i>Pinnotheres pisum</i>	Crustacean	Reduces market value	<i>M. edulis</i>
	<i>Polydora ciliate</i>	Polychaete	Burrows and blisters; mortalities; reduced market value	<i>M. edulis</i>
	<i>Marteilia maurini</i>	Protozoan	Potentially lethal; extensive destruction of digestive glands	<i>M. galloprovincialis</i> ; <i>M. edulis</i>
	<i>Cliona</i> sp.	Sponge	Holes in outer surface and tunnel network of shell	<i>M. edulis</i>
	<i>Proisorhyncus</i> sp.	Trematode	Abnormal coloration of mantle, weakness, gaping	<i>M. edulis</i>
	<i>Steinhausia mytilovum</i>	Microsporidian	Infects cytoplasm of mature ova	<i>M. edulis</i>
Red worm disease	<i>Mytilicola</i>	Copepods	Usually commensal but may slow growth	<i>M. galloprovincialis</i> ; <i>M. edulis</i>
Gill ciliate infection	Unknown	Protozoans	No pathological changes reported	<i>P. canaliculus</i>
Haemocytosis	Unknown	Unknown	Non-specific responses	<i>P. canaliculus</i>

Disease and the production system

Infectious diseases have the potential to occur in all aquaculture systems, including hatcheries, nurseries, and growout systems; and may be associated with the transfer of broodstock, larval and seedstock. Many of the infectious diseases associated with shellfish in hatcheries, nurseries, and concentrated growout systems are caused by opportunistic agents that become pathogenic to the shellfish species because of the nature of the culture system in which they are held (Elston and Ford 2011). For many of these diseases there is no curative measure, but control methods include avoidance of stock transfer from infected regions, monitoring mussel transfer and site selection, and decreasing stocking density (FAO 2004-2014a,b, 2005-2014).

Aquaculture farms or production systems that are open to the natural environment like on-bottom or long line mussel culture tend to pose a moderate to high pathogen and parasite interaction risk; however, there have been few [mass] mortality events described for adult blue mussels (Eggermont et al. 2014). Munford (1981) attributed the mass mortality of *M. edulis = galloprovincialis* in Italy to a trematode infection. No other references were found to support mass mortality in mussels, but that does not mean that mussels remain disease free. Baseline sampling for infectious diseases in cultured mussels in Galicia revealed that despite negligible mortalities in intensive culture, the mussel population hosted pathogenic and parasitic agents. It was hypothesized that the reason for low mortality was the relatively short amount of time required for mussels to reach marketable size (Figueras et al. 1991). Another study in Galicia revealed the occurrence of various symbionts in mussel culture. Some protistan symbionts were detected in mussel seed at the beginning stage of culture, but the prevalence of most symbionts increased as mussels grew. It was posited that the increase in symbiont prevalence was due to the filtration rate associated with mussel growth. It was stressed that transplantation of mussel seed for culture could contribute to the spread of some symbionts (Villalba et al. 1997, See Section 6.2x).

Hatchery production of mussels has been established, but remains economically unfeasible in many areas and is not the standard of practice (FAO 2004-2014a, Eggermont et al. 2014). Shellfish hatcheries provide a highly concentrated environment in which opportunistic disease agents have the potential to become established and reduce larval yield (Elston and Ford 2011). Eggermont et al. (2014) were able to stimulate bacterial growth in wild-caught adult blue mussels inducing mass mortality of mussel larvae under hatchery conditions, which may explain the reason for impractical mussel larviculture.

Biosecurity and Authority for disease control

The U.S. Department of Agriculture requires that shellfish farms applying for Animal and Plant Health Inspection Service certifications for interstate export of live shellfish product comply with the Shellfish High Health Plan. The plan requires participating shellfish producers to establish and practice a customized animal health management plan for their farms, ultimately reducing the risks associated with infectious disease outbreaks (Elston and Ford 2011). Outside of the U.S., the World Organization for Animal Health adopted the Aquatic Animal Health Code and the Manual of Diagnostic Tests for Aquatic Animals, inclusive of molluscs (OIE 2011, 2012). These documents are used by member country authorities to develop individual country

standards for all matters related to aquatic products that carry risk of disease (Elston and Ford 2011). These preventive measures aim to limit imports to those countries where there is no outbreak of diseases caused by notifiable pathogens (OIE 2011, 2012). The protistan parasite *Marteilia maurini* that is hosted by the blue mussel is not on the list of notifiable pathogens, whereas the epizootic parasite *M. refringens* hosted by the oyster is on the list of notifiable pathogens. This indicates that mussel movements may not be subject to legal regulations on notifiable diseases.

Mussel farms all over the world employ best or better management practices for controlling disease. In the U.S., for example, most farms employ BMPs that aim to isolate the culture facility (if applicable) from sources of infection, ensure appropriate stocking densities, properly quarantine or dispose of infected stock and contaminated materials, and limit wet storage activity (Creswell and McNevin 2008). In a New Zealand example, strict rules apply to harvesting mussels during or after rainfall in order to minimize the risk associated with bacterial contamination that may result from microbes being transported in runoff from land to growing waters (FAO 2005-2014).

Generally, there is a moderate risk of pathogen and parasite interaction with cultured animals when farm systems are open to the environment; however, implementation of biosecurity measures and best or better management practices, coupled with the fact that there have been few [mass] mortality events due to disease described for mussels, reduces this risk to low. The fact that production practices (especially those of natural settlement) do not increase the likelihood of pathogen amplification compared to natural populations further reinforces a low risk, and correlates to a final pathogen and parasite interaction score of 8 (out of 10).

Criterion 8: Source of Stock – independence from wild fisheries

Impact, unit of sustainability and principle

- *Impact: the removal of fish from wild populations for on-growing to harvest size in farms*
- *Sustainability unit: wild fish populations*
- *Principle: aquaculture operations use eggs, larvae, or juvenile fish produced from farm-raised broodstocks thereby avoiding the need for wild capture*

Source of stock parameters	Score
C8 % of production from hatchery-raised broodstock or natural (passive) settlement	90-100
C8 Source of stock Final Score	9.00
	GREEN

Brief Summary

The source of stock for farmed mussels comes from active collection (via dredging) and natural or passive settlement. There are very few hatcheries that supply seed to mussel culture around the world. Active collection does have the potential to impact wild mussels, but passive collection of mussel spat is much more common and not expected to have any negative impacts on the wild stock. Due to large majority of production from natural (passive) settlement, the source of stock final score for farmed mussels is 9 (out of 10).

Justification of Ranking

The independence of farmed mussels from wild mussel stocks is measured by the percent of production from hatchery-raised broodstock, natural (passive) settlement, or sustainable fisheries. The use of passively settled mussel spat dominates global production:

- The current Greenshell Mussel industry in New Zealand is based entirely on the use of wild spat that settles on seaweed or spat catching lines; however, the technology for a small-scale hatchery has been established and commercial hatchery seed production is anticipated within 5 years (FAO 2005-2014).
- *Perna viridis* culture is also based on natural spatfall, but the potential of hatchery production of spat has recently been investigated (Laxmilatha et al. 2011).
- The spat of *M. galloprovincialis* is collected from natural beds using a shovel or from collector ropes hung from rafts (FAO 2004-2014b).
- Most *M. edulis* culture depends on the use of natural spat due to the “generally abundant supply,” but hatchery technology is available and has been and could be used to enhance seed supply when there is inadequate natural supply. Hatchery-produced seeds were used in the 1970s in China and more recently in the Pacific Northwest to supplement wild-set spat. The use of hatchery spat production is not yet commonplace, but it may provide an

option for addressing the irregular spat settlement that has affected natural *M. edulis* populations over the last decade in European waters (FAO 2004-2014a).

Adequate seed collection is anticipated as the most difficult challenge in sustaining and expanding the mussel culture industry due to the recent shortages that have affected the industry in several countries (DFO 2007). In some Canadian regions, high-capacity growers supply seed to smaller growers, but most operators collect their own and culture the mussels to market size in the same vicinity as the seed collectors.

Though the use of passively settled mussel spat is the standard, active collection or dredging of spat may be employed in areas of bottom culture like the Irish Sea. Dredging for mussel seed has the potential to impact wild stock due to the disruption of the seabed, resulting in increased burial of organic material and anoxic conditions, dislodged sediment and increased turbidity, as well as dislodged mussels and non-target organisms causing increased stress or mortality (Maguire et al. 2007, Creswell and McNevin 2008).

The final numerical score for Source of Stock is 9 out of 10 due to the dominant use of the passively settled mussel spat in global production.

Criterion 9X: Wildlife and predator mortalities

A measure of the effects of deliberate or accidental mortality on the populations of affected species of predators or other wildlife. This is an “exceptional” criterion that may not apply in many circumstances. It generates a negative score that is deducted from the overall final score. A score of zero means there is no impact.

Wildlife and predator mortality parameters	Score	
C9X Wildlife and predator mortality Final Score	-2.00	GREEN
Critical?	NO	

Brief Summary

The use of passive, non-harmful barriers yields no evidence of direct or accidental mortality of predators or wildlife, while the use of visual, acoustic, or biological deterrents result in behavioral changes only. Some physical and chemical forms of fouling control may result in direct or accidental mortality of fouling organisms, but no population level effects would be expected from either method. Most off-bottom harvest techniques result in low levels of mortality of those organisms associated with mussels (mostly fouling organisms). Mortality would occur during the cleaning of ropes, poles, and stakes. In contrast, dredge harvest techniques result in mortality of wildlife beyond exceptional cases, but due to rapid recovery and some potential benefit to predators, there is no expectation of long term significant impact to the affected species’ population size. Furthermore, suspension culture is more common than on-bottom culture, reducing the risk of impact. Predator exclusion, predator deterrence, fouling control and harvest techniques are all encouraged to be conducted using best management practices. These factors contribute to the overall score of -2 (out of -10).

Justification of Ranking

Predator control methods

A variety of shellfish predators exist among mussel farms, including oyster drills, sea stars, crabs, benthic fishes, seabirds and mammals (Aypa 1990, Creswell and McNevin 2008). The losses occurring from predation by starfish, crabs, and fishes are not substantial, while diving seabirds, or ducks, have been identified as one of the most significant predators of cultured mussels and can be responsible for large losses of stock (Aypa 1990, Galbraith 1992, Lidster et al. 1994, Ross et al. 2001).

Some farming methods are more susceptible to predation than others. For example, mussel longlines are more difficult to protect than raft culture systems (Furness 1996). On some farms, control methods are not employed at all. On other farms, control methods vary by predator. For example, passive and benign barrier netting can be used to prohibit any type of predator and is usually scaled to be species specific. Duck deterrents generally fall into three categories: acoustic, biological, and visual (Draulans 1987). Biological deterrents consist of playbacks of distress or alarm calls, but they produce varying results and some duck species show no evidence of alarm or distress calls (Schmidt and Johnson 1983, Draulans 1987, Ross et al. 2001). Acoustic deterrents consist of “wailers” that emit a range of different sounds through a loud speaker, but also have varying results (Moerbeek et al. 1987, Lidster et al. 1994). Visual

deterrents consist of scarecrows, presence of workers, flashing lights, and laser lights (Lien and Hennebury 1997, Ross 2000). Sometimes, multiple deterrents are employed at the same time, e.g., visual pyrotechnics and loudspeakers. Other deterrents and predator exclusion devices that have been tried but not necessarily implemented on farms include: passive, non-harmful barriers such as biodegradable socking material and lasers, harassment such as chasing with boats, and the use of nursery sites to protect seed (Ross et al. 2001, Barbeau et al. 2006, Prince Edward Island Aquaculture Alliance 2011).

Some methods resulting in the harassment and behavioral modification of the predator (e.g., chasing with boats and visual deterrents), are usually illegal, and generally not practiced (Beveridge 2001). Moreover, aquaculturists claim that predators become habituated to such deterrents and stop responding after multiple exposures (Ross et al. 2001). In all cases, the lowest impact control methods are generally used first, graduating to higher impact methods only as needed (Flimlin and Beal 1993).

Fouling Control Strategies

The mussel aquaculture industry has the potential to be severely impacted by native and invasive fouling species that compete with mussels for space and resources, and can overgrow the stock, effectively smothering them. Most mussel farms employ physical (manual), containment or chemical methods to prevent or mitigate biofouling.

- Physical methods involve the removal of fouling organisms by hand or with the use of a high-pressure water nozzle after air/sun heat treatment of materials. High-pressure nozzles either wash off the fouling organisms or pierce them, ultimately resulting in mortality (DFO 2006, Creswell and McNevin 2008).
- Containment methods simply involve the restriction of transfer of mussels within or into fouling infested waters, especially if invasive fouling species are present (DFO 2006).
- The use of chemicals, herbicides, or pesticides is not permitted by the United States Food and Drug administration and are generally not used in global aquaculture due to their toxic effects on non-target organisms. Antifoulant coatings may be used on net surfaces, but the impact to the surrounding environment would be negligible (Creswell and McNevin 2008). Application of quicklime (CaO) to mussel socks is not regulated and has little cumulative effect on the environment (Shumway 1988). When the lime solution was employed in a recent study, the application design incorporated a lime recovery system to reduce or prevent the amount of solution entering the environment; thus reducing or preventing effects to non-target species.

While both physical and chemical methods can result in the mortality of fouling organisms, no population level effects are expected (DFO 2006).

Harvest

Methods used to harvest mussels grown in suspension generally do not result in direct impacts to predators, but may result in direct mortality of fouling or other small benthic organisms that live on and among mussels attached to poles, lines, ropes, stakes, etc.; however, mortality is expected to be low and population level effects are not expected.

Mussel harvest by dredging can result in an immediate and initial decline in abundance and biomass for all species (i.e., predators, target species and other benthic organisms) that occur on and in mussel farms, but the decline is often followed by rapid benthic recovery (Mercaldo-Allen and Goldberg 2011). While dredging may initially damage or reduce organisms associated with the substrate over which the dredge passes, scavengers and opportunistic predators may benefit from feeding on exposed prey or by colonizing newly exposed seafloor. For example, predatory fish and crustaceans increase in density in the vicinity of clam dredges (as reviewed by Mercaldo-Allen and Goldberg 2011). Additionally, dredging effects may be outweighed by the fact that suspension techniques are more common than on-bottom culture (Creswell and McNevin 2008).

Overall, mussel farms attract predators and other wildlife, but effective management and control measures limit mortality of said wildlife to exceptional cases. The final score for wildlife and predator mortalities is -2 out of -10.

Criterion 10X: Escape of unintentionally introduced species

A measure of the escape risk (introduction to the wild) of alien species other than the principle farmed species unintentionally transported during live animal shipments.

This is an “exceptional” criterion that may not apply in many circumstances. It generates a negative score that is deducted from the overall final score.

Escape of unintentionally introduced species parameters	Score	
F6.2Xa International or trans-waterbody live animal shipments (%)	9.00	
F6.2Xb Biosecurity of source/destination	0.00	
C6 Escape of unintentionally introduced species Final Score	-1.00	GREEN

Brief Summary

There is a minor percentage of trans-waterbody movement of mussel seed at the global level, but there is a high risk of introducing non-native species where it does occur due to the low biosecurity at source locations and farm destinations. This results in an overall minor deduction for the escape of unintentionally introduced species.

Justification of Ranking

The majority of mussel culture relies on the natural settlement of planktonic spat, but in some instances the movement of larger mussel seed from collection areas to farm locations has been associated with the introduction of non-native species. For example, the slipper limpet was inadvertently introduced into commercial mussel lays within the eastern Menai Strait in North Wales, UK with mussel seed from the English Channel (CCW 2009, McNeill et al. 2010).

Since the movement of mussel seed is conducted only in a small proportion of global mussel production, the reliance on animal movements is considered low (0%–10%) and a score of 9 out of 10 is allocated for Factor 6.2Xa on the international or trans-waterbody movement of live animals. Both the source and destination of these movements have low biosecurity (i.e., the source collection bed and the destination farmed mussel beds are “open” to the collection or release of non-native species), the biosecurity score is 0 out of 10. The final score for the exceptional factor 10X is a minor deduction of -1 out of -10 and reflects the minor trans-waterbody movement of mussel seed at the global level, but acknowledges the risk of introducing non-native species where it does occur.

Acknowledgements

Scientific review does not constitute an endorsement of the Seafood Watch® program, or its seafood recommendations, on the part of the reviewing scientists. Seafood Watch® is solely responsible for the conclusions reached in this report.

Seafood Watch® would like to thank Brian Kingzett of Deep Bay Field Station, Vancouver Island University, Dr. Sandra Shumway of the University of Connecticut, and one anonymous reviewer for graciously reviewing this report for scientific accuracy.

References

- Auster, P.J., R.W. Langton. 1999. The effects of fishing on fish habitat. In: Benaka, L.R. (Ed.) Fish Habitats: Essential fish habitat and Rehabilitation. American Fisheries Society Symposium 22, Bethesda, Maryland.
- Aypa, S.M. 1990. Mussel Culture. In: Fisheries and Aquaculture Department of the Fisheries and Agriculture Organization. Selected papers on mollusc culture. P. 74.
- Barbeau M.A., Hamilton D.J., Lauzon-Guay J. & Dionne M. 2006. Protective socking material for cultivated mussels: a potential non-disruptive deterrent to reduce losses to diving ducks. *Aquaculture International*. 14: 595-613.
- Barnes, P. 2006. Shellfish culture and particulate matter production and cycling: A literature review. Prepared for B.C. Aquaculture Research and Development Committee. AE 02.03-02.01. <https://www.viu.ca/csr/documents/BarnesLiteratureReviewCSR.pdf>
- Baulch, H. 1999. Clear-cutting the ocean floor: trawling gear devastates the world's continental shelves. *Alternatives Journal*. 25: 7.
- Beveridge M.C.M. Aquaculture and wildlife interactions. In: Uriarte A. (ed.), Basurco B. (ed.). Environmental impact assessment of Mediterranean aquaculture farms. Zaragoza : CIHEAM, 2001 . p. 57 -66 (Cahiers Options Méditerranéennes; n . 55).
- Bishop, D. 2004. Shallow water siting consequences. http://www.fukuina.com/articles/mar_apr97.htm Accessed May 31, 2012.
- British Columbia Shellfish Growers Association. 2001. Environmental Management System Code of Practice. http://bcsga.ca/wp-content/uploads/2011/09/Enviro-Mgmt-Code-of-Practice_02Feb7.pdf. Pp. 50.
- British Columbia Shellfish Growers Association. 2012. <http://bcsga.ca/about/frequently-asked-questions/> Accessed August 19, 2012.
- Brooks, K.M. 1993. Impacts on benthic invertebrate communities caused by aerial application of carbonyl to control burrowing shrimp in Willapa Bay, WA IN: Abstracts of technical papers presented at the 85th annual meeting of the National Shellfisheries Association, Portland, Oregon, May 31-June 3 199. *Journal of Shellfish Research* 12: 146.
- Burkholder, D. and S.E. Shumway. 2011. Bivalve shellfish aquaculture and eutrophication. In: Shumway, S.E. (Ed.) *Shellfish Aquaculture and the Environment*. United Kingdom: Wiley-Blackwell. Pp: 155-215.

Chamberlain, J., T.F. Fernandes, P. Read, T.D. Nickell, I.M. Davies. 2001. Impacts of biodeposits from suspended mussel (*Mytilus edulis* L.) culture on the surrounding surficial sediments. *Journal of Marine Science*. 58:411–416.

Chen L., C. Zhu, S. Dong. 2011. Aquaculture site selection and carrying capacity management in China. *Guandong Agricultural Sciences*. 21: 1-7.

Coen, L.D. 1995. A review of the potential impacts of mechanical harvesting on subtidal and intertidal shellfish resources. Prepared for South Carolina Department of Natural Resources. Pp. 46.

Coen, L.D., B.R. Dumbauld, M.L. Judge. 2011. Expanding shellfish aquaculture: a review of the ecological services provided by and impacts of native and cultured bivalves in shellfish-dominated ecosystems. In: Shumway, S.E. (Ed.) *Shellfish Aquaculture and the Environment*. United Kingdom: Wiley-Blackwell. Pp: 239-295.

Collie, J.S., G.A. Escanero, P.C. Valentine. 1997. Effects of bottom-fishing on the benthic megafauna of George's Bank. *Marine Ecology Progress Series*. 155: 159-172.

Countryside Council for Wales. 2009. Advice provided by the Countryside Council for Wales in fulfillment of Regulation 33 of the Conservation (natural habitats, &c.) Regulations 1994. Comprising Y Fenai a Bae Conwy / Menai Strait and Conwy Bay Special Area of Conservation/ Traeth Lafan Special Protection Area Ynys Seiriol / Puffin Island Special Protection Area. Issue 2. 74 pp.

Creswell, R.L., A.A. McNevin. 2008. Better management practices for bivalve molluscan aquaculture. In: Tucker, C.S. and J.A. Hargreaves. *Environmental best management practices for aquaculture*. Iowa: Blackwell Publishing. Pp. 427-486.

Dame, R.F. 1993. Bivalve filter feeders in estuarine and coastal processes. *NATO ASI Series G: ecological sciences* 33. Springer, Heidelberg.

Department of Fisheries and Oceans Canada (DFO), Aquaculture Science Branch. 2010. Containment and mitigation of nuisance tunicates on Prince Edward Island to improve mussel farm productivity. *Aquaculture Collaborative Research and Development Program Fact Sheet*. Issue 6.

Department of Fisheries and Oceans (DFO) Canada. 2007. Seeding an industry: mussel culture in Newfoundland. *DFO Science*. <http://www.dfo-mpo.gc.ca/science/publications/article/2007/03-12-2007-eng.htm> (Accessed March 21, 2013).

Dewey, W., J.P. Davis, D.C. Cheney. 2011. Shellfish aquaculture and the environment: an industry perspective. In: Shumway, S.E. (Ed.) *Shellfish Aquaculture and the Environment*. United Kingdom: Wiley-Blackwell. Pp: 33-50.

Dolmer, P., H.T. Christensen, B.W. Hansen, B. Vismann. 2012. Area-intensive bottom culture of blue mussels *Mytilus edulis* in a micro-tidal estuary. *Aquaculture Environment Interactions*. 3: 81-91.

Dorsey, E.M., J. Pederson. (Eds.) 1998. Effects of fishing gear on the sea floor of New England. In: *Effects of trawling and dredging on the seafloor habitat (2002)* Ocean Studies Board (OSB). MIT Sea Grant Publication 98-4, Boston, MA.

Draulans, D. 1987. The effectiveness of attempts to reduce predation by fish-eating birds: a review. *Biological Conservation*. 41: 219–232.

Eggermont, M., A. Tamanji, N. Nevejan, P. Bossier, P. Sorgeloos, T. Defoirt. 2014. Stimulation of heterotrophic bacteria associated with wild-caught blue mussel (*M. edulis*) adults results in mass mortality. *Aquaculture*. 431: 136-138.

Ferreira, J.G., A.J.S. Hawkins, S.B. Bricker. 2007. Management of productivity, environmental effects, and profitability of shellfish aquaculture – the Farm Aquaculture Resource Management (FARM) model. *Aquaculture*. 264: 160-174.

Ferreira, J.G., A.J.S. Hawkins, S.B. Bricker. 2011. The role of shellfish farms in provision of ecosystem goods and services. In: Shumway, S.E. (Ed.) *Shellfish Aquaculture and the Environment*. United Kingdom: Wiley-Blackwell. Pp: 3-31.

Figueras, A.J., C.F. Jardon, J.R. Caldas. 1991. Diseases and parasites of rafted mussels (*Mytilus galloprovincialis*): preliminary results. *Aquaculture*. 99: 17-33.

Flimlin, G., B.F. Beal. 1993. Major predators of cultured shellfish. *Northeast Regional Aquaculture Center Bulletin*. 180: 1-6.

Flimlin, G., S. MacFarlane, E. Rhodes, K. Rhodes. 2010. *Best Management Practices for the East Coast Shellfish Aquaculture Industry*. East Coast Shellfish Growers Association. 81 pp.

Food and Agriculture Organization (FAO) of the United Nations. 2004-2014a. Cultured Aquatic Species Information Programme. *Mytilus edulis*. Cultured Aquatic Species Information Programme. **Text by Gouletquer, P.** In: *FAO Fisheries and Aquaculture Department* [online]. Rome. Updated 1 January 2004. [Cited 17 August 2014].

http://www.fao.org/fishery/culturedspecies/Mytilus_edulis/en#tcNA00B1

Food and Agriculture Organization (FAO) of the United Nations.. © 2004-2014b. 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 7 June 2005. [Cited 17 August 2014].

http://www.fao.org/fishery/culturedspecies/Mytilus_galloprovincialis/en

Food and Agriculture Organization (FAO) of the United Nations.. © 2005-2014. Cultured Aquatic Species Information Programme. *Perna canaliculus*. Cultured Aquatic Species Information Programme. **Text by Kaspar, H.** In: *FAO Fisheries and Aquaculture Department* [online]. Rome. Updated 11 April 2005. [Cited 17 August 2013].
http://www.fao.org/fishery/culturedspecies/Perna_canaliculus/en

Food and Agriculture Organization (FAO) of the United Nations.2007-2013. National Aquaculture Legislation Overview. Canada. National Aquaculture Legislation Overview (NALO) Fact Sheets. **Text by Jull, C.** In: *FAO Fisheries and Aquaculture Department* [online]. Rome. Updated 21 February 2007. [Cited 22 September 2013].
http://www.fao.org/fishery/legalframework/nalo_canada/en

Food and Agriculture Organization (FAO) of the United Nations. 2004. The hatchery culture of bivalves: a practical manual. FAO Fisheries Technical Paper – T471. Pp. 201.

Food and Agriculture Organization (FAO) of the United Nations.2004-2014. National Aquaculture Legislation Overview. China. National Aquaculture Legislation Overview (NALO) Fact Sheets. Text by Spreij, M. In: *FAO Fisheries and Aquaculture Department* [online]. Rome. Updated 3 May 2004. [Cited 10 October 2014].
http://www.fao.org/fishery/legalframework/nalo_china/en

Food and Agriculture Organization (FAO) of the United Nations. 2006-2014. National Aquaculture Legislation Overview. New Zealand. National Aquaculture Legislation Overview (NALO) Fact Sheets. Text by Skonhøft, A. In: *FAO Fisheries and Aquaculture Department* [online]. Rome. Updated 9 May 2006. [Cited 10 October 2014].
http://www.fao.org/fishery/legalframework/nalo_newzealand/en

Food and Agriculture Organization (FAO) of the United Nations. 2005-2014. National Aquaculture Legislation Overview. Spain. National Aquaculture Legislation Overview (NALO) Fact Sheets. Text by Olivert, A.A. In: *FAO Fisheries and Aquaculture Department* [online]. Rome. Updated 16 May 2005. [Cited 10 October 2014].
http://www.fao.org/fishery/legalframework/nalo_spain/en

Food and Agriculture Organization (FAO) of the United Nations. 2013. Yearbook of Fisheries Statistics extracted with FishStatJ (Copyright 2013). Fisheries database: Aquaculture production quantities 1950-2010; aquaculture production values 1984-2010; capture production 1960-2010; Commodities Production and Trade 1976-2010.
<http://www.fao.org/fishery/statistics/en>. Accessed April 2013.

Food and Agriculture Organization of the United Nations. 2013. Fisheries and Aquaculture Department. Species Fact Sheets. *Perna viridis*. <http://www.fao.org/fishery/species/2691/en> Accessed April 2013.

- Ford, S.E. 2001. Pests, parasites, diseases, and defense mechanisms. In: Krauter, J.N., M. Castagna (eds.). *Biology of the hard clam*. Elsevier: The Netherlands.
- Furness, R.W. 1996. Interactions between seabirds and aquaculture in sea lochs, In: *Aquaculture and Sea Lochs*, Black, K.D. (ed.). Scottish Association for marine Science, Dunstaffnage Marine Laboratory, Oban, pp. 50-55.
- Getchis, T.L., C.M. Rose. 2011. Balancing economic development and conservation of living marine resources and habitats: the role of resource managers. In: Shumway, S.E. (Ed.) *Shellfish Aquaculture and the Environment*. United Kingdom: Wiley-Blackwell. Pp: 425-446.
- Giles, H., N. Broekhuizen, K.R. Bryan, C.A. Pilditch. 2009. Modeling the dispersal of biodeposits from mussel farms: the importance of simulating biodeposit erosion and decay. *Aquaculture*. 291: 168-178.
- Guo, X., S.E. Ford, F. Zhang. 1999. Molluscan Aquaculture in China. *Journal of Shellfish Research*. 18: 19-31.
- Hedgecock, D. 2011. Genetics of shellfish on a human-dominated planet. . In: Shumway, S.E. (Ed.) *Shellfish Aquaculture and the Environment*. United Kingdom: Wiley-Blackwell. Pp: 339-357.
- Jory, D.E., M.R. Carriker, E.S. Iversen. 1984. Preventing predation in molluscan mariculture: an overview. *Journal of World Mariculture Society*. 15: 421-432.
- Laxmilatha, P., G.S. Rao, P. Patnaik, T. Nageshwara Rao, M. Prasad Rao, Biswajit Dash. 2011. Potential for hatchery production of spat of the green mussel *Perna viridis* Linnaeus (1758). *Aquaculture*. 312: 88-94.
- Lee, R., A. Lovatelli, L. Ababouch. 2008. Bivalve depuration: fundamental and practical aspects. Food and Agriculture Organization of the United Nations. *FAO Fisheries Technical Paper No. 511*. 161 pp.
- Levy, S. 1998. Watery wastelands. *New Scientist*. 158: 40-44.
- Lidster, W., Ryan, P., and Baldwin, C. 1994. Saving Cultured Mussels and Waterfowl in Newfoundland. Summary report by the Canadian Wildlife Service. 35 pp.
- Lien, J., and Hennebury, P. 1997. You can fool all of the ducks some of the time; you can fool some of the ducks all of the time; but you can't fool all of the ducks all of the time: an investigation of diving duck predation on farmed mussels, and evaluation of a harassment procedure to minimize it. Report for the Department of Agriculture, Fisheries and Forestry, Government of PEI and the Department of Fisheries, Government of Nova Scotia. 69 pp.

- Loosanoff, V.L., C.L. MacKenzie, L.W. Shearer. 1960. Use of chemicals to control shellfish predators. *Science*. 131: 1522-1523.
- Lloyd, B.D. 2003. Potential effects of mussel farming on New Zealand's marine mammals and seabirds: a discussion paper. Department of Conservation, Wellington. vii + 34 p.
- Maguire, J.A. and 17 others. 2007. Management recommendations for the sustainable exploitation of mussel seed in the Irish Sea. *Marine Environment and Health Series*, No. 31. Reference No. ST/02/03. 87 pp.
- McKindsey, C.W., P. Archambault, M.D. Callier, F. Olivier. 2011. Influence of suspended and off-bottom mussel culture on the sea bottom and benthic habitats: a review. *Canadian Journal of Zoology*. 89: 622-646.
- McNeill, G., J. Nunn, D. Minchin. 2010. The slipper limpet *Crepidula fornicata* Linnaeus 1758 becomes established in Ireland. *Aquatic Invasions*. 5 (Supplement 1): S21-S25.
- Mercado-Allen, R., R. Goldberg. 2011. Review of the ecological effects of dredging in the cultivation and harvest of molluscan shellfish. NOAA technical memorandum NMFS-NE-220. pp. 84.
- Moerbeek, D. J., W.H. van Dobben, E.R. Osieck, G.C. Boere, G. C., and C.M. Bungenberg de Jong. 1987. Cormorant damage prevention at a fish-farm in the Netherlands. *Biological Conservation*. 39: 23-38.
- Morse, D., M.A. Rice. 2010. Mussel aquaculture in the Northeast. Northeastern Regional Aquaculture Center Publication No. 211-2010. Pp. 10.
- Munford, J.G., L. DaRos, R. Strada. 1981. A study on the mass mortality of mussels in the Laguna Veneta. *Journal of the World Aquaculture Society*. 12(2): 186-199.
- Netherlands Business Support Office (NBSO) Dalian. 2010. An overview of China's aquaculture. 24pp. http://china.nlbassade.org/binaries/content/assets/postenweb/c/china/zaken-doen-in-china/import/kansen_en_sectoren/agrofood/rapporten_over_agro_food/an-overview-of-chinas-aquaculture
- Norkko, A., J.E. Hewitt, S.F. Thrush, G.A. Funnell. 2001. Benthic-pelagic coupling and suspension-feeding bivalves: linking site specific sediment flux and biodeposition to benthic community structure. *Limnology and Oceanography*. 46: 2067-2072.
- OIE. 2011. Manual of diagnostic tests for aquatic animals. <http://www.oie.int/international-standard-setting/aquatic-manual/access-online/> Accessed August 2012.

OIE. 2012. Aquatic animal health code. <http://www.oie.int/international-standard-setting/aquatic-code/access-online/> Accessed August 2012.

Pacific Coast Shellfish Growers Association (PCGSA). 2001. Environmental Policy. <http://www.pcsga.org/pub/uploads/EPS.pdf>. Pp. 12.

Padilla, D.K., M.J. McCann, S.E. Shumway. 2011. Marine invaders and bivalve aquaculture: sources, impacts, and consequences. In: Shumway, S.E. (Ed.) Shellfish Aquaculture and the Environment. United Kingdom: Wiley-Blackwell. Pp: 395-424.

Pinnell, N. 2008. Mussel Aquaculture Industry Development Experiences in Different Jurisdictions. Literature Review 1 for the Golden Mussel Project. Canadian Centre for Community Renewal (CCCR) The BC_Alberta Social Economy Research Alliance. Pp. 68. www.socialeconomy-bcalberta.ca Accessed April 3, 2013.

Prince Edward Island Aquaculture Alliance. 2011. Workshop: Mitigating the impact of sea duck predation on PEI mussel farms. Program: http://www.aquaculturepei.com/media/whats_new/whats_new40.pdf. Accessed April 30, 2013.

Ragnarsson, S.A.,D. RaVaelli. 1999. Effects of the mussel *Mytilus edulis* L. on the invertebrate fauna of sediments. Journal of Experimental Marine Biology and Ecology. 241: 31–43.

Ross, B. P. 2000. The manipulation of feeding behaviour of diving ducks on mussel farms. PhD Thesis. University of Glasgow. 130 pp.

Ross, B.P., J. Lien, R.W. Furness. 2001. Use of underwater playback to reduce impact of eiders on mussel farms. ICES Journal of Marine Science. 58: 517-524.

Sapkota, A., A. R. Sapkota, M. Kucharski, J. Burke, S. McKenzie, P. Walker, R. Lawrence. 2008. Aquaculture practices and potential human health risks: Current knowledge and future priorities. Environmental International. 34: 1215-1226.

Schmidt, R. H., and Johnson, R. J. 1983. Bird dispersal recordings: an overview. In Vertebrate Pest Control and Management Materials: Fourth Symposium, ASTM STP 817, pp. 43–65. Ed. by D. E. Kaukeinen. American Society for Testing and Materials, Philadelphia.

Shellfish Association of Great Britain. 2008. Shellfish Industry Development Strategy: A Case for Considering MSC Certification for Shellfish Cultivation Operations. <http://www.shellfish.org.uk/files/26238Impacts%20of%20Shellfish%20Aquaculture%20on%20the%20Environment.pdf> (Accessed April 1, 2013).

- Shumway, S. E., D. Card, R. Getchell, C. Newell. 1988. Effects of calcium oxide (quicklime) on non-target organisms in mussel beds. *Bulletin of Environmental Contamination and Toxicology*. 40:503-509.
- Shumway, S.E. (Ed.) 2011. *Shellfish Aquaculture and the Environment*. United Kingdom: Wiley-Blackwell. Pp: 507.
- Smith, J., S.E. Shackley. 2004. Effects of a commercial mussel *Mytilus edulis* lay on a sublittoral, soft sediment benthic community. *Marine Ecology Progress Series*. 282:185–191.
- Stokesbury, K.D.E., E.P. Baker, B.P. Harris, R.B. Rheault. 2011. Environmental impacts related to mechanical harvest of cultured shellfish. In: Shumway, S.E. (Ed.) *Shellfish Aquaculture and the Environment*. United Kingdom: Wiley-Blackwell. Pp: 319-338.
- Tollefson, C., & Scott, R. (2006). Charting a course: Shellfish aquaculture and indigenous rights in New Zealand and British Columbia. *BC Studies*, 150, 3-43.
- Varenes, E. S.A. Hanssen, J. Bonardelli, M. Guillemette. 2013. Sea duck predation in mussel farms: the best nets for excluding common eiders safely and efficiently. *Aquaculture Environment Interactions*. 4: 31-39.
- Villalba, A., S.G. Mourelle, M.J. Carballal, 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.
- Watson, D.I., S.E. Shumway, R.B. Whitlatch. 2009. Biofouling and the shellfish industry. In: Shumway, S.E. and G.E. Rodrick (Ed.) *Shellfish safety and quality*. Cambridge: Woodhead Publishing Limited. Pp: 317-336.
- Weise, A.M., C.J. Cromey, M.D. Callier, P. Archambault, J. Chamberlain, C.W. McKindsey. 2009. Shellfish-DEPOMOD: modeling the biodeposition from suspended shellfish aquaculture assessing benthic effects. *Aquaculture*. 288: 239-253.
- Yamamuro, M., J.I. Hiratsuka, Y. Ishitoba, S. Hokosawa, Y. Nakamura. 2006. Ecosystem shift resulting from loss of eelgrass and other submerged vegetation in two estuarine lagoons, Lake Nakaumi and Lake Shinji Japan. *Journal of Oceanography*. 62: 551-558.

Appendix 1: Data points and all scoring calculations

This is a condensed version of the criteria and scoring sheet to provide access to all data points and calculations. See the Seafood Watch Aquaculture Criteria document for a full explanation of the criteria, calculations and scores. Yellow cells represent data entry points.

Criterion 1: Data quality and availability

Data Category	Relevance (Y/N)	Data Quality	Score (0-10)
Industry or production statistics	Yes	7.5	7.5
Effluent	Yes	10	10
Locations/habitats	Yes	7.5	7.5
Predators and wildlife	Yes	10	10
Chemical use	Yes	7.5	7.5
Feed	Yes	Not relevant	enter score
Escapes, animal movements	Yes	10	10
Disease	Yes	10	10
Source of stock	Yes	7.5	7.5
Other – (e.g., GHG emissions)	Yes	Not relevant	enter score
Total			70

C1 Data Final Score	8.75	GREEN
----------------------------	------	--------------

Criterion 2: Effluents

Effluent Rapid Assessment

C2 Effluent Final Score	10.00	GREEN
--------------------------------	--------------	--------------

Criterion 3: Habitat

3.1 Habitat conversion and function

F3.1 Score	9
-------------------	----------

3.2 3.2 Habitat and farm siting management effectiveness (appropriate to the scale of the industry)

Factor 3.2a – Regulatory or management effectiveness

Question	Scoring	Score
1 - Is the farm location, siting and/or licensing process based on ecological principles, including any EIAs requirement for new sites?	Yes	1
2 - Is the industry's total size and concentration based on its cumulative impacts and the maintenance of ecosystem function?	Mostly	0.75
3 – Is the industry's ongoing and future expansion appropriate locations, and thereby preventing the future loss of ecosystem services?	Yes	1
4 - Are high-value habitats being avoided for aquaculture siting? (i.e., avoidance of areas critical to vulnerable wild populations; effective zoning, or compliance with international agreements such as the Ramsar treaty)	Yes	1
5 - Do control measures include requirements for the restoration of important or critical habitats or ecosystem services?	Moderately	0.5
		4.25

Factor 3.2b – Siting regulatory or management enforcement

Question	Scoring	Score
1 - Are enforcement organizations or individuals identifiable and contactable, and are they appropriate to the scale of the industry?	Mostly	0.75
2 - Does the farm siting or permitting process function according to the zoning or other ecosystem-based management plans articulated in the control measures?	Yes	1
3 - Does the farm siting or permitting process take account of other farms and their cumulative impacts?	Mostly	0.75
4 - Is the enforcement process transparent— e.g., public availability of farm locations and sizes, EIA reports, zoning plans, etc.?	Yes	1
5 - Is there evidence that the restrictions or limits defined in the control measures are being achieved?	Partly	0.25
		3.75

F3.2 Score (2.2a*2.2b/2.5)	6.38
---------------------------------------	------

C3 Habitat Final Score	8.13	GREEN
	Critical?	NO

Criterion 4: Evidence or Risk of Chemical Use

Chemical Use parameters	Score	
C4 Chemical Use Score	10.00	
C4 Chemical Use Final Score	10.00	GREEN

Critical?	NO
-----------	----

Criterion 5: Feed

C5 Feed Final Score	10.00	GREEN
	Critical?	NO

Criterion 6: Escapes

6.1a. Escape Risk

Escape Risk	0
-------------	---

Recapture & Mortality Score (RMS)	
Estimated % recapture rate or direct mortality at the escape site	40
Recapture & Mortality Score	0.4
Factor 6.1a Escape Risk Score	4

6.1b. Invasiveness

Part B – Non-Native species

Score	2.5
-------	-----

Part C – Native and Non-native species

Question	Score
Do escapees compete with wild native populations for food or habitat?	Yes
Do escapees act as additional predation pressure on wild native populations?	No
Do escapees compete with wild native populations for breeding partners or disturb breeding behavior of the same or other species?	No
Do escapees modify habitats to the detriment of other species (e.g. by feeding, foraging, settlement or other)?	To some extent
Do escapees have some other impact on other native species or habitats?	To some extent
	3

F 6.1b Score	5.5
---------------------	------------

Final C6 Score	4.00	YELLOW
	Critical?	NO

Criterion 7: Diseases

Pathogen and parasite parameters	Score	
C7 Biosecurity	8.00	
C7 Disease; pathogen and parasite Final Score	8.00	GREEN
Critical?	NO	

Criterion 8: Source of Stock

Source of stock parameters	Score	
C8 % of production from hatchery-raised broodstock or natural (passive) settlement	90	
C8 Source of stock Final Score	9	GREEN

Factor 9X: Wildlife Mortalities

Wildlife and predator mortality parameters	Score	
F3.3X Wildlife and predator mortality Final Score	-2.00	GREEN
Critical?	NO	

Factor 10X: Escape of unintentionally introduced species

Escape of unintentionally introduced species parameters	Score	
F6.2Xa International or trans-waterbody live animal shipments (%)	9.00	
F6.2Xb Biosecurity of source/destination	0.00	
F6.2X Escape of unintentionally introduced species Final Score	-1.00	GREEN