Clams

Anadara spp., *Venerupis* spp., *Ruditapes* spp., *Mercenaria mercenaria*, *Protothaca staminea*, *Mya arenaria*, *Sinonovacula constricta*, *Scapharca broughtnii*, *Meretrix lusoria*, *Cerastoderma edule*, *Clinocardium nuttallii*, *Austrovenus stutchburyi*

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Worldwide

Bottom and Off-Bottom Culture

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Final Seafood Recommendation

Updated: See Appendix 2 for Justification

Criterion	Score	Rank	Critical?
C1 Data	7.96	GREEN	
C2 Effluent	10.00	GREEN	NO
C3 Habitat	7.20	GREEN	NO
C4 Chemicals	8.00	GREEN	NO
C5 Feed	10.00	GREEN	NO
C6 Escapes	4.00	YELLOW	NO
C7 Disease	7.00	GREEN	NO
C8X Source	–2.00	GREEN	NO
C9X Wildlife mortalities	–2.00	GREEN	NO
C10X Introduced species escape	–2.40	GREEN	
Total	**47.76**		
Final score (0–10)	**6.82**		

OVERALL RANKING

Final Score	6.82
Initial rank	GREEN
Red criteria	0
Interim rank	GREEN
Critical Criteria?	NO

FINAL RANK
GREEN

Scoring note: scores range from 0 to 10, where 0 indicates very poor performance and 10 indicates the aquaculture operations have no significant impact. Criteria 8X, 9X, and 10X are exceptional criteria, where 0 indicates no impact and a deduction of –10 reflects a very significant impact. Two or more Red criteria result in a Red final result.

Summary

The final numerical score for clams produced globally is 6.82 out of 10. With a numerically Green-ranked score, and no Red-ranked criteria, the final rating is Green and a recommendation of "Best Choice."

Executive Summary

This assessment was originally published in April 2018 and reviewed for any significant changes in November 2022. Updates were made to Criterion 1—Data and Criterion 6—Escapes, but did not result in a change to the report rating. See Appendix 2 for details of review.

This Seafood Watch assessment involves a number of different criteria covering impacts associated with effluent, habitats, wildlife and predator interactions, chemical use, feed production, escapes, introduction of nonnative organisms (other than the farmed species), disease, the source stock, and general data availability. The species under consideration here are clam species, produced globally, that are available to consumers in the United States. Approximately 5,392,277 metric tons (MT) of clams, cockles, and arkshells (excludes Pacific geoduck) were produced through aquaculture globally in 2015 (FAO 2018). Approximately 24,300 MT of clam products were imported to the U.S. in 2015 from around the world (NMFS 2016). Because of the similarity of clam farming techniques used worldwide, with most clams available in the United States either produced domestically or imported primarily from China, and some from Canada and Vietnam, the scores were sometimes focused on North America and Asia to reflect the clams available on the U.S. market.

Data

There are abundant research publications regarding the biology, production, and potential environmental impacts of farmed clams, especially for those cultured in North America. Fewer publications are readily available for those clam species cultured in Asia, which is where most production comes from, and many publications are not translated. The most recent reliable information regarding production statistics is available in reports or databases produced by international organizations such as the Food and Agriculture Organization (FAO) and national or state governments. Therefore, information was available, and data quality and availability are considered robust. The final score for Criterion 1—Data is 7.96 out of 10.

Effluent

Farmed clams are not provided external feed or nutrient fertilization. Effluent may be released from the hatchery or nursery phases, but this is not considered to have any negative effects on the environment, and filter-feeding of clams during grow-out is often cited as improving water quality and/or nutrient cycling near farms. In isolated cases, antipredator netting or other plastics may be unintentionally released from the farm, but this is not typical, particularly in regions that globally dominate clam production. Therefore, the Evidence-Based Assessment was used to determine that there is low to no concern regarding resultant effluent or waste impacts, and the score for Criterion 2—Effluent is 10 out of 10.

Habitat

Farmed clam grow-out operations are primarily located in intertidal or shallow subtidal environments of estuaries, coastal lagoons, and bays, all of which are generally considered high-value environments. But, the impact of farmed clam operations on habitat is considered minimal, with the main concerns stemming from biodeposition and harvest. The lack of impact coupled with reasonably robust regulation and enforcement regarding licensing and site selection results in a final score of 7 out of 10 for Criterion 3—Habitat.

Chemical Use

No chemicals are known to be used during the grow-out phase of clam culture in North America. Evidence shows that best management practices for clam farming designate manual labor (e.g., hand removal, pressure washing, freshwater baths, and/or air drying) to prevent and remove predators and fouling from gear, and that improved husbandry and cleaning methods, rather than antibiotics, are employed to prevent bacterial infections. But, there is some evidence of chemical use in China; namely, to remove predators and competitors. Therefore, the final score for Criterion 4—Chemical Use is 8 out of 10.

Feed

External feed is not provided to farmed clams. Therefore, the final score for Criterion 5—Feed is 10 out of 10.

Escapes

Many farmed clam species are cultured within their native ranges. The risk of escape is considered moderate to high because, although farmed clams are infaunal and escape mitigation management practices are in place, there is a risk of spawning events occurring before harvest. But, the risk of ecological impact is low; where clams are farmed within their native range, they typically have high genetic similarity to their wild counterparts, and where they are farmed outside their native range, they have been ecologically established for several decades. Ultimately, there is little evidence available to support negative effects of escaped clams on ecosystems or wild populations. Therefore, the final score for Criterion 6—Escapes is 4 out of 10.

Disease

Diseases in farmed clams can occur at every stage of production, from the hatchery to grow-out. Farmed clam grow-out systems are open to the natural environment, and there is the possibility of disease exchange between wild and farmed animals. But, biosecurity measures that reduce the risk of parasite and pathogen infection have been put in place from the individual farm level to the intergovernmental and international levels. This score is further improved by the fact that best management practices and/or environmental management codes of practice are in place. Thus, the final score for Criterion 7—Disease is 7 out of 10.

Source of Stock

Globally, because of the lack of data on seed used by farmers, the percentage of production from farm-raised broodstock or natural (passive) settlement is difficult to quantify. It appears that in both Asia and North America, approximately 80% of stock is from domesticated, farm-raised stock, while approximately 20% may come from wild collection (either as adult broodstock or spat). But, the removal of wild clams for broodstock or spat is not known to have any definitive negative impacts on the wild stock, and it is beneficial in reducing the ecological risks associated with domestic selection across generations. Because of the lack of information available to quantify this score, the source of stock criterion score was based on the available data. Thus, the final score for Criterion 8X—Source of Stock is –2 out of –10.

Wildlife and Predator Mortalities

Aquaculture operations can attract a variety of predators and result in direct or indirect mortality from trapping, entanglement, drowning, etc. Predator exclusion devices used on clam farms are usually in the form of netting or mesh bags (both are passive barriers), which would typically not result in direct or accidental mortality of predators or other wildlife; however, mechanical harvest of farmed clams by dredging has the potential to affect clam predators or other wildlife attracted to clam farms. This impact is mitigated by best management practices and preventative measures and would not result in a population-level effect. Therefore, clam farming has a low impact on predators or other wildlife. The final score for Criterion 9X—Wildlife and Predator Mortalities is –2 out of –10.

Unintentional Species Introductions

There are international, national, and regional regulations and permitting requirements in place to prevent the spread of nonnative species. There is known to be shipment of live clams, particularly larvae and seed, between hatcheries, nurseries, and farms. This is necessary in the industry because the production of seed is costly and intensive, which means that relatively few hatcheries and nurseries exist to supply the industry. The final score for Criterion 10X: Escape of Unintentionally Introduced Species is –2.4 out of –10.

Summary

The final numerical score for clams produced globally is 6.82 out of 10. With a numerically Green-ranked score, and no Red-ranked criteria, the final rating is Green with a recommendation of “Best Choice.”

Table of Contents

Introduction

Scope of the analysis and ensuing recommendation

Species
Farmed clams available on the U.S. market include: *Anadara* spp., *Cyclina* spp., *Mercenaria* spp., *Meretrix* spp., *Ruditapes* spp., *Sinonovacula* spp., *Mya* spp., *Venerupis* spp., Clinocardium nuttallii, and Austrovenus stutchburyi

Geographic Coverage
This report assesses clam production worldwide (with emphasis on the United States, Canada, and China). Methods for culturing clams are similar worldwide.

Production Method(s)
Grow-out methods are assessed and focused on "seeding" juvenile clams in a variety of substrates—from mud to sand and gravel—in intertidal or shallow subtidal zones. Seeding methods can involve "planting" young clams and sometimes laying a plastic mesh cover to reduce predation. Other similar methods can include the use of large polyester mesh bags, which the young clams are placed in and "planted," again to reduce predation and prevent escapes.

Species Overview

Brief Overview of the Species
The word "clam" is a broad term, often used to describe species of molluscs in the class Bivalvia. For the purpose of this report, the focus is on infaunal species, which burrow into intertidal or subtidal sediments, excluding geoducks (these have a separate report). The general clam life cycle includes separate-sex parents (some individuals and species are hermaphroditic), fertilization of gametes in the water column, larval developmental stages, settlement, and a final adult stage (Figure 1).

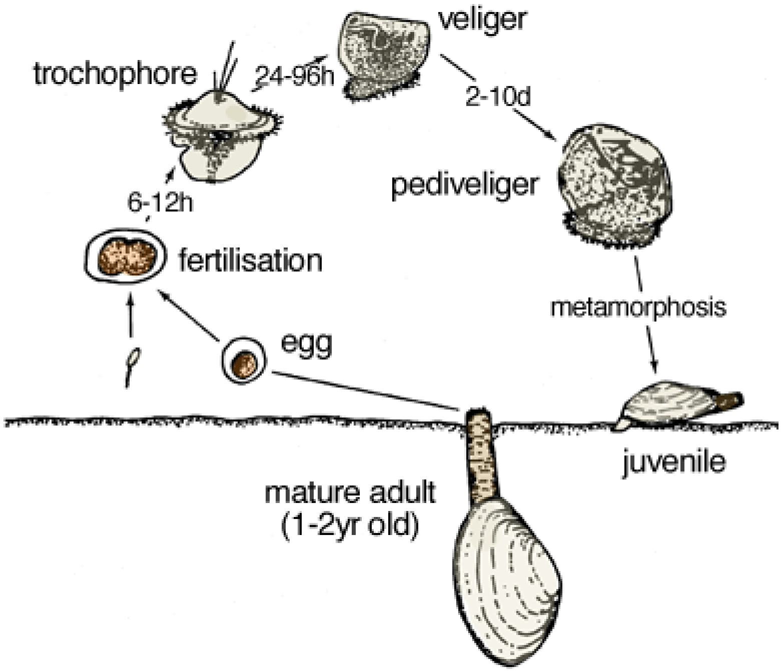

Figure 1: The general clam lifecycle. Note that timeframes in the figure vary by species and environmental conditions. Image from http://www.asnailsodyssey.com/LEARNABOUT/CLAM/clamRepr.php

There are hundreds of species of clams, cockles, and arkshells; this report will focus on the major edible species that are produced globally. Clams that are available in the United States may be grown domestically or imported from Canada, Asian countries (namely China, but also Vietnam, Korea, and Japan), and others.

Production System

Production systems are similar worldwide. The industry primarily relies on "seedlings" raised in hatcheries and nurseries until they are large enough to be "planted" in intertidal or subtidal substrates (Figure 2, Figure 3). Clam growers must choose suitable substrates and beach zones to plant their clams.

This assessment will focus on the grow-out stage of production in the intertidal or subtidal zone. Grow-out methods can involve "planting" young clams and possibly laying a plastic mesh cover to reduce predation. Other similar methods can include the use of large polyester mesh bags, which the young clams are placed in and "planted," again to reduce predation.

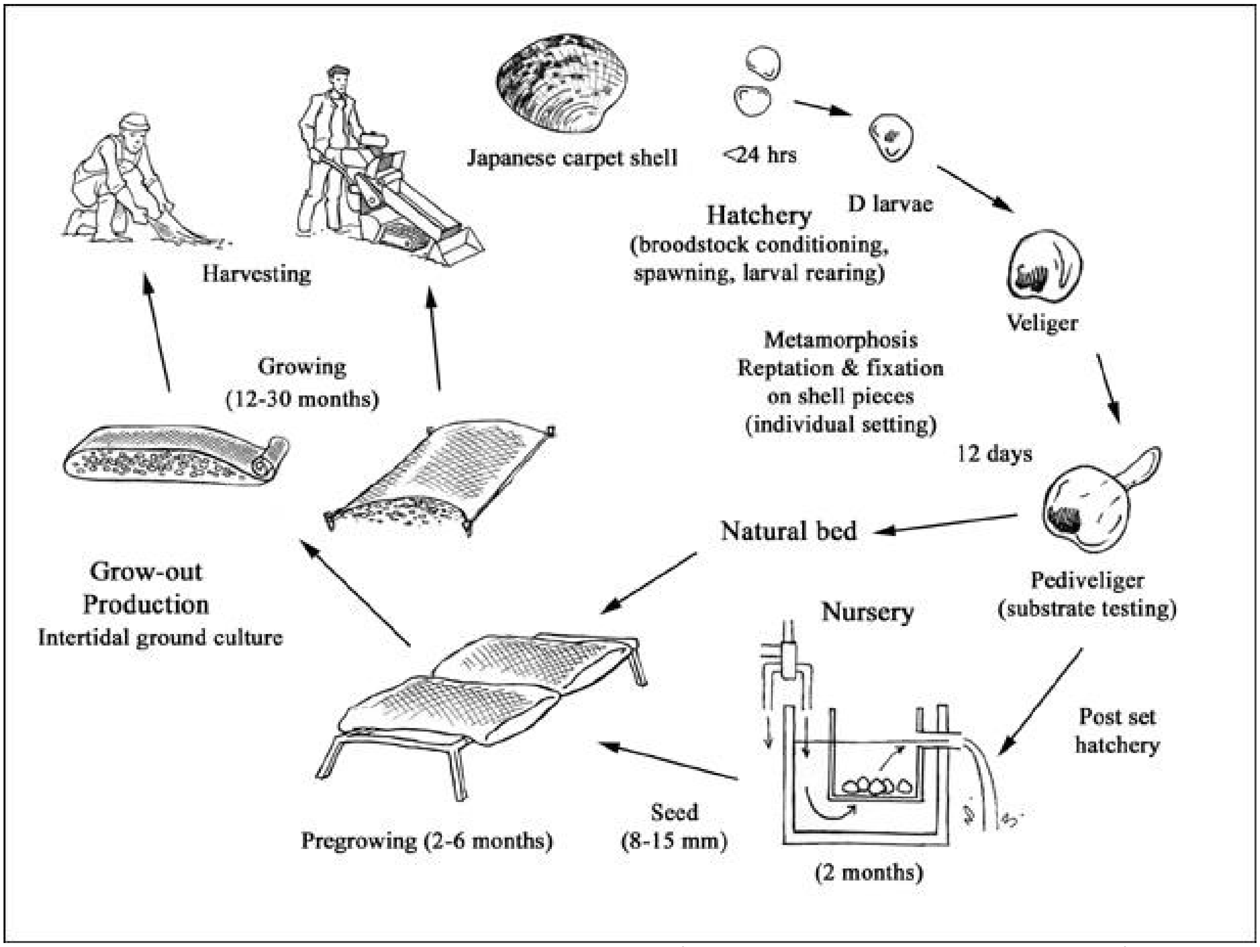

Figure 2: Production cycle of *Ruditapes philippinarum* (Japanese carpet shell or Manila clam). Image from http://www.fao.org/fishery/culturedspecies/Ruditapes_philippinarum/en#tcNA00C5

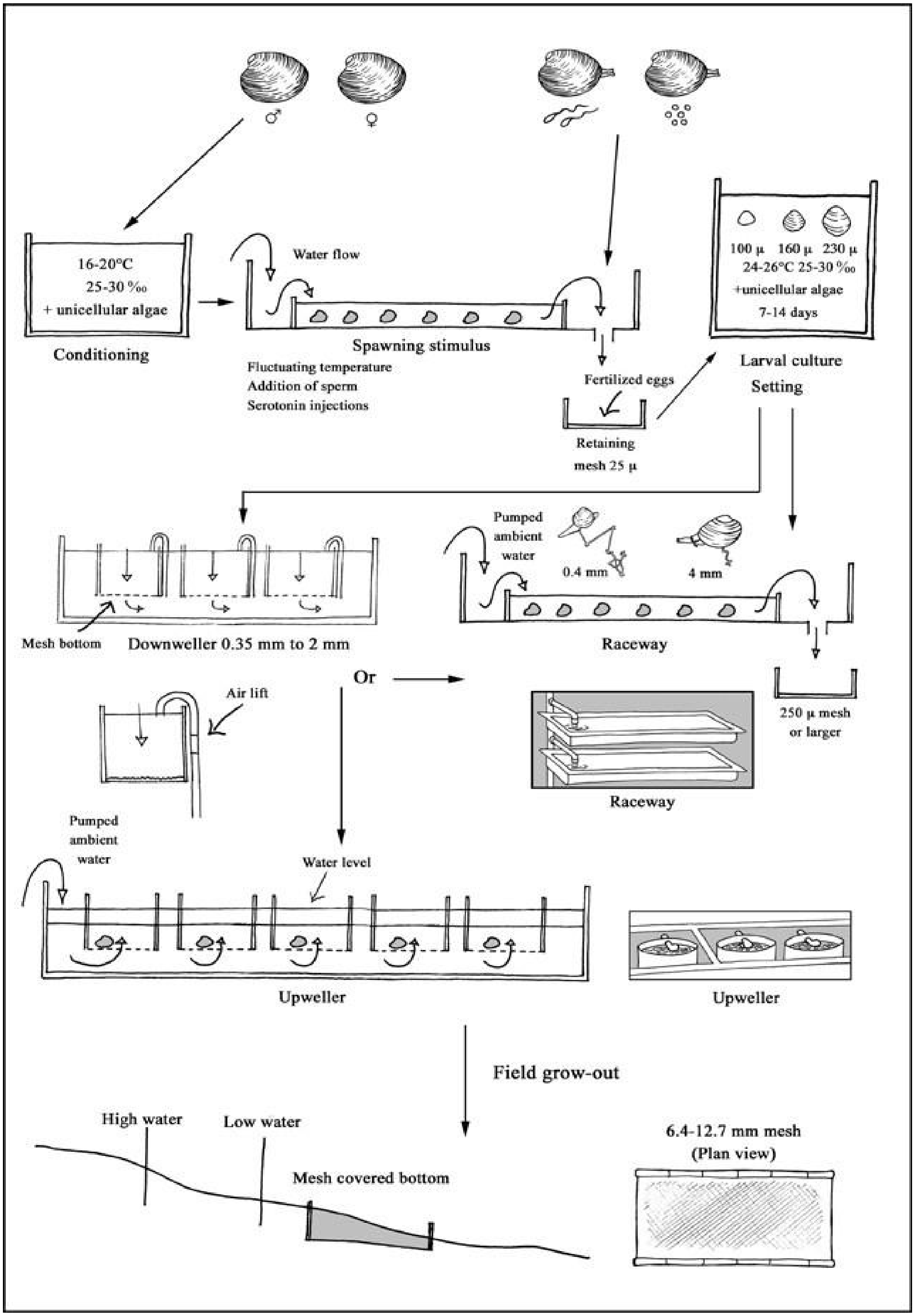

Figure 3: Production cycle of *Mercenaria mercenaria*. Image from http://www.fao.org/fishery/culturedspecies/Mercenaria_mercenaria/en

Production Statistics

Since 1990, there has been a rapidly increasing trend in global clam aquaculture production and value (Figure 4 and Figure 5; these figures exclude geoducks).

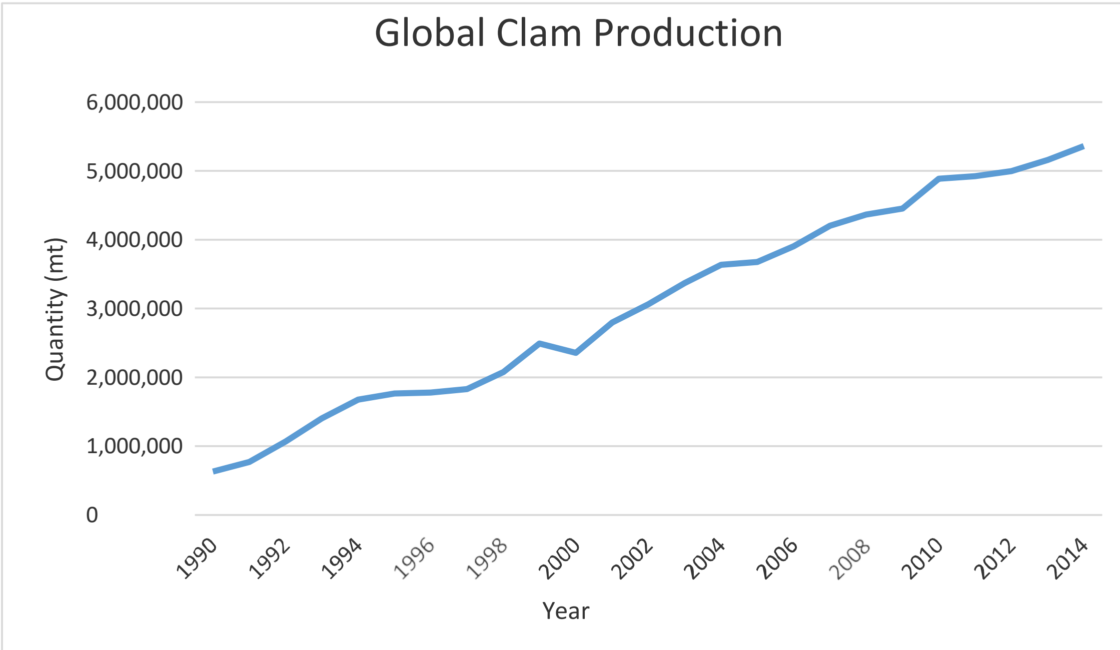

Figure 4: Global clam aquaculture production in metric tons (MT, 1,000 kg) (FAO 2016).

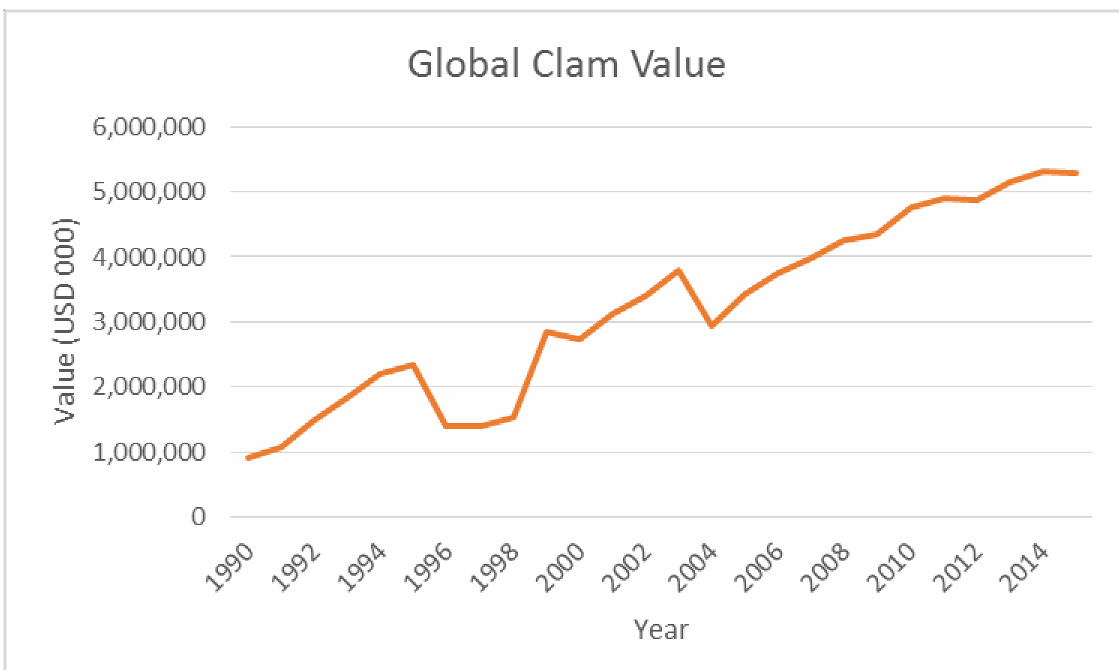

Figure 5: Global clam aquaculture value in USD 000 (FAO 2016).

This trend reflects the global demand for clams, which has exceeded natural production. As the quantity of wild-caught clams declines, the quantity of cultured clams is expected to continue to increase.

Anadara spp.: Harvesting cockles (*Anadara* spp.) from either natural or cultured beds is an important activity in the Malaysian fishing communities in Penang, Perak, and Selangor. The greatest development of this industry is in Perak, where about 1,200 ha (hectares) of the foreshore are under culture. *Anadara* spp. are also popular species in Thailand, where consumption exceeds the local production every year. In addition, Thailand has been importing seed and commercial-sized cockles from Malaysia. In 2014, China produced 336,870 MT of *Anadara* spp., with most of that produced through aquaculture. The top producing provinces in order were Zhejiang, Guangdong, and Fujian (Chinese Agriculture Press n.d.).

Cyclina spp.: *Cyclina sinensis* is one of the most popular commercially cultivated clam species in China, where there has been a fair amount of research on aquaculture methods and best practices (Ding et al. 2005)(Wang et al. 2006)(Yu et al. 2001). Coastal farms are common, and Zhejiang, Shandong, and Fujian Provinces are the main producers. Zhejiang's annual production was approximately 45,000 MT in 2005 (Ding et al. 2005).

Mercenaria spp.: *Mercenaria mercenaria* is the most extensively distributed commercial clam in the United States and has the greatest total market value (Figure 6). Annual harvests can exceed 38,000 MT. Most of this production has developed over the past decade, and Virginia and Florida are the greatest contributors (Rheault 2012). It is also popularly cultured in Canada and Europe (Rice 1992).

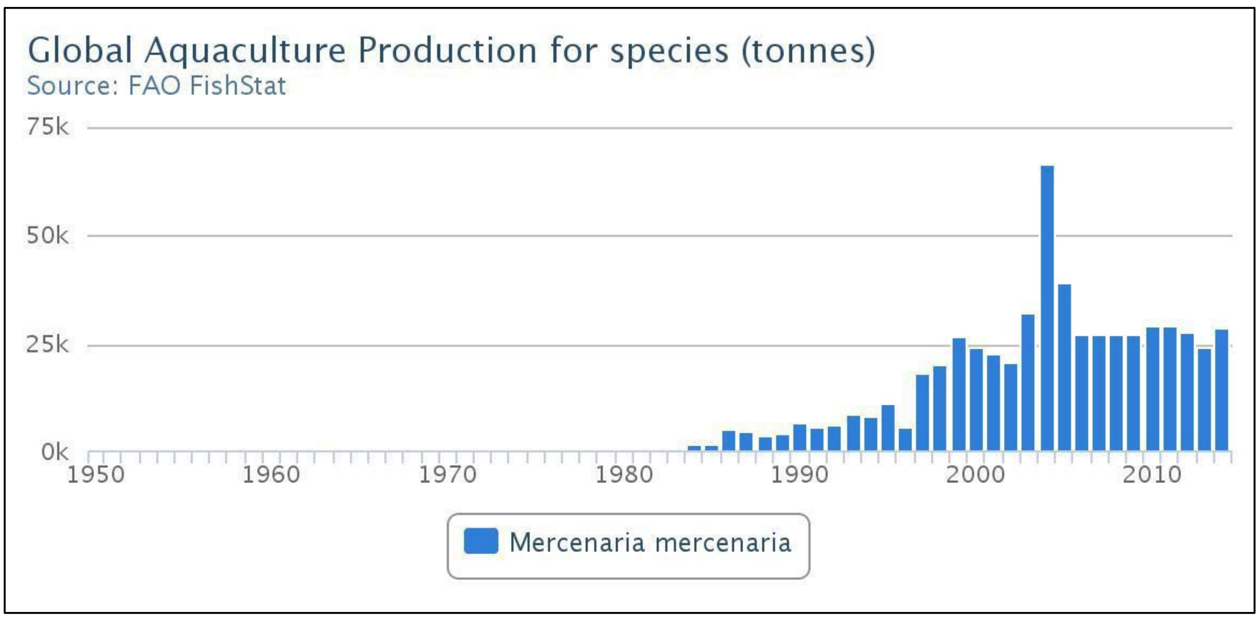

Figure 6: Global aquaculture production of *M. mercenaria* (FAO 2016).

Meretrix spp.: Culture of *Meretrix lyrata* has been increasing since the early 1980s. This species is broadly distributed along the coast of China, mainly along the south China coastal provinces, in fine sand beaches. It is also a highly valued fishery resource in Vietnam (Chen 2014).

Ruditapes spp.: *Ruditapes philippinarum* originates from southeastern Asia (Indo-Pacific) and was introduced for commercial purposes in the Mediterranean (Adriatic Sea only) and in Brittany, France, where it lives in the same habitat as its congener, *R. decussatus*. The species has also been introduced in the Hawaiian Islands and along the Pacific coast of the United States and Canada. Aquaculture statistics are given in Figure 7. China's production of *R. philippinarum* exceeds 3 million MT annually, and regional annual harvests in the Pacific Northwest (U.S.) are valued at over USD 25 million (Rheault 2012). China dominates production by far, followed by Italy (≈30,000 MT in 2014), and Korea (≈7,000 MT in 2014) (FAO Statistical Query, 2016).

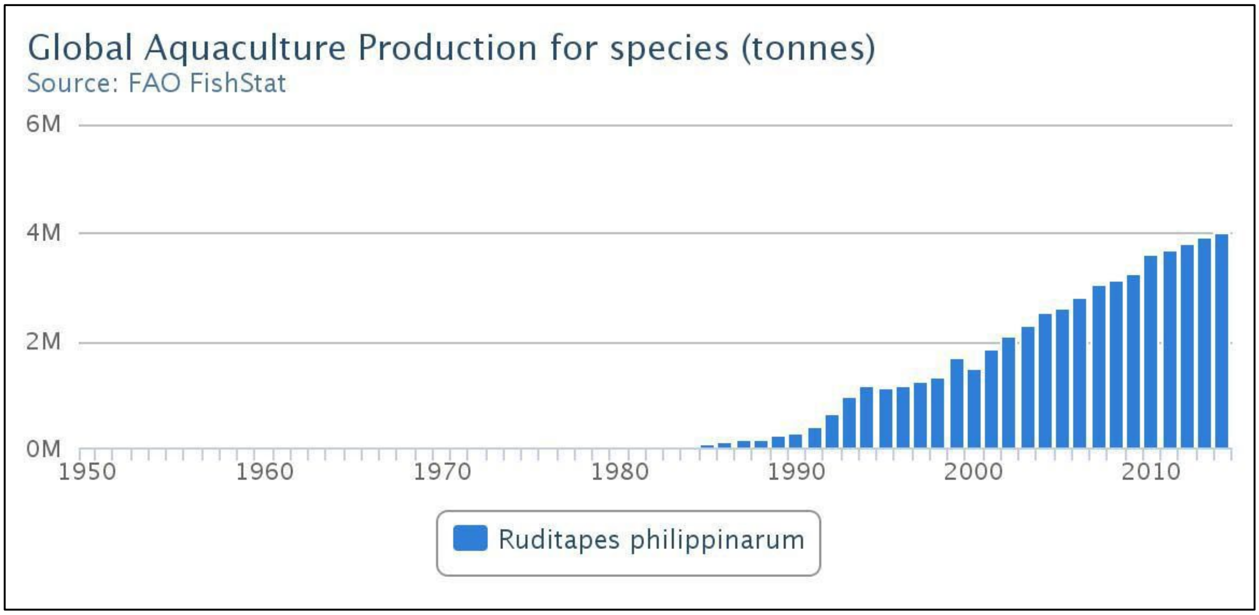

Figure 7: Global aquaculture production for *Ruditapes philippinarum* (FAO 2016).

Sinonovacula spp.: *Sinonovacula constricta* (razor clam) is a commercially important species of bivalve native to the estuaries and mudflats of China and Japan. It is extensively cultured in China and other countries, with 720,804 MT harvested in China in 2013 (down from 742,084 mt in 2008). *Sinonovacula* spp. are among the four most-important bivalve aquaculture species (with oyster, scallop, and *Venerupis* spp.) for rearing and consuming (Chinese Agriculture Press n.d.).

Venerupis spp.: Production levels in Spain varied from 1,900 to 3,100 MT per year from 1996 until 2002, when they fell markedly to only 50 MT, increasing to 195 MT in 2015. Previous decreases in production were likely due to disease and poor management of farms. Quite limited production has been reported from Europe, with less than 200 MT total in 2015 (FAO 2016).

Also of note is the geoduck, *Panopea generosa*. These clams are native to the Pacific Coast of North America and burrow as deep as 1 meter in intertidal or subtidal substrates. Growers are trying to expand production of this species to meet the demand from the Asian markets (Rheault 2012). This species is included in a separate Seafood Watch assessment for geoduck.

Import and Export Sources and Statistics

Clam farming continues to play an increasing role in the U.S. market. Figure 8 illustrates the trade in 2015, excluding geoduck trade, and it is evident that the U.S. imports more clam products than it exports. Within the U.S., Virginia is the leader in clam production (hard clams in particular), where it planted approximately 491 million clams in 2015. Virginia producers typically have their own hatcheries and supply themselves with seed (VIMS 2015).

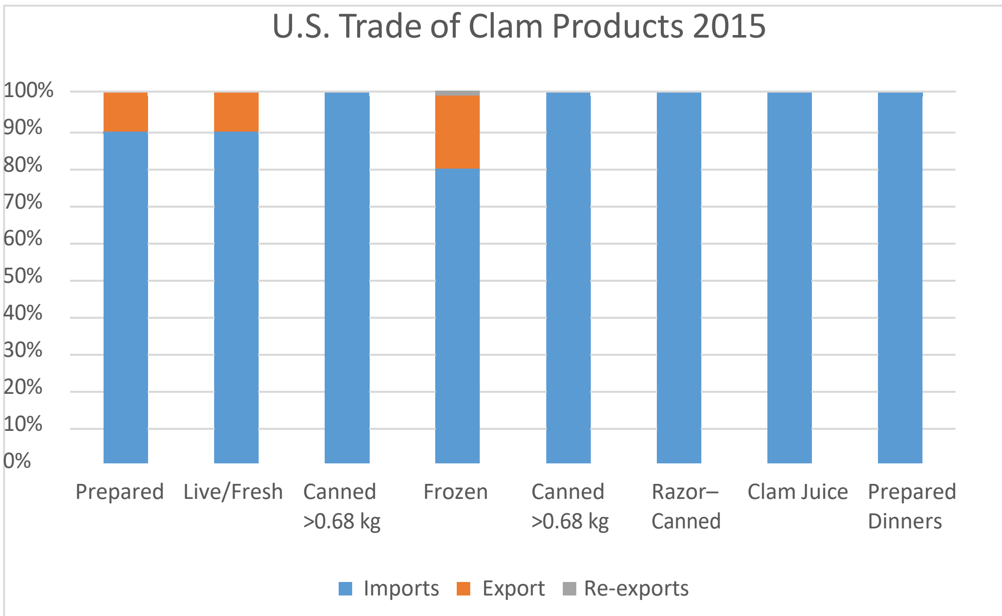

Figure 8: Trade of clams in the United States in 2015 (NMFS 2016).

The total clam imports to the U.S. in 2014 was approximately 23,145 MT (NMFS 2016). The U.S. produced approximately 24,483 MT of hard clams and approximately 3,374 MT of Japanese carpet shell in 2014 (FAO 2016). The U.S. exported approximately 2,691 MT of clam products in 2014. Approximately 97 MT of clam products were re-exported in 2014 (NMFS 2016). This results in approximately 48,214 MT of clams remaining in the U.S. for consumption in 2014. This indicates that the U.S. produces about half of its demand for clams domestically, and imports the remainder (Table 1).

Table 1: U.S. 2014 Trade Statistics.

U.S. Trade 2014			
Imports (MT)	U.S. Production (MT)	Exports (MT)	Re-exports (MT)
23,145	27,857	2,691	97

Major countries exporting to the United States include China (over 15,000 MT in 2015), Canada (over 3,387 MT in 2015), and Vietnam (over 2,063 MT in 2015) (NMFS 2016). Japanese carpet shell, more commonly known as the Manila clam, is the clam species most produced in all these countries (FAO 2016).

Because of the large percentage of domestic clams that are available for consumption in the United States (about 50%), and the import of clams primarily from China, the scores in this report are focused on North America and Asia to reflect aquaculture practices in these two regions. It is recognized that the United States and China may not always be completely representative of practices on their respective continents, but because of the domination of these two countries in clam products available in the United States, and the global nature of this report, it is fitting to allow the two countries to be representative, when necessary, for this report.

Common and Market Names

Scientific Name	*Anadara granosa*
Common Name	Blood cockle

Scientific Name	*Cyclina sinensis*
Common Name	Venus clam

Scientific Name	*Mercenaria mercenaria*
Common Name	Northern quahog (hard clam), littleneck, cherrystone

Scientific Name	*Leukoma staminea*
Common Name	Pacific littleneck clam

Scientific Name	*Meretrix lyrata*
Common Name	Asiatic hard clam

Scientific Name	*Sinonovacula* spp.
Common Name	Razor clams

Scientific Name	*Tapes* spp.
Common Name	Synonymous with *Ruditapes* and *Venerupis* spp. (*Ruditapes philippinarum* = Japanese littleneck, Japanese carpet shell, or Manila clam)

Product Forms

Relatively few species of clams are currently being produced in culture; the most significant is the Manila clam *Ruditapes phillipinarium*, followed by *Sinonovacula constricta* and *Mercenaria mercenaria* (Rheault 2012). *Anadara*, *Cyclina*, *Meretrix*, *Sinonovacula*, and *Tapes* species are available in the U.S. market in canned or cured forms (i.e., pickled or in vacuum-sealed packages). *Mercenaria*, *Tapes*, and *Venerupis* species are available live, frozen, or in other canned or cured forms.

Analysis

Scoring guide

- With the exception of the exceptional criteria (8X, 9X and 10X), all scores result in a zero to ten final score for the criterion and the overall final rating. A zero score indicates poor performance, while a score of ten indicates high performance. In contrast, the three exceptional criteria result in negative scores from zero to minus ten, and in these cases zero indicates no negative impact.
- The full Seafood Watch Aquaculture Standard that the following scores relate to are available on the Seafood Watch website. http://www.seafoodwatch.org/-/m/sfw/pdf/standard%20revision%20reference/mba_seafoodwatch_aquaculture%20criteria_finaldraft_tomsg.pdf?la=en

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: having robust and up-to-date information on production practices and their impacts publicly available.

Criterion 1 Summary *This criterion was updated with new information in November 2022. The update can be found in Appendix 2 at the end of this document. The scores resulting from the update are shown here.*

Data Category	Data Quality	Score (0–10)
Industry or production statistics	7.5	7.5
Management	10	10
Effluent	10	10
Habitat	7.5	7.5
Chemical use	10	10
Feed	10	10
Escapes	5	5
Disease	5	5
Source of stock	5	5
Predators and wildlife	10	10
Introduced species	7.5	7.5
Other (e.g., GHG emissions)	Not Applicable	n/a
Total		**87.5**

C1 Data Final Score (0–10)	**7.96**	**GREEN**

Brief Summary

There are abundant research publications regarding the biology, production, and potential environmental impacts of farmed clams, especially for those cultured in North America. Fewer publications are readily available for those clam species cultured in Asia, which is where most production comes from, and many publications are not translated. The most recent reliable information regarding production statistics is available in reports or databases produced by international organizations such as the FAO and national or state governments. Therefore, information was available and data quality and availability are considered robust. The final score for Criterion 1—Data is 7.96 out of 10.

Justification of Rating

Production

Industry or production statistics on worldwide clam farming are readily available to the public, namely through large global organizations such as the Food and Agriculture Organization (FAO) of the United Nations and the National Marine Fisheries Service (NMFS) for the United States. This industry has been studied in depth by academics and industry scientists, leading to robust information and statistics on worldwide production. There is some information on production statistics that is not readily available or is of questionable accuracy, particularly for Asian countries. Industry or production statistics for worldwide clam farming scored 7.5 out of 10.

Management

Management of worldwide clam farming is considered robust and is described in the literature. There are international, national, and regional management measures in place and being enforced, as well as best management practices (BMPs) (SEMAC n.d.) (Virginia Marine Resources Commission 2016) (DFO, 2014). The robust management of clam farming can be partly credited to the industry's long history. Management scored 10 out of 10.

Effluent

The effluent category scored 10 out of 10 for data quality and availability. The effluents from clam farming contain minimal waste products, are generally harmless to the environment, and may actually contribute to greater overall health of the ecosystem. No water column oxygen-depletion events have been observed with on-bottom culture techniques, and biodeposits from shellfish are in fact not even considered "discharges" under the U.S. Clean Water Act (Rice, 2008).

Habitat

Data quality for habitat is robust and there is information available to confidently score this criterion, primarily from peer-reviewed sources, with support from regulatory sources, particularly in North America. Although information for Asian countries is available to a lesser extent, some inconsistency in information leads to reduced confidence in scoring. The data score for habitat is 7.5 out of 10.

Chemical Use

Chemical use scored 10 out of 10 for data quality and availability. There are multiple peer-reviewed articles about the use of chemicals in shellfish farming, with support from regulatory sources, resulting in the high score.

Feed

Clams are not provided feed for the bulk of the production cycle, so this data quality and availability category is not applicable.

Escapes
The data quality and availability score for escapes is 10 out of 10. The data come from peer-reviewed sources as well as industry groups and representatives. There is a low risk of escape coupled with a low risk for invasiveness, and best management practices are in place.

Disease
Disease, pathogen, and parasite interactions scored 5 out of 10 for data quality and availability. The FAO, an international body, has addressed this issue, as have academic articles and the industry. But, there is a paucity of information regarding disease transmission, which is the primary factor under consideration, resulting in a reduced score.

Source of Stock
The exceptional criterion for source of stock scored 5 out of 10. There is a lack of data on genetics for clams globally; however, the source of stock is known to generally come from local sources, either passive settlement or local broodstock, and this has been discussed in peer-reviewed literature. It was difficult to quantify the source of stock for all areas, and even then it was necessary to average the results. This has resulted in the ability to score the source of stock criterion only with some uncertainty, particularly regarding the source of stock in Asian countries. The data quality and availability can be considered adequate overall.

Predator and Wildlife Mortalities
The exceptional criterion for wildlife and predator mortality scored 10 out of 10 for data quality and availability. The methods used to prevent predators from consuming stock, as well as to harvest the stock, have been well documented and studied, resulting in a high level of confidence for scoring this criterion.

Secondary Species Introductions
The exceptional criterion for escape of unintentionally introduced species scored 7.5 out of 10 for data quality and availability. Data quality is complete and accurate for the purpose of this assessment, with some averaging that was necessary; any gaps in information were noncritical. Personal communication with industry helped to provide information that was not readily available.

Conclusions and Final Score
An abundance of high-quality data is readily available about clam aquaculture all over the world. The industry is well established and the techniques used are generally considered successful and sustainable. Clam aquaculture has been studied vigorously by the academic community, the industry, and is well regulated by international, national, and regional bodies. The final numerical score for Criterion 1—Data is 7.96 out of 10.

Criterion 2: Effluent

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: not allowing effluent discharges to exceed, or contribute to exceeding, the carrying capacity of receiving waters at the local or regional level.

Criterion 2 Summary

Effluent Evidence-Based Assessment

C2 Effluent Final Score (0–10)		**10**	**GREEN**

Brief Summary

Farmed clams are not provided external feed or nutrient fertilization. Effluent may be released from the hatchery or nursery phases, but this is not considered to have any negative effects on the environment, and filter-feeding of clams during grow-out is often cited as improving water quality and/or nutrient cycling near farms. In isolated cases, antipredator netting or other plastics may be unintentionally released from the farm, but this is not typical, particularly in regions that globally dominate clam production. Therefore, the Evidence-Based Assessment was used to determine that there is low to no concern regarding the resultant effluent or waste impacts, and the score for Criterion 2—Effluent is 10 out of 10.

Justification of Rating

Evidence-Based Assessment:

Because the effluent data quality and availability is good (i.e., Criterion 1 score of 10 of 10 for the effluent category), the Evidence-Based Assessment was utilized.

Hatchery

Clam production generally relies heavily on a hatchery phase, where broodstock are maintained to produce seed. Broodstock, which are often selected from local stocks and for specific traits, are kept conditioned in high-flow unfiltered seawater from which natural food is available, or in recirculating or filtered flow-through seawater to which cultured unicellular marine algae is added. Algae are typically cultured from pure cultures of commercially available algae. Spawning and larval development occur in seawater baths. Larval cultures also are fed unicellular marine algae. Water changes occur several times a week in larval rearing tanks (Helm et al. 2004) (Rheault 2012). In China, the main source of Manila clam seed (up to shell length of 4 mm) is produced in reclamation ponds in Fujian Province (Fang and Lin 2016).

There has been little research regarding effluents from shellfish hatcheries because, typically, no drugs, pesticides, or herbicides are added to the seawater that flows through hatchery facilities. Shellfish filter and sequester bacteria and phytoplankton from the surrounding water. For this reason, several states within the U.S. do not require discharge permits. The National Pollutant Discharge Elimination System has an exemption for hatcheries that produce less than 20,000 pounds (≈9 MT) of animals. Furthermore, because no pelleted feeds are administered, the only particulate wastes that are flushed from hatcheries are feces and pseudofeces of growing animals. These small amounts of diffuse particulate waste from clam operations have little or only temporary impact on the surrounding marine environment (Creswell and McNevin 2008) (Flimlin et al. 2010).

Nursery

The nursery phase interfaces between hatchery production and grow-out, and may occur in land-based or in-water production systems. At this stage, clams feed exclusively on materials in ambient seawater. Several types of nursery systems exist, including upwellers, downwellers, and trays placed in raceways or intertidal ponds. Upwellers and downwellers are systems in which spat are suspended on screens and water flows up through the bottom or down through the top. Trays containing spat can also be placed in raceways or intertidal ponds (BCSGA 2016) (Flimlin n.d.) (Hadley and Whetstone 2007).

Land-based nurseries pump ambient seawater to the facility and may require a discharge permit solely for this reason. But, the relatively small volume of shellfish seed in nursery facilities results in only small changes to the contents of a nursery facility's effluent and is not usually of environmental concern (Creswell and McNevin 2008) (Flimlin et al. 2010).

In-water nurseries are often designed such that clam seed are placed in mesh bags, and the bags are positioned directly on the seafloor in intertidal or shallow subtidal environments (Guo et al. 1999) (Dumbauld 2009). Waste generated from in-water nurseries are feces and pseudofeces of growing animals, which would have little to no impact on the surrounding environment.

Grow-out

Seed clams are planted in plots in the intertidal or shallow subtidal zones. Other methods including coastal pond systems (reservoirs and earth ponds) and polyculture are employed; however, tidal aquaculture accounts for the majority of production, and volume data on pond and polyculture systems are not available (Liu et al. 2003) (Ji 2005) (Wang et al. 2006) (Fu et al. 2005). Predator exclusion devices (e.g., mesh bags or overhead netting/fences) are often used (Wang 2005).

During the grow-out phase, clams feed exclusively on materials (e.g., microalgae, organic detritus, bacteria, viruses) in ambient seawater. Waste products generated include feces and pseudofeces (note that the deposition of these wastes [termed "biodeposits"] from shellfish farms is not classified as "discharge" under the U.S. Clean Water Act, after a U.S. Ninth Circuit Court of Appeals decision in 2002) (Rice 2008). The amount of ammonia released from hard clams has been measured as 9.35 mg NH_3/g of soft tissue per day (NRAC 2013). Where the accumulation of biodeposits usually results in increased nitrogen and reduced oxygen, on-bottom clam farming stimulates the transfer of both organic matter and oxygen to the sediments via the bioturbation that is created by these animals as they filter seawater and burrow. Despite generating small amounts of waste products, clam farming can result in more balanced benthic metabolism with a net loss of nitrogen from the sediment (Dumbauld et al. 2009), thus reducing eutrophication effects and providing valuable ecosystem goods and services (Saurel et al. 2014). There have been a few cases where suspended shellfish aquaculture has resulted in high deposition of waste products and caused the sediments to "go sour" (sulfides and/or organic content in the sediment are high) and become depleted of oxygen; this is often a result of high stocking densities (Chen et al. 2005). Turning over sediments every few years has been identified as a good practice to prevent sediments from "going sour" (Liu 2003). But, this problem has never been observed in on-bottom culture methods, such as those used for clam aquaculture (Rice 2008). In addition, clam farmers understand that excessively high stocking densities do not benefit overall production; thus, farmers are committed to maintaining good water quality in their growing areas (Dewey et al. 2011). There are no perceived negative impacts of "effluents" from clam farms (Rice 2008).

It should be noted that a publication by Bendell (2015) identifies the shellfish aquaculture industry in British Columbia, Canada as a source of plastics and Styrofoam to the marine environment. These plastics include plastic ropes and net shell bags. Beach clean-ups in Baynes Sound, where 50% of the province's shellfish industry is located, result in the retrieval of approximately 3 to 4 MT of debris per year, 90% of which was plastic and Styrofoam from shellfish aquaculture (Bendell 2015). Bendell (2015) also notes that in China, where the majority of clams are produced, antipredator netting is typically not used, which may reduce the amount of plastic pollution from clam farms there.

Conclusions and Final Score

Clams are not given feed or nutrient fertilization. The natural filter-feeding patterns of clams typically result in the removal of nitrogen from the water, and they often facilitate mineral cycling from the water to the sediments. On-bottom culture methods are not known to cause anoxia or excessive biodeposition. But, it should be noted that the release of plastics and aquaculture materials from farms has been identified as a source of marine pollution in isolated cases. This issue may become more pronounced with the increasing focus on sources of plastics in the marine environment.

With evidence that clam aquaculture does not typically represent an effluent-related impact risk, and it often improves water quality in the vicinity of farms, the Evidence-Based Assessment results in a final score of 10 out of 10 for Criterion 2—Effluent.

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: being located at sites, scales and intensities that maintain the functionality of ecologically valuable habitats.

Criterion 3 Summary

Habitat parameters	Value	Score
F3.1 Habitat conversion and function		9
F3.2a Content of habitat regulations	3	
F3.2b Enforcement of habitat regulations	3	
F3.2 Regulatory or management effectiveness score		4
C3 Habitat Final Score (0–10)		**7**
Critical?	NO	**GREEN**

Brief Summary

Farmed clam grow-out operations are primarily located in intertidal or shallow subtidal environments of estuaries, coastal lagoons, and bays, all of which are generally considered high-value environments. But, the impact of farmed clam operations on habitat is considered minimal, with the main concerns stemming from biodeposition and harvest. The lack of impact coupled with reasonably robust regulation and enforcement regarding licensing and site selection results in a final score of 7 out of 10 for Criterion 3—Habitat.

Justification of Rating

Factor 3.1—Habitat Conversion and Function

Farm Siting and Infrastructure

Habitat conversion is measured by the effect of aquaculture on ecosystem services. In contrast to some types of aquaculture production systems (coastal ponds sited in ecosystems that previously comprised mangroves or other high-value habitats), clam farming, and shellfish farming as a whole, can provide valuable ecosystem goods and services, with relatively few negative impacts (Saurel et al. 2014). Some ecosystem goods and services provided by clams can include reduced turbidity and nutrient control through filtration (Pollack et al. 2013), water quality improvement (Ferreira et al. 2007), provision of habitat and food for predators (Segvic-Bubic et al. 2011) (Bendell 2015), and potential improvement of shellfish recruitment in adjacent areas (Wilbur et al. 2005).

Clam farms are typically sited in intertidal or shallow subtidal zones. Farming methods include "planting" young clams and laying a plastic mesh cover or fences over them to reduce predation (Wang et al. 2005) (Bendell 2015). Antipredator netting is typically not used in China (Bendell 2015). Other similar methods can include the use of large polyester mesh bags, which the young clams are placed in and "planted," again to reduce predation. Because clams are planted and covered with nets in a natural environment, it can be expected that there may be some level of impact on the surrounding habitat. Some impacts may include localized organic loading (Weise et al. 2009), changes to nutrient cycling (Thouzeau et al. 2007) (also described in Bendell [2015]), benthic macrofaunal communities (Callier et al. 2008) (Bendell 2015), and seston availability (Guyondet et al. 2013). A study by Lavoie et al. (2016) found that the presence of farmed clams resulted in a significantly higher percentage of organic matter in the first centimeter of sediment, compared to plots without clams. Abundance and taxonomic richness of organisms was significantly affected by the presence of nets. Nutrient fluxes and oxygen consumption increased significantly with the presence of clams and also with the presence of nets and fouling on nets (Lavoie et al. 2016).

Munroe and McKinley (2007) found minor temperature buffering from antipredator mesh and significantly higher levels of organic carbon beneath netting in Manila clam farm plots. The responses of the benthic environment to such changes include increases in bacterial abundance and meiofaunal biomass and diversity, and decreases to macrofaunal abundance and diversity. Spencer et al. (1997) found that organic enrichment from netting used in clam aquaculture changed dominant infaunal taxa, and Galliardi (2014) states that diverse benthic communities dominated by suspension feeders have been transformed to ones dominated by smaller deposit feeders, scavengers, and carnivores in association with bivalve aquaculture.

These impacts should be considered in context, and the potential ecosystem benefits of clams must also be considered. Although clam farming methods can have measurable effects on the surrounding habitat, these effects are not exclusively, or always significantly, negative. Also, these effects may not be attributable to the clams themselves; rather, to the infrastructure (i.e., netting) used to farm them. Therefore, clam farming methods may be adjusted as needed to prevent any negative impacts. Even when clam farmers alter the intertidal zone by building up bars of sediment to alter the flow of water (e.g., to prevent freshwater input that would adversely affect clams), the impacts are believed to be quite limited (Wang and Wang 2001).

<u>Biodeposition</u>

Biodeposition of fecal matter from farms is one of the greatest habitat concerns. Zhang et al. (2004) indicated that intensive farming of *Venerupi*s spp. in China has resulted in a higher probability of eutrophication and has induced clam diseases and mortality in some areas. But, it is also widely recognized that the real or potential organic enrichment effects of clam farming are insignificant compared to other forms of aquaculture, because artificial feeds are not used (Giles et al. 2009) (Weise et al. 2009) (Ferreira et al. 2011). In addition, clam farmers want to employ best practices to reduce the effects of biodeposition; overall, few effects have been reported for bottom culture. Instead, it is widely recognized that clam farms remove phytoplankton and organic detritus from the water column through filtration for feeding, thus providing a key ecosystem service by reducing the primary symptoms of eutrophication (Bricker et al. 2003) (Xiao et al. 2007) (Ferreira et al. 2011). This reduction can have two major benefits: it filters the water and allows an increase in subsurface light penetration, which enables photosynthesis at greater depths, and it potentially enables the recovery of submerged aquatic vegetation (SAV) and macroalgae (Ferreira et al. 2011). SAV provides further ecosystem services, such as a refuge and nursery for juvenile fish and increased sediment stability (Yamamuro et al. 2006). The 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.

Ferreira et al. (2009, 2011) quantified the value of ecosystem services provided by *Ruditapes* spp. culture by applying the FARM model to an 11.34 ha farm in Ria Formosa, Portugal. They used a cultivation period of 180 days and a clam seeding density of 90 individuals/m^2. Nutrient loading to the Ria Formosa area (49 km^2 and volume of 92×10^6 m^3) results in eutrophication, evidenced by the overgrowth of opportunistic seaweeds, and clam growth is largely determined by particulate organic matter. Approximately 60% of the nitrogen removed from the system by filtration is retained by the clams. The value of this service, compared to the cost of land-based treatment, is estimated at a gross removal of about 325 tons of carbon per year, of which only 1% is attributable to phytoplankton. This corresponds to the emissions of 8,748 population equivalents (unit per capita loading), a net annual nitrogen removal of 29 tons per year, and a value of 0.26 million euro per year—approximately 10% of the direct income from shellfish culture.

Harvest

Farmed clams can be harvested by a variety of methods, including by hand, rake, or dredge (Mercado-Allen and Goldberg 2011) (Stokesbury et al. 2011) (FAO 2012) (Fang and Lin 2016). For example, the hard clam *Mercenaria mercenaria* is often grown in bags and harvested by picking up the bag, or, in situations where clams are planted in- or on-bottom, by digging with a hand or a rake (FAO 2012). Hand and rake harvest techniques are believed to have no significant impacts on the habitat.

Dredge harvest techniques for clams often involve dredges or rakes with long teeth or water jets to loosen the sediment and bring clams to the surface; commonly referred to as a “hydraulic dredge.” The impacts of dredges on seafloor habitat have historically 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) (Mercado-Allen and Goldberg 2011). Dredging has been shown to directly reduce habitat complexity and species diversity, to cause shifts in community structure and the loss of vertical structure, and to reduce productivity or biomass. Dredging can also increase or decrease nutrient cycling, cause hypoxia, increase the exposure of organisms to predation, and increase turbidity (Stokesbury et al. 2011).

But, there is a difference between dredging for wild clams and dredging for farmed clams. For instance, the dredges used inshore to collect *M. mercenaria* are much smaller in size (1 to 2 m) than the large hydraulic dredges used offshore to collect surf clams (*Spisula solida*) and ocean quahogs (*Arctica islandica*) (Stokesbury et al. 2011). Wild harvest fishers often sample vast areas because they do not know the exact location and expanse of clam density, and this practice can result in high mortality of nontarget organisms. In contrast, clam farmers know exactly where and when to dredge because they seeded the area. Thus, tows for farmed clams are usually much shorter and more targeted, resulting in a greatly reduced mortality of nontarget organisms. In addition, most shellfish farming occurs in shallow coastal areas, which are naturally highly disturbed, and 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). For example, the harvest of the Manila clam (*Ruditapes philippinarum*) by hand raking and suction dredging from a farm in the United Kingdom resulted in a 50% to 90% initial reduction, respectively, in species diversity and abundance, but the invertebrate community recovered within 8 months (as reviewed in Mercado-Allen and Goldberg 2011). Another important issue to consider is that, although dredging has been shown to flatten vertical structure and habitat provided by emergent epifauna such as sponges and corals, clam lease sites are generally devoid of such sensitive species. There also is evidence that the space created by harvesting adult clams provides space for new clam recruits. Furthermore, clam farmers often reseed their crops on an annual basis, which can restore vertical structure to the seafloor, enhance habitat for many additional species, and promote resource sustainability (Mercado-Allen and Goldberg 2011) (Stokesbury et al. 2011). When conducted in a manner consistent with the harvest of cultured clams, dredging may also provide benefits to the sediment. For instance, the concept of "marine soil cultivation" using dredges, rakes, and tongs has long been advocated by the shellfish industry to loosen and oxygenate sediments and to remediate unoxygenated and heavily silted bottom devoid of clams (Mercado-Allen and Goldberg 2011).

Because the direct impacts of farm infrastructure are typically negligible and there is little concern for the accumulation of particulate matter, the habitats in which clam farms are sited may be improved through filtration and maintain functionality when harvested by hand. Habitats in which clams are farmed and then harvested by dredge are subject to increased turbidity, changes to sediment, and reduction in species diversity and biomass. But, these areas have been shown to recover quickly from these impacts (Chen et al. 2005) (Zhu 2013) (Weixin 2017). The score for Factor 3.1 is 9 out of 10.

Factor 3.2—Farm Siting Regulation and Management

Factor 3.2a—Content of habitat management measures

The U.S. produces about half of the farmed clams available on the U.S. market, while importing the rest. The majority of imports are from China, followed by Canada, Vietnam, and other countries. Each country may regulate and enforce aquaculture policies differently, but often with similar goals in mind. In the following paragraphs, the United States, Canada, and China are examined as examples of management and enforcement for clam aquaculture, and these can be used to produce a score for clam production that is representative of global production.

United States: A suite of federal, state, tribal, and local-level management bodies regulate aquaculture activities. At the federal level, the U.S. Army Corps of Engineers issues aquaculture permits. Before a farm is established, extensive consultation is required to identify any issues with the Endangered Species Act and Essential Fish Habitat, and to identify how to minimize effects on the environment. Consultations are coordinated collaboratively by the Army Corps of Engineers, National Marine Fisheries Service, and the U.S. Fish and Wildlife Service (NMFS 2016).

The permits issued by the Army Corps of Engineers for commercial shellfish aquaculture directly address requirements under the Rivers and Harbors Act and the Clean Water Act. The process of research and consultation also addresses legal requirements for other laws, including those under the National Environmental Policy Act, Endangered Species Act, Magnuson-Stevens Fishery Conservation and Management Act, Coastal Zone Management Act, National Historic Preservation Act, Fish and Wildlife Coordination Act, the National Marine Sanctuaries Act, and treaties (NMFS 2016).

Shellfish farms can be permitted under the Nationwide Permit 48 or other types of general permits issued by the Army Corps of Engineers, depending on the state. Permits are re-authorized every 5 years, and require re-assessment of the farm based on available research and monitoring (NMFS 2016).

Alongside the federal permit that is required for aquaculture operations, there are additional state, federal, tribal, and local regulations that must be met. All states (except Alaska) in the U.S that border an ocean or Great Lake participate in the Coastal Zone Management Program, which involves assessing aquaculture siting and impacts on the environment. In addition, regional environmental best management practices (BMPs), such as the Environmental Code of Practice produced by the Pacific Coast Shellfish Growers Association, are 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).

Canada: Three methods of aquaculture regulation are employed, depending on the province: 1) in British Columbia, the province issues the lease and the Department of Fisheries and Oceans (DFO; a federal agency) issues the license; 2) in Prince Edward Island, there is a management board that issues leases and licenses; and 3) in all other provinces, the provincial government issues the leases and licenses. British Columbia is the province with the largest share of aquaculture industries.

The federal government sets out guidelines for siting and regulation based on environmental protection and provides information and resources to the public. There is also some use of spatial management, which is aimed more at disease and pest control, but may also benefit native species. Canada's regulations have language aimed at protecting critical ecosystem elements (such as squid, forage fish, sponges, eelgrass, and other habitats). The primary legislations for the regulation of aquaculture are the Fisheries Act (1996) and the Fisheries Act Regulations (1976), the Aquaculture Regulation (2002), and the Environmental Management Act (SCBC 2003 C.53).

Aquaculture Activities Regulations within the Fisheries Act give conditions under which operators can treat their fish for disease and parasites, deposit organic matter, and manage facilities, and it reports on environmental monitoring and sampling requirements (DFO 2016). In addition, the B.C. Shellfish Growers Association employs the Environmental Management System Code of Practice that fosters commitment to working with growers to protect marine resources (Dewey et al. 2011).

China: The Fisheries Law (2004) and the Regulation for the Implementation of the Fisheries Law (1987) provide the legal framework for the fisheries and aquaculture, integrating the two industries. The Fisheries Law provides for the enhancement and conservation of fisheries resources. There are many other laws, regulations, international treaties, administrative acts, local regulations, and management in place to regulate fisheries and aquaculture (Zou and Huang 2015). Some of the laws that govern aquaculture practices are the Sea Area Use Management Law (2002), the Environmental Protection Law (1989), the Marine Environment Protection Law (1982), The Law on the Prevention and Control of Water Pollution (1984), and the Environmental Impact Assessment Law (2002).

It is clear that there is a legal framework in place for the regulation of fisheries and aquaculture activities; however, it is also recognized that site selection for aquaculture has no specific legislation (Chen et al. 2011) (Zhu and Dong 2013). Nonetheless, the use of state-owned land and water areas must meet the local functional zoning scheme set by the Land Administration Law, including conservation areas, industry, aquaculture, etc. (Chen et al. 2011) (FAO 2017). The focus of current policy development for aquaculture is on “green growth” and improving licensing, environmental protection, and aquaculture product quality (Zou and Huang 2015).

Most clam farms in China are family operated, and clam leases are managed by local communities (pers. comm., X. Guo, November 2012). An Environmental Impact Assessment (EIA) is required in different environmental laws, and although there is no specific referral to aquaculture, EIAs are required for new construction projects that include aquaculture or that involve sensitive environments such as mangroves (People’s Republic of China Environmental Impact Assessment Law, 2016). These EIAs must address pollution from aquaculture sites, the impact that pollution may have on the environment, and ways to mitigate effects; however, there is no standardized process for assessing risk at a farm site before it is licensed. The Environmental Impact Assessment Law (2016) 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 2017). The Environmental Protection Law (1989) indicates that EIAs are the responsibility of appropriate departments of the Environmental Protection Administration of the Peoples’ Government, at or above the county level (NALO 2012), leading to variability from one county to another.

Globally, regulations governing clam aquaculture are comprehensive and, in some cases, are integrated with other industries based on maintaining the overall functionality of habitats.

Regulations are appropriate to the industry and are largely effective. In China, aquaculture regulations are slightly less clear, leading to a minor reduction in score. The score for Factor 3.2a is 3 out of 5.

<u>Factor 3.2b—Enforcement of Habitat Management Measures</u>

United States: The U.S. Army Corps of Engineers issues permits for shellfish aquaculture and is the lead enforcement agency on all Corps-issued permits (EPA n.d.). The Army Corps of Engineers has national goals to do yearly follow-up inspections on 10% of the previous year's permits.

The Army Corps of Engineers and the Environmental Protection Agency have a memorandum of understanding for working together on the enforcement of Section 404 of the Clean Water Act. Third parties, like the Fish and Wildlife Service, may enter agreements with the Army Corps of Engineers or the Environmental Protection Agency to take on some enforcement responsibilities (EPA n.d.).

State and local regulatory bodies also enforce aquaculture regulations. For example, in Washington, multiple state departments play a role in aquaculture regulation, management, and enforcement. Shellfish aquaculture is partly regulated by the state's Department of Ecology, which issues water quality permits and approves local shoreline masters programs (WDE 2017). The Department of Fish and Wildlife has an enforcement team to enforce national laws, and state and county regulations through memorandums of understanding (WDFW 2017).

There is clearly a suite of management methods used, with different state departments and federal agencies working together in each state or region to effectively implement laws and regulations that apply to aquaculture. Although potentially confusing at times, this system can be considered robust in terms of enforcement.

Canada: In Canada, the federal Department of Fisheries and Oceans works to enforce the laws governing aquaculture activities and with relation to marine habitat. Federal fisheries officers ensure that aquaculture operations comply with national and regional regulations under the Fisheries Act. Fisheries and Oceans works closely with other federal and provincial bodies to enforce all aquaculture regulations. In addition, other federal departments, such as the Canadian Food Inspection Agency, Health Canada, and Transport Canada, implement their own regulations and may become involved, if needed, with enforcement of aquaculture regulations (DFO 2015).

China: In China, fisheries and aquaculture operate under a hierarchy, involving fisheries administration departments at the national, provincial, regional, and municipal levels. In provinces and autonomous regions, counties and cities may also play a role. Fisheries administrative bodies in local regions are responsible for monitoring and enforcing national fisheries regulations and establishing local regulations. The national Bureau of Fisheries leads the Fisheries Law Enforcement Command of China, which coordinates fisheries law enforcement. Regional Fisheries Management Bureaus enforce regional laws (Zou and Huang

2015). 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 (pers. comm., X. Guo, November 2012) (Fishfirst n.d.). Overall, enforcement of aquaculture regulations has been deemed weak in the past. Aquaculture is favored by the government as an important economic activity; therefore, there are limited numbers of enforcement officers, insufficient financial support, and an ineffective management hierarchy (Chen et al. 2011) (Fishfirst n.d.) (Yan and Huang 2009). There is no center for information on punitive measures or any documented action against farms that do not comply. Enforcement agencies appear regionally fragmented, and there is little public evidence of monitoring or compliance data. Often, economic development takes precedence over compliance with environmental regulation (Zhu and Dong 2013). Nonetheless, this is perhaps changing, with the focus for policy development shifting to enhance environmental protection and the sustainable growth of aquaculture (Zou and Huang 2015).

The score for Factor 3.2b is 3 out of 5, because enforcement organizations are identifiable, appropriate, active, and provide information on activities; however, China represents a large portion of the industry, and it is sometimes difficult to confirm strict enforcement of regulations. When Factor 3.2a and 3.2b scores are combined, the final Factor 3.2 score is 4 out of 10.

Conclusions and Final Score

Adverse habitat impacts from clam aquaculture activities are neither significant nor lasting. Clam farms may provide some valuable ecosystem services, and clams can be harvested in a sustainable and noninvasive manner. Management of worldwide clam aquaculture operations can be considered robust, with generally adequate enforcement. Particularly when compared to many other forms of aquaculture, clam culture has little impact on marine habitat. Factors 3.1 and 3.2 combine to give a final Criterion 3—Habitat score of 7 out of 10.

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: limiting the type, frequency of use, total use, or discharge of chemicals to levels representing a low risk of impact to non-target organisms.

Criterion 4 Summary

Chemical Use parameters	Score	
C4 Chemical Use Score (0–10)	**8**	
Critical?	NO	**GREEN**

Brief Summary
No chemicals are known to be used during the grow-out phase of clam culture in North America. Evidence shows that best management practices (BMP) for clam farming designate manual labor (e.g., hand removal, pressure washing, freshwater baths, and/or air drying) to prevent and remove predators and fouling from gear, and that improved husbandry and cleaning methods rather than antibiotics are employed to prevent bacterial infections. But, there is some evidence of chemical use in China, specifically to remove predators and competitors. Therefore, the final score for Criterion 4—Chemical Use is 8 out of 10.

Justification of Rating
Historically, chemical treatments have been applied in clam farming to prevent predation, fouling, and infection by disease-causing bacteria. The use of chemical substances (e.g., copper sulfate, calcium oxide, sand coated with trichloroethylene, and insecticides) to control predation of molluscs was pioneered in the 1930s in the U.S. (Loosanoff 1960) (Jory et al. 1984) (Shumway et al. 1988). Although such chemicals proved effective, the potential environmental and public health risks associated with their use far outweighed the benefits, and the chemicals are no longer used to control predators at clam 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. Many shellfish growers' associations have adopted BMPs in which predator control is addressed by exclusionary devices and frequent inspection of sites, followed by hand removal of predators (Creswell and McNevin 2008) (Flimlin et al. 2010).

Fouling is a significant problem in clam culture, which uses bottom netting to exclude predators; the netting's high surface area is prone to fouling and subsequent clogging that restricts water flow through the nets. Constant cleaning is required to remove fouling organisms. There have been many attempts to prevent fouling in bivalve culture through the use of chemicals and biocides such as Victoria Blue B, copper sulfate, quicklime, saturated salt solutions, chlorinated hydrocarbon insecticides, cuprous oxide, copper isothianate, copper pyrithione, zinc pyrithione, zinc oxide econea, and others (Loosanoff 1960) (MacKenzie 1979) (Shumway et al. 1988) (Brooks 1993) (Swain and Shinjo 2014). But, 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 nontarget organisms. 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 typically made (Bishop 2004). A study by Cassiano et al. (2012) demonstrated that a commercially available silicone fouling release coating reduced biofouling build-up on nets used by the Florida clam industry; these silicone-based applications do not contain any biocides that may be harmful to marine life. Experiments are being conducted on netting, but they are inconclusive to date, and the East Coast Shellfish Growers Association Best Management Practices (Flimlin et al. 2010) caution about the use of chemicals to control fouling. Air drying, brine or freshwater dips, power washing, and manual control are not only more successful, but also are more environmentally friendly antifouling methods (Creswell and McNevin 2008) (Watson et al. 2009). In addition, antifoulant chemicals are not used in the hatchery because larval tolerance to such chemicals is typically low (Castagna and Manzi 1989).

Typically, antibiotics and chemicals are not used in the grow-out phase of clam farming, primarily due to the rarity of disease during that time (British Columbia Shellfish Growers Association 2013) (MacGillvray 2012). Bacteria that may cause disease in the larval phase often originate in algal cultures or from incoming water and pipes or other hatchery equipment (Ford et al., 2001). Though bacteria can be controlled with antibiotics, hatchery operators are often concerned with the development of antibiotic resistance; instead, they rely on improved animal husbandry and regular cleaning of hatchery equipment (Ford et al. 2001) (Creswell and McNevin 2008) (Flimlin et al. 2010). Dilute hypochlorite (bleach) solutions often are used for disinfection of equipment, but they may be disposed of in the municipal sewer system instead of the marine environment (Creswell and McNevin 2008) (Flimlin et al. 2010). But, in the United States and Canada, dilute bleach is often neutralized with sodium thiosulfate, which is diluted and disposed of in floor drains that discharge to the marine environment. There are best practices in place to discharge these chemicals, but they are not known to be regulated, except that the chemicals are approved for use (Summerfeldt and Vinci 2008) (PCSGA 2011). Because of neutralization, this practice is of minor concern. 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 the use of unapproved chemicals (FDA 2011) (NAA 2016). The U.S. Environmental Protection Agency (EPA) also strictly regulates nonpharmaceutical chemicals that are used in shellfish culture (EPA 2013). Ultimately, in Canada and the United States, there is no evidence of antibiotic use or other potentially harmful chemical use for clam farming (BCSGA 2013).

In China, the use of drugs in aquaculture is governed by a variety of regulations, but these stipulate that the administration of drugs and drug residue tests is controlled at or above the county level (FAO 2017). China has developed a list of prohibited and allowed chemicals for aquaculture, and chemicals are still used to some extent: namely, to deter or kill predators and competitors (Fishfirst n.d.), (pers. comm., Fenjie Chen, May 2017). Yu et al. (2001) reported that *Cyclina* spp. hatcheries may apply antibiotics to treat diseases in China. In addition, Wang et al. (2011) detected 14.8 ng L^{-1} of ofloxacin, a residual antibiotic in razor clam ponds, in the Jiulong River estuary, southeastern China, which was among the seven highest concentrations measured out of five aquaculture ponds (fish, crab, shrimp, razor clam, and duck). It is not apparent that antibiotics or chemicals are used to any extent in the shellfish aquaculture sector outside of China.

Conclusions and Final Score

Evidence demonstrates that, in North American clam farming, the use of chemicals is typically not employed, and BMPs caution against chemical use, preferring nonchemical methods for de-fouling and preventing disease. Manual removal is considered the most effective method of treatment for predator and fouling control, and does not entail the discharge of active chemicals. Although clams typically have a low need for chemical application, there are limited data that indicate some use of chemicals in China, primarily to remove predators and competitors. The final numerical score for Criterion 4—Chemical Use is 8 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: sourcing sustainable feed ingredients and converting them efficiently with net edible nutrition gains.

Criterion 5 Summary

C5 Feed Final Score (0–10)	10.00	GREEN
Critical?	No	

Brief Summary

External feed is not provided to farmed clams. Therefore, the final score for Criterion 5—Feed is 10 out of 10.

Justification of Rating

External feed is not provided to farmed clams for the bulk of the production cycle because clams are filter feeders and consume plankton and other particles that naturally occur in the water column (NOAA 2016). Cultured algae is often provided in the hatchery setting as a food source. Under certain circumstances, hard clam ponds in China may require additional algae input when natural levels are low (e.g., due to cloudy days). There are also methods for feeding clams dissolved soybean powder, which helps boost algae growth. But, these feeding methods are uncommon and only used under special circumstances (Zhu et al. 2007). Thus, there is zero reliance on marine or terrestrial resources that are typical in the culture of fed species.

Conclusions and Final Score

The final score for Criterion 5—Feed 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: preventing population-level impacts to wild species or other ecosystem-level impacts from farm escapes.

Criterion 6 Summary *This criterion was updated with new information in November 2022. The update can be found in Appendix 2 at the end of this document. The scores resulting from the update are shown here.*

Escape parameters	Value	Score
F6.1 System escape risk	0	
F6.1 Recapture adjustment	0	
F6.1 Final escape risk score		0
F6.2 Invasiveness		8
C6 Escapes Final Score (0–10)		**4**
Critical?	NO	YELLOW

Brief Summary

Many farmed clam species are cultured within their native ranges. The risk of escape is considered moderate to high because, although farmed clams are infaunal and escape mitigation management practices are in place, there is a risk of spawning events occurring before harvest. But, the risk of ecological impact is low; where clams are farmed within their native range, they typically have high genetic similarity to their wild counterparts, and where they are farmed outside their native range, they have been ecologically established for several decades. Ultimately, there is little evidence available to support negative effects of escaped clams on ecosystems or wild populations. Therefore, the final score for Criterion 6—Escapes is 5 out of 10.

Justification of Rating

Factor 6.1—Escape Risk

The risk of escape is directly related to the degree of connection to the natural ecosystem. Typical production systems for farmed clams include a hatchery phase, a nursery phase, and a grow-out phase. The grow-out phase occurs in open systems (e.g., netted covers or enclosures sited in subtidal and intertidal flats in coastal and estuarine areas). But, more than half the clams available on the United States market are grown domestically or imported from Canada, and both countries employ BMPs or environmental codes of practice for shellfish aquaculture that include escape management, such as the use of nets or mesh bags used to secure the clams

(BCSGA 2013) (PCSGA 2001) (Creswell and McNevin 2008) (Flimlin et al. 2010). Clams are farmed in open systems, but unlike farmed crustaceans and finfish, they live an infaunal and mostly sedentary lifestyle as adults. *Meretrix* spp. are unique and can secrete mucus and float at the surface, moving with the waves and currents (Zhang et al. 2004). Chen et al. (2013) noted that some middle- to large-sized *Meretrix lyrata* can migrate to deeper waters using this method. Fences and cross lines above clam beds are used to prevent escapes of *Meretrix* spp. on farms. Therefore, the likelihood of active escape is low, and post-escape movements (if any) would be minimal. Coupled with the widespread use of BMPs, this makes direct escape of farmed clams of low concern. There are currently no specific regulations or other management measures in place in China for mitigation of clam species escapes, but as mentioned previously regarding *Meretrix* spp., farmers do use techniques to prevent escapes from their farms (pers. comm., Fenjie Chen, May 2017).

There is a risk that spawning events may occur during grow-out, potentially releasing large numbers of eggs to receiving ecosystems. For example, hard clam (*Mercenaria mercenaria*) reaches sexual maturity at approximately 32 to 38 mm, and is harvested only after reaching this size (Maryland DNR 2016). *Venerupis philippinarum* is harvested in British Columbia only after it is sexually mature, allowing it to broadcast spawn for at least one season (Whiteley and Bendell-Young 2007). Personal communications (2017) with industry in the United States and Canada indicate it is likely that spawning events occur during the grow-out phase. In addition, triploidy or sterility is not used in the industry at a commercial scale, with only a mention of it as a potential research topic (pers. comm., Cherrystone Aqua Farm 2017) (pers. comm., BC Shellfish Growers' Association, 2017). Given these findings, the risk of escape is considered moderate, resulting in an Escape score of 3 out of 10.

If a juvenile or adult clam were to escape, it could easily be recaptured by hand. But, there is a paucity of information available regarding clam escapes and recapture. Therefore, the recapture and mortality adjustment is 0 out of 10. Altogether, the final score for Factor 6.1 is 3 out of 10.

Factor 6.2—Competitive and Genetic Interactions

Clams for broodstock are usually selected from a combination of wild stocks and hatchery-raised clams for optimal color, morphological traits, optimal growth rates, high fecundity, survival, and to maintain genetic diversity regardless of the species being cultured (Guo et al. 1999) (FAO 2004) (Whetstone et al. 2005) (Thiet and Kumar 2008) (pers. comm., Cherrystone Aqua Farm,2016). But, farms in China may not rely solely on hatchery production of seed; seed is also collected from the wild for the cultivation of *Ruditapes* spp., *Meretrix* spp., and *Sinonovacula* spp. (Guo et al. 1999). Because farmed (i.e., grow-out) stock are the progeny of both wild-caught and hatchery-raised broodstock, their genotype is highly similar to that of purely wild conspecifics (Vargas et al 2010). But, Nie et al. (2015) suggest that there are about eight distinct Manila clam populations in the Liaodong Peninsula that have some degree of genetic isolation. Yan et al. (2005) noted marked physiological differences between the Putian and Dandong Manila clams in terms of temperature trigger points and timing of gonad development, fecundity, and metamorphosis. Genetic variability may be decreasing in cockles in China because farmers are buying broodstock from different areas and interbreeding it with wild stocks, a practice that is not restricted in China (Zhou 2005).

Of the farmed clam species analyzed in this report, only two are known to be cultured outside their native range: the northern quahog or hard clam (*Mercenaria mercenaria*) and the Japanese littleneck (*Venerupis philippinarum* or *Ruditapes philippinarum*) (Padilla et al. 2011). The northern quahog, native to North America, was intentionally introduced to France and China for the purpose of aquaculture (Goulletquer et al. 2002) (Weixin n.d.). In Europe and China, no effects on ecosystems or native species have been reported (NOBANIS 2012) (Weixin n.d.). The Japanese littleneck, native to Asia, is believed to have been accidentally introduced to the West Coast of North America in the 1930s (Toba 2005) (FAO 2016) (Cordero et al. 2017). Japanese littleneck clam is reported to have been established in the wild on the coast of Hawaii, and it may have been established as early as the late 1800s (Zhu 2013) (exoticsguide.org n.d.). It was later introduced to Europe and spread through intertidal bottom culture to several European coastal areas (as reviewed in Mortensen and Strand [2000] [FAO 2016] [Cordero et al. 2017]). This species, although nonnative, has become ecologically established. But, the effects on ecosystems and native species are apparently limited to the surrounding habitat by farming infrastructure and/or biodeposition and harvest of the species where it is cultured, not by escaped clams or clam eggs/larvae; see (Spencer 1997) (Saurel et al. 2014) (Lavoie et al. 2016). There is no evidence to suggest that the escape of farmed clams has had a negative impact on wild stocks.

In most cases where clam species are farmed in their native range, they have a high degree of genetic similarity to their wild counterparts through intentional broodstock replenishment. Where clams are farmed outside their native range, they are typically fully ecologically established, and have been for several decades. Thus, the score for Factor 6.2 is 8 out of 10.

Conclusions and Final Score

Although it is unlikely that planted clams escape from farming infrastructure, there is the likelihood that those organisms spawn before harvest. Therefore, farmed clams can be considered to have a moderate to high risk of escape. But, the sourcing of wild stock preserves much of the wild genotype in grow-out stock, and there is no evidence that clam escapees have negatively affected the ecosystems that might receive them. There is some lack of information on clam escapes and recapture, and only two species are seen cultured outside their native range. Factors 6.1 and 6.2 combine to give a final numerical score of 5 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: preventing population-level impacts to wild species through the amplification and retransmission, or increased virulence of pathogens or parasites.

Criterion 7 Summary

Disease Risk-Based Assessment

Pathogen and parasite parameters	Score	
C7 Disease Score (0–10)	7	
Critical?	NO	GREEN

Brief Summary

Diseases in farmed clams can occur at every stage of production, from the hatchery to grow-out. Farmed clam grow-out systems are open to the natural environment and there is the possibility of disease exchange between wild and farmed animals. But, biosecurity measures that reduce the risk of parasite and pathogen infection have been put in place from the individual farm level to the intergovernmental and international levels. This score is further improved by the fact that best management practices (BMPs) and/or environmental management codes of practice are in place. Thus, the final score for Criterion 7—Disease is 7 out of 10.

Justification of Rating

Disease data quality and availability is moderate (i.e., Criterion 1 score of 5 out of 10 for the disease category), and the Seafood Watch Risk-Based Assessment was used.

Diseases associated with clams

There is a plethora of information on diseases that affect clams, the management measures that are in place to control diseases, and the historical introduction of disease agents to new areas (Elston and Ford 2011) (DFO 2003). The following diseases are known to be associated with the farmed clam species analyzed in this report.

Vibriosis (brown ring disease), caused by *Vibrio tapetis*, is a systemic bacterial infection of larval tissue and juveniles that can be associated with multiple clam species but is only known to cause mortalities in *Venerupis philippinarum* (Bower 2010). Vibriosis has infected and been associated with mass mortalities of Manila clams cultured in France since the mid-1980s. It has also been found in populations of native carpet clams in Canada, but not fatal in the native species (DFO 2003). Mass mortalities were also observed in Korea in the early 1990s, leading to prolonged declines in clam harvests (Bower 2010). Control measures for vibriosis include improved husbandry techniques and, through the hatchery phase, sterilization of water used in algal and batch culture (DFO 2016a) (FAO 2004).

Quahog parasite unknown (QPX) disease, a protozoan parasite that can cause severe mortality rates, is associated with *M. mercenaria* (quahog or hard clams) and multiple other clam species. There are no known control measures for QPX aside from planting resistant stocks (DFO 2016a) (FAO 2004). QPX was found to be more prevalent in cultured samples than wild samples of hard clams, which supported the concept that QPX prevalence and severity is related to some aspect of husbandry in cultured stocks (Lyons 2008). QPX outbreaks were first recorded in Atlantic Canada in the 1950s, with severe economic losses seen in Prince Edward Island in 1989. After that, outbreaks occurred in Massachusetts, New Jersey, Virginia, New York, and Rhode Island. Mortality rates from QPX disease have been reported as high as 80% to 95% in some cases. QPX has been detected in 0.3% of clams studied in the state of Connecticut (6 out of 2,358 clams studied between 1997 and 2007), but none originated from commercial clam grounds, and the disease is not considered a threat to the state's industry (Connecticut Department of Agriculture n.d.). Clams studied in Florida did not contain QPX (Baker et al. 2006, reviewed 2015). Only adult clams are affected by QPX (Connecticut Department of Agriculture n.d.).

Notably, *M. mercenaria* can carry *Perkinsus* spp., a protozoan that causes dermo disease in oysters, but the clams are not affected by this disease (Connecticut Department of Agriculture n.d.).

There are two diseases that may affect production of soft-shell clam (*Mya arenaria*) within its range from Labrador, Canada to South Carolina, United States. The first is hemic neoplasia (uncontrolled multiplication of blood cells), and mortality occurs in more than 90% of affected clams within 60 days; however, the prevalence of this disease is generally low. The second is gonadal neoplasia (the presence of primary germ cells in reproductive tissue that proliferate rather than develop into gametes), but the mortality rate of this disease is unknown, and its range is limited to Atlantic Canada and Maine, although a similar disorder can occur in the quahog (Barber 1999).

Venerupis pullastra, or pullet carpet shells, harvested mainly in Europe, can be infected with clam perkinsus, icosahedral virus, brown ring disease, trichodinid ciliate infestation, turbellarian infestation, and trematode infestation (FAO 2016b). For many of these infestations, there are no known methods of prevention or control other than reducing the density at which they are cultured and preventing transplantation of clams from areas with records of the disease (DFO 2016b) (FAO 2006).

Many diseases, such as clam perkinsus, icosahedral virus, brown ring disease, larval mycosis, *Haplosporidium* infection, *Rickettsia*-like and *Chlamydia*-like organisms, and red worm disease, have been associated with various clam species (DFO 2016c) (FAO 2005a) (FAO 2005b).

Disease and the production system

Shellfish hatcheries provide a highly concentrated environment in which opportunistic disease agents have the ability to become established, resulting in significantly reduced production (Elston and Ford 2011). Clam larvae are particularly vulnerable to bacterial and viral infections, including members of the genus *Vibrio* (Paillard 2004). Such opportunistic disease agents may be introduced from ambient seawater, broodstock transfer, or via algal food sources (Elston and Ford 2011).

In shellfish nurseries, risk factors for disease are high animal density, poor flushing, and the likely build-up of bacteria (Boettcher et al. 2006). The reduction of animal density, rinsing with fresh water, and enhanced water flow and sanitation can all be used to reduce the risk of disease (Elston and Ford 2011).

Infectious diseases are also recorded in grow-out systems, but the origin may not be clear because diseases could be from hatchery seed or the wild. For example, QPX has occurred on farms (Whyte et al. 1994) (Ragone Calvo et al. 1998) (Smolowitz et al. 1998) (Ford et al. 2002), but has also been found in wild-set hard clams (SeaGrant 2003) (Allam et al. 2005). Quahog parasite unknown (QPX) disease is correlated with density, whether in culture or the wild, and clam growers now avoid using stocks from outside their region, to avoid introducing pathogens from wild clams (Elston and Ford 2011). Zhang et al. (2004) reported that some clam farms in China's Guangxi Province had a mortality rate of between 60% and 95% because of pathogen infection. Because of the continuum between cultured stock and wild stocks during grow-out, it can be difficult or impossible to determine where a disease originates (DFO 2003).

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). There are also state-level measures aimed at disease risk management and BMPs promoted by industry that aim to maximize participation in the High Health program. For example, the Pacific Coast Shellfish Growers Association provides guidelines to shellfish growers on the High Health Program, which helps them develop and implement a program on their farms, including a disease outbreak response plan, and provides information and contacts for specific state regulations (PCSGA 2013). According to the Pacific Shellfish Institute (pers. comm., February 2018), there have been no major problems with disease on clam farms in the recent past, and mortalities are typically caused by weather events, not disease.

Outside the United States, 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—including countries of significant relevance to this assessment, such as Canada and China—to develop individual country standards for all matters related to aquatic products that carry a risk of disease. Canada has developed the National Aquatic Animal Health Program to protect wild and cultured animals against infectious diseases, and uses spatial management to limit the spread and introduction of diseases (DFO 2016d). China has an aquatic animal epidemic prevention system that works to study, detect, monitor, and report aquatic diseases, as well as to develop prevention plans and work plans (Feng 2013). There are 13 provincial aquatic animal disease control centers and 628 county aquatic animal disease prevention stations that carry out technical work for the program. Although China is working to strengthen aquatic animal health management through programs such as this, disease prevention and control is still lacking (Feng 2013).

Generally, there is a moderate to high risk of pathogen and parasite interaction with cultured animals when farm systems are open to the environment. But, the implementation of biosecurity measures and BMPs or environmental management codes of practice reduces this risk in most cases, and results in a score of 7 out of 10 for Criterion 7—Disease.

Conclusions and Final Score

Diseases in clams can exist at all stages of production. Because of the openness of clam production systems during grow-out culture and the continuum with wild populations, disease interactions can occur. And, it is difficult or impossible to determine in which population the disease originated, and what role, if any, disease spillback plays in wild clam disease incidence or mortality. Evidence demonstrating whether or not disease levels are amplified in wild stocks as a result of aquaculture is lacking. Clam aquaculture facilities do employ best management practices for health management, but they are still open to the introduction and discharge of local pathogens. The final score for Criterion 7—Disease is 7 out of 10.

Criterion 8X: 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: using eggs, larvae, or juvenile fish produced from farm-raised broodstocks thereby avoiding the need for wild capture.

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.

Criterion 8X Summary

Source of stock parameters	Score	
C8 Independence from unsustainable wild fisheries (0–10)	–2	
Critical?	NO	GREEN

Brief Summary

Globally, because of the lack of data on seed used by farmers, the percentage of production from farm-raised broodstock or natural (passive) settlement is difficult to quantify. It appears that in both Asia and North America, approximately 80% of stock is from domesticated, farm-raised stock, while approximately 20% may come from wild collection (either as adult broodstock or spat). But, the removal of wild clams for broodstock or spat is not known to have any definite negative impacts on the wild stock, and it is beneficial in reducing the ecological risks associated with domestic selection across generations. Because of the lack of information available to quantify this score, it was based on the available data. Thus, the Criterion 8X—Source of Stock final score was –2 out of –10.

Justification of Rating

The impact of farmed clams on wild clam fisheries is measured by the farms' independence from the active capture of wild clams for on-growing or broodstock. Currently, there is a lack of data regarding the bivalve genetics, breeding, and genomics for the top seven cultured species, which include *Ruditapes* spp., *Sinonovacula* spp., and *Anadara* spp. (Hedgecock 2011) (Astorga 2014). There is also a paucity of information available for the remaining farmed clams analyzed in this report. It is known that, in the United States and western Canada, clams for broodstock use in hatcheries may be originally selected from wild stocks and then maintained as broodstock, or, as is the case in Asia and some farms in eastern Canada, seed (spat) may be collected from the wild (passive settlement) (Buttner and Weston 2010) (BCSGA 2013). In Nova Scotia, clam farms harvesting soft shell clams and quahogs collect their seed from the wild, with no known or recorded impacts to natural populations (pers. comm., Aquaculture Association of

Nova Scotia February 2018). But, there is a huge variation in wild seed production in most parts of the world, based on environmental conditions; therefore, the global clam industry is often reliant on hatcheries for seed (Hargrove et al. 2015) (Fang and Lin 2016) (FAO 2018).

There are currently three ways to obtain seed in China: 1) seed produced in hatcheries from wild broodstock; 2) wild-caught juveniles; and 3) seed produced in hatcheries from domesticated broodstock. Most seed comes from hatcheries. There is no regulation in China for broodstock use in aquaculture, and some wild clam populations may be declining, reportedly due to overexploitation and unregulated interbreeding at hatcheries (Wang et al. 2006) (Fu et al. 2005) (Zhang 2009) (Institute of Ocean n.d.). Quantifying the amount of spat produced in hatcheries in Asia is difficult because of a lack of information on the number of producers that rely on hatchery seed. It is estimated that approximately 80% of Manila clam seed for aquaculture in China is produced in reclamation areas (large ponds with areas of approximately 100 ha) in Fujian Province, and the rest (20%) is from natural seed (Fang and Lin 2016).

In Europe, some countries, including Spain and the Netherlands, have clam hatcheries producing seed for farms. But Italy, which is the second-largest producer of Manila clams after China, relies mostly on natural spat collection, with only a small amount supplied by hatcheries (Robert et al. 2013).

Best practices in Florida indicate that hatcheries must use clam broodstock from Florida waters in their genetic selection program, and if a farm purchases seed from an out-of-state hatchery, that hatchery must use Florida broodstock; documentation of broodstock origin must be provided to the farm by the hatchery (SeaGrant Florida 2014). It is thought that broodstock may be supplemented by clams harvested from aquaculture farms that display favorable characteristics (Hargrove et al. 2015). Indeed, clam hatcheries in the U.S. usually do use their own farm-raised broodstock, but will bring in approximately 15% to 20% wild broodstock each year to maintain genetic diversity (pers. comm., Cherrystone Aqua Farm 2017). Hedgecock (2011) states that no shellfish can be considered domesticated, and suggests that the risk of cumulative effects of domestication selection can be mitigated by the continual replacement of hatchery broodstock with wild adults and the exclusion of hatchery-bred adults from hatchery broodstock.

Conclusions and Final Score

Globally, there is a lack of data on the source of stock for clam aquaculture, and it is necessary to average the findings to represent the industry. But, the lack of data may also indicate the minimal concern that exists regarding the source of stock for clam aquaculture. At least two sources—one from the United States and one from China—indicate that, globally, approximately 80% of clam stock is from domesticated clams, while approximately 20% may be collected from the wild (as adult broodstock or spat) to maintain genetic diversity. Therefore, there is little reliance on wild populations of clams to sustain aquaculture, and where wild clams do provide seed for aquaculture, there are no indications of negative impacts. Approximately 20% of farmed stock is dependent on wild broodstock, but there are no data that definitively show that the use of wild clams (for adults or spat) is negatively affecting wild populations, and 0% of farmed stock is dependent on endangered species. As a result, the final numerical score for Criterion 8X—Source of Stock is –2 out of –10.

Criterion 9X: Wildlife and Predator Mortalities

Impact, unit of sustainability and principle

- Impact: mortality of predators or other wildlife caused or contributed to by farming operations
- Sustainability unit: wildlife or predator populations
- Principle: aquaculture populations pose no substantial risk of deleterious effects to wildlife or predator populations that may interact with farm sites.

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.

Criterion 9X Summary

Wildlife and predator mortality parameters	Score	
C9X Wildlife and predator mortality Final Score (0–10)	–2	
Critical?	NO	GREEN

Brief Summary

Aquaculture operations can attract a variety of predators and result in direct or indirect mortality from trapping, entanglement, drowning, and other means. Predator exclusion devices used on clam farms are usually in the form of netting or mesh bags (both are passive barriers), which would typically not result in the direct or accidental mortality of predators or other wildlife; however, mechanical harvest by dredge of farmed clams has the potential to affect clam predators or other wildlife attracted to clam farms. This impact is mitigated by best management practices and preventative measures and would not result in a population-level effect. Therefore, clam farming has a low impact on predators or other wildlife, and the final score for Criterion 9X—Wildlife and Predator Mortalities is –2 out of –10.

Justification of Rating

Predator exclusion

A variety of clam predators exist among clam farms, including echinoderms, snails, crabs, fishes, and seabirds. Signs of predation include chipped, broken, or empty shells. The most reliable method for preventing predators from gaining access to clams is to employ a passive physical barrier (Leavitt and Burt 2007). Predator exclusion netting prevents most bivalve-eating animals from preying upon farmed clams (Toba 2005). These protective nets are often placed over the seeded substrate and tucked in at the edges, and are made from a variety of plastic netting or woven rope, with mesh sizes ranging from 1.25 cm to 3.5 cm. Nets are applied in one or two layers, then anchored with large rocks or steel posts (Whiteley and Bendell-Young 2007). Where certain predators are able to get under the nets when they are submerged by tides, in-ground bags are used (Toba 2005). In-ground bag culture entails enclosing clam seed in mesh bags partly buried in sediment. Culture bags are made of heavy plastic mesh with 1/2-inch mesh size, which facilitates water flow through the bags while excluding snails and other infaunal predators. Because the mesh size of both netting and in-ground bags is small, the risk of trapping or entangling predators is low. Those predators that do recruit to the enclosure and become trapped will likely grow to a size where they can prey upon the clams (Leavitt and Burt 2007). Predators may also be removed from the farm by hand and either moved to another location or killed (pers. comm., Fenjie Chen, May 2017).

Antipredator netting is typically not used in China (Bendell 2016), but some farms may use chemicals to eliminate predators, although these predators are not endangered species, and mortalities are limited to the time and area of application (Fishfirst n.d.) (pers. comm., Fenjie Chen, May 2017).

<u>Harvest</u>
Clam harvest by dredging can result in an immediate decline in abundance and biomass for all species (i.e., predators, target species, and other benthic organisms) that occur on and in clam farms, but the decline is often followed by rapid benthic recovery (Mercado-Allen and Goldberg 2011). Dredging may initially affect certain organisms, but scavengers and opportunistic predators may also benefit from the effects of dredging by feeding on exposed prey or by colonizing newly exposed seafloor. For example, predatory fish and crustaceans have been found to increase in density in the vicinity of clam dredges (as reviewed by Mercado-Allen and Goldberg 2011). Farmers in China may occasionally plow up intertidal sediments in clam areas to allow these benefits: releasing deposited sulfide, organic compounds, and heavy metals; loosening sediments; and improving habitat for clams. The effects of this practice have not been studied, but would likely be similar to those for dredging (Chen et al 2005) (Ji and Zhang 2001).

The use of passive, nonharmful barriers yields no evidence of direct or accidental mortality of predators or wildlife. In contrast, dredge harvest techniques result in mortality of wildlife beyond exceptional cases, but the rapid recovery and some potential benefit to predators result in no significant impact to the affected species’ population size. Furthermore, harvest dredging is highly targeted and conducted using best management practices. These factors contribute to the overall score of –2 out of –10.

Conclusions and Final Score
The main concern regarding wildlife and predator mortalities comes from mechanical dredging during harvest. This could result in unintentional wildlife or predator mortality. But, dredging is highly targeted, and best management practices are in place to mitigate its effects. There is some evidence that predators may be removed from farms and potentially killed during this process. The final numerical score for Criterion 9X—Predator and Wildlife Mortalities is –2 out of –10.

Criterion 10X: Escape of Unintentionally Introduced Species

Impact, unit of sustainability and principle

- Impact: movement of live animals resulting in introduction of unintended species
- Sustainability unit: wild native populations
- Impact: aquaculture operations by design, management or regulation avoid reliance on the movement of live animals, therefore reducing the risk of introduction of unintended species.

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.

Criterion 10X Summary

Escape of unintentionally introduced species parameters	Score	
F10Xa International or trans-waterbody live animal shipments (%)	4	
F10Xb Biosecurity of source/destination	6	
C10X Escape of unintentionally introduced species Final Score	**–2.40**	**GREEN**

Brief Summary

There are international, national, and regional regulations and permitting requirements in place to prevent the spread of nonnative species. There is known to be shipment of live clams, particularly larvae and seed, between hatcheries, nurseries, and farms. This is necessary in the industry because the production of seed is costly and intensive, which means that relatively few hatcheries and nurseries exist to supply the industry. The final score for Criterion 10X—Escape of Unintentionally Introduced Species is –2.4 out of –10.

Justification of Rating

Factor 10Xa—International or trans-waterbody live animal shipments

The global clam industry relies on some international and trans-waterbody movement of live animals, particularly larvae moving to nurseries and juvenile clams (seed) moving from nursery to grow-out areas.

Many U.S. farms are self-sufficient and produce their own seed within the same area or waterbody as grow-out occurs. For example, as the leader in U.S. clam production, Virginia producers typically have their own hatcheries and supply themselves with seed (VIMS 2015). But, other farms do rely on trans-waterbody shipment to obtain stock (pers. comm., Agricultural Research Corporation, 2016). In most states, clam larvae or seed may be shipped between states and between ecologically distinct areas (e.g., Hawaii to Washington, Washington to California) (Seagrant SC 2002). California has been identified as the leading global supplier of Manila clam seed (Gosling 2015)—the most cultured species worldwide. There are actually no

Manila clam hatcheries in California; rather, the larvae (certified and disease free) are imported from Hawaii, Oregon, and Washington and grown to "seed" size in nurseries (California Department of Fish and Wildlife 2008).

In British Columbia, Canada, live clam seed, spat, or juveniles may be transferred, often internationally, from collection locations, hatcheries, or nurseries to grow-out areas within the province. It is estimated that up to 90% of British Columbia's demand for clam seed is met by hatcheries and nurseries in the United States (e.g., headquartered in Washington, with hatcheries in Hawaii). Access to clam seed is a major limiting factor in British Columbia's clam aquaculture industry (Vancouver Island University 2008) (Svanhill 2012). In 2016, a new hatchery facility opened in the province, with the aim of aiding the production of local seed and decreasing the reliance on international shipment of seed (HQ Vancouver 2016).

In China, clam aquaculture (in particular, Manila clam culture) tends to rely on natural seed that is collected in specially constructed seed collection ponds (FAO 2018). The level of trans-waterbody shipment is unclear, but there is no available evidence that there is international shipment occurring.

Although there is international and/or trans-waterbody shipment of live clams or clam larvae, the level of shipment required by clam farms in different areas may vary dramatically. Therefore, a score of 4 out of 10, representing a moderate 50% to 59.9% reliance on animal shipments, was given to Factor 10Xa to incorporate areas that rely heavily on transport of live larvae/seed and those that do not.

Factor 10Xb—Biosecurity of source/destination

Within the United States, clam seed may be shipped between states and between ecologically distinct areas (e.g., Hawaii to Washington, Washington to California), but best management practices are in place to reduce the risk of transferring diseases and alien species (Seagrant SC 2002). East Coast states have three basic management strategies and related procedures for inspection in place: 1) reducing the risk of importing shellfish diseases, thus preventing pathogens from spreading to culture and wild stocks; 2) inhibiting the importation of exotic and nontarget species; and 3) allowing seed and broodstock importation to sustain a healthy shellfish mariculture industry (Seagrant SC 2002). In Florida, best management practices require hatcheries to use Florida clam broodstock and, if importing seed from another state, that hatchery must also use Florida clam broodstock (SeaGrant Florida 2014).

Outside the United States, the European regulatory framework likewise controls the movement of any species that is locally absent for use in all types of aquaculture (Padilla et al. 2011). In Canada, it is mandatory to have an Introduction and Transfer permit from the Federal/Provincial Introductions Committee and an import permit from the Canadian Food Inspection Agency (CFIA) for all transfers in Canadian waters. All introductions and transfers must comply with Department of Fisheries and Oceans (DFO) and CFIA regulations (BCSGA 2013) (DFO 2016e). The BC Shellfish Growers Association also has a code of practice for the industry, which addresses the process of importing shellfish, with the objective of minimizing the risk of transferring harmful organisms of invasive species with live shellfish and minimizing the risk of transferring disease or unwanted genetic material (BCSGA 2013).

China also has strict regulations on imported fish products, particularly after an event in 2000 where approximately 10,000 ha of farmed Manila clams died, possibly caused by a parasite carried by nonnative species (General Administration of Quality Supervision, Inspection and Quarantine of the People's Republic of China 2011) (Liang and Wang 2001) (Liu et al. 2001). Seafood suppliers are requested to register with China's General Administration for Quality Supervision, Inspection, and Quarantine, but suppliers of live seafood are not required to register (USDA Foreign Agricultural Service 2015). Explicit rules on the imports of live shellfish products are not clear.

There are also best management practices (BMPs) in place for the prevention and management of diseases in bivalve hatcheries, nurseries, and farms. These typically include procedures for water filtration, hygiene of the system, water changes, and bacteriological sampling (Laramore 2015). These BMPs are applied by industry to maintain the yield and quality of the product.

Scoring for Factor 10Xb is:

- Source: hatcheries and nurseries are considered a low to moderate risk and score 6 out of 10.
- Destination: grow-out operations are open systems and considered a moderate to high risk and score 2 out of 10.

The 10Xb score is the higher of the two scores, resulting in a score of 6 out of 10.

Conclusions and Final Score

There is a significant amount of international/trans-waterbody shipment of live clams or clam larvae for the purpose of aquaculture. This is necessary within the industry because seed supply is often an issue for farms, and relatively few hatcheries and nurseries seem to exist to provide that supply. But, it seems apparent that there are management measures in place globally to reduce the risk of introducing unintended species. This, combined with the fact that most shipments would consist of larvae or seed clams originating from hatcheries or nurseries with adequate biosecurity, helps to improve the score. The final numerical score for Criterion 10X—Escape of Unintentionally Introduced Species is –2.4 out of –10.

Overall Recommendation

Updated: See Appendix 2 for Justification

The overall recommendation is as follows:

The overall final score is the average of the individual criterion scores (after the two exceptional scores have been deducted from the total). The overall rating is decided according to the final score, the number of red criteria, and the number of critical scores as follows:

– **Best Choice** = Final Score ≥6.661 **and** ≤10, and no Red Criteria, **and** no Critical scores
– **Good Alternative** = Final score ≥3.331 and ≤6.66, **and** no more than one Red Criterion, **and** no Critical scores.
– **Red** = Final Score ≥0 and ≤3.33, **or** two or more Red Criteria, **or** one or more Critical scores.

Criterion	Score	Rank	Critical?
C1 Data	7.96	GREEN	
C2 Effluent	10.00	GREEN	NO
C3 Habitat	7.20	GREEN	NO
C4 Chemicals	8.00	GREEN	NO
C5 Feed	10.00	GREEN	NO
C6 Escapes	4.00	YELLOW	NO
C7 Disease	7.00	GREEN	NO
C8X Source	–2.00	GREEN	NO
C9X Wildlife Mortalities	–2.00	GREEN	NO
C10X Introduced Species Escape	–2.40	GREEN	
Total	**47.76**		
Final score (0–10)	**6.82**		

OVERALL RANKING

Final Score	6.82
Initial rank	GREEN
Red criteria	0
Interim rank	GREEN
Critical Criteria?	NO

FINAL RANK

GREEN

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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.

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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.

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.

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Guiding Principles

Seafood Watch™ defines sustainable seafood as originating from sources, whether fished[1] 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.
- 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).

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

Once a score and rating has been assigned to each criterion, an overall seafood recommendation is developed on additional evaluation guidelines. Criteria ratings 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.

Appendix 1—Data Points and all Scoring Calculations

Criterion 1: Data Quality and Availability

Data Category	Data Quality (0–10)
Industry or production statistics	7.5
Management	10
Effluent	10
Habitats	7.5
Chemical use	10
Feed	n/a
Escapes	10
Disease	5
Source of stock	5
Predators and wildlife	10
Unintentional introduction	7.5
Other (e.g., GHG emissions)	n/a
Total	**82.5**

C1 Data Final Score (0–10)	**8.25**	**GREEN**

Criterion 2: Effluents

Effluent Evidence-Based Assessment

C2 Effluent Final Score (0–10)	**10**	**GREEN**
Critical?	NO	

Criterion 3: Habitat

Factor 3.1—Habitat conversion and function

F3.1 Score (0–10)	9

Factor 3.2—Management of farm-level and cumulative habitat impacts

3.2a Content of habitat management measure	3
3.2b Enforcement of habitat management measures	3
3.2 Habitat management effectiveness	**3.6**

C3 Habitat Final Score (0–10)	**7**	**GREEN**
Critical?	NO	

Criterion 4: Evidence or Risk of Chemical Use

Chemical Use parameters	Score	
C4 Chemical Use Score (0–10)	8	
C4 Chemical Use Final Score (0–10)	**8**	**GREEN**
Critical?	NO	

Criterion 5: Feed

Feed Final Score

C5 Feed Final Score (0–10)	**10.00**	**GREEN**
Critical?	NO	

Criterion 6: Escapes

6.1a System escape risk (0–10)	3	
6.1a Adjustment for recaptures (0–10)	0	
6.1a Escape Risk Score (0–10)	**3**	
6.2. Invasiveness score (0–10)	**8**	
C6 Escapes Final Score (0–10)	**5**	**YELLOW**
Critical?	NO	

Criterion 7: Diseases

Disease Evidence-based assessment (0–10)		
Disease Risk-based assessment (0–10)	6	
C7 Disease Final Score (0–10)	**7**	**GREEN**
Critical?	NO	

Criterion 8X: Source of Stock

C8X Source of stock score (0–10)	–2	
C8 Source of stock Final Score (0–10)	**–2**	**GREEN**
Critical?	NO	

Criterion 9X: Wildlife and Predator Mortalities

C9X Wildlife and Predator Score (0–10)	**–2**	
C9X Wildlife and Predator Final Score (0–10)	**–2**	**GREEN**
Critical?	NO	

Criterion 10X: Escape of Unintentionally Introduced Species

F10Xa live animal shipments score (0–10)	4.00	
F10Xb Biosecurity of source/destination score (0–10)	6.00	
C10X Escape of unintentionally introduced species Final Score (0–10)	**–2.40**	**GREEN**
Critical?	NO	

Appendix 2—Update

An update of this assessment was conducted in November 2022 in the most-up-to-date Seafood Watch Aquaculture Standard Version 4.0. An update focuses on an assessment's limiting criteria (i.e., Critical or Red) (inclusive of a review of the availability and quality of data relevant to those criteria), so this review evaluates Criterion 6—Escapes. No information was found or received to suggest that the final rating is no longer accurate. No substantive edits were made to the text of the report (except an update note in the Executive Summary and all updated criteria). The following text summarizes the findings of the review.

Update Scoring Summary
Results of the update support the findings of the previous assessment and the Overall Recommendation for clams and cockles grown in on- and off-bottom systems globally. This recommendation remains a Best Choice with a Green rating. The recommendation and rating are driven by entirely Green criteria, except for Criterion 6—Escapes, which is Yellow. In this update, the Criterion 1—Data score was changed from 8.25 to 7.96 and remains Green, while the Criterion 6—Escape score was changed from a 5 out of 10 to a 4 out of 10 and remains Yellow. The change in score was driven by the availability of detailed information demonstrating that spawning events are regular occurrences in clam and cockle aquaculture, alongside additional information indicating that this results in minimal to no impacts to wild populations.

As a result, the Final Score for clams and cockles grown in on- and off-bottom production systems globally is 6.82 out of 10, and with zero Red criteria, the Overall Recommendation is considered Green or Best Choice.

Criterion 1—Data
Data for Criterion 6—Escapes were mainly captured from recent peer-reviewed literature. Evidence describing the potential impact of broadcast spawning by farmed populations on wild, native populations is lacking; however, research showing the health status and vulnerability of wild populations is available. As a result, the availability of information for Criterion 6—Escapes is moderate and scores 5 out of 10. Overall, the availability and quality of data for clams and cockles grown in on- and off-bottom systems globally is moderate to high and scores 7.96 out of 10.

Criterion 6—Escapes

Factor 6.1—Escape Risk
The risk of escape is directly related to the degree of connection to the natural ecosystem. Typical production systems for farmed clams include a hatchery phase, nursery phase, and a grow-out phase. The grow-out phase occurs in open systems (e.g., netted covers or enclosures sited in subtidal and intertidal flats in coastal and estuarine areas). But, more than half the clams available on the United States market are grown domestically or imported from Canada, and both countries employ best management practices (BMPs) or environmental codes of

practice for shellfish aquaculture, which include escape management such as nets or mesh bags to secure the clams (BCSGA 2013) (PCSGA 2001) (Creswell and McNevin 2008) (Flimlin et al. 2010). Clams are farmed in open systems, but unlike farmed crustaceans and finfish, they live an infaunal and mostly sedentary lifestyle as adults. *Meretrix* spp*.* are unique and can secrete mucus and float at the surface, moving with the waves and currents (Zhang et al. 2004). Chen et al. (2013) noted that some midsize to large *Meretrix lyrata* can migrate to deeper waters using this method. Fences and cross lines above clam beds are used to prevent escapes of *Meretrix* spp. on farms. Therefore, the likelihood of active escape is low, and post-escape movements (if any) would be minimal. This, coupled with the widespread use of BMPs, makes direct escape of farmed clams of low concern. There are currently no specific regulations or other management measures in place in China for the mitigation of clam species escapes, but as mentioned previously regarding *Meretrix* spp., farmers do use techniques to prevent escapes from their farms (pers. comm., Fenjie Chen, May 2017).

There is a risk that spawning events may occur during grow-out, potentially releasing large numbers of eggs to receiving ecosystems. For example, hard clam (*Mercenaria mercenaria*) reaches sexual maturity at approximately 32 to 38 mm, and is harvested only after reaching this size (Maryland DNR 2016). *Venerupis philippinarum* is harvested in British Columbia only after it is sexually mature, allowing it to broadcast spawn for at least one season (Whiteley and Bendell-Young 2007). Personal communications (2017) with industry in the United States and Canada indicate it is likely that spawning events occur during the grow-out phase. In addition, triploidy or sterility is not used in the industry at a commercial scale, with only a mention of it as a potential research topic (pers. comm., Cherrystone Aqua Farm 2017) (pers. comm., BC Shellfish Growers' Association 2017). Given these findings and the inability of implemented BMPs to safeguard against reproductive escapes, the risk of escape of spawning material is considered "high," resulting in a Factor 6.1—Escape Risk score of 0 out of 10.

If a juvenile or adult clam were to escape, it could easily be recaptured by hand. But, there is a paucity of information available regarding clam escapes and recapture. Therefore, the recapture and mortality adjustment is 0 out of 10. Thus, the final score for Factor 6.1—Escape Risk is 0 out of 10.

Factor 6.2. Competitive and Genetic Interactions

Globally, clams selected for broodstock are sourced from a combination of wild stocks and hatchery-raised clams for optimal color, morphological traits, growth rates, fecundity, survival, and to maintain genetic diversity (Guo et al. 1999) (FAO 2004) (Whetstone et al. 2005) (Thiet and Kumar 2008) (pers. comm., Cherrystone Aqua Farm, 2016).

Although the use of wild-collected clams for broodstock maintenance is common, the use of wild spat collected for grow-out is less common. This practice has been documented in some Chinese farms producing *Ruditapes* spp., *Meretrix* spp., and *Sinonovacula* spp. (Guo et al. 1999) (Wang et al. 2006) (Fu et al. 2005) (Zhang 2009) (Institute of Ocean n.d.); however, this practice is less common in other countries (Buttner and Weston 2010) (BCSGA 2013) (Hargrove et al. 2015) (Fang and Lin 2016) (FAO 2018). In these cases, because grow-out stock is the progeny of both wild-caught and hatchery-raised broodstock (which are often raised from both wild-caught and farmed individuals), their genotype can be highly similar to that of purely wild conspecifics (Vargas et al. 2010).

The Manila clam (*Ruditapes philippinarum*) is native along coastal areas of East Asia, with seven populations occurring in North China, South China, Japan, and North Korea (Tan et al., 2020). Approximately 86% of the total global clam production in 2020 was Manila clam grown in China (FAO FishStatJ, 2022). The same year, the United States imported 5,928.47 mt of clams from China (numbers specific to Manila clam are unknown) and increased the amount of Chinese clam imports to 10,445.63 mt in 2021 (NOAA 2022).[2] Chinese clams represent 38.9% and 48.1% of total United States clam imports in 2020 and 2021, respectively, and it is assumed that the majority of these are Manila clam. It has been determined that there is a high level of gene exchange between Manila clam populations in North and South China, resulting in low genetic differentiation between populations in these regions (Tan et. al., 2020). This is not the case for the Japanese and North Korean populations, which have a high level of genetic differentiation from each other. Commercial production of Manila clam in China is thought to be the main cause of the significant gene exchange, because 90% of seed collection and production occurs in the south (Fujian and Guangxi Provinces), and seed is transported to the north where the majority of commercial grow-out production occurs (Tan et. al., 2020). This results in an exchange of southern population genetic material with northern populations when commercial populations spawn. Despite this genetic exchange, Manila clam populations maintain a high level of genetic diversity and variation (Tan et. al., 2020).

Research shows that in native blood cockle (*Anadara granosa*) populations along the Pacific coast of Asia, genetic variation between populations is relatively low (only 10.92% of genetic variation occurs between populations), while 89.09% occurs within populations (Shao et al., 2016). This is attributed to passive larval dispersal from wild populations carried by the South China Sea Warm Current, as well as broadcast spawning of farmed populations. It is unclear whether this has resulted in negative impacts to wild native populations. But, it is considered that, although several distinct populations exist, they are genetically similar, with healthy intra-population genetic diversity. Thus, even though broadcast spawning from farmed populations likely occurs, it is considered that wild populations remain healthy.

In addition, razor clam (*Sinonovacula constricta*) has 10 genetically distinct populations along the northern, middle, and southern coasts of China (Niu et al., 2012). In contrast to blood cockle populations, which have high degrees of similarity, razor clam populations are significantly differentiated. It is posited that populations are relatively isolated due to geographic barriers disrupting potential larval dispersal (*S. constricta* generally inhabits semi-enclosed bays). In addition, variations in climates along the coast of China result in different spawning seasons for populations in temperate and subtropical areas, further restricting gene flow between populations (Niu et al., 2012). Culture of *S. constricta* in China began

[2] The volume of clams imported from China in 2020 is likely low due to the COVID-19 pandemic and associated trade interruptions. Import volumes of Chinese clams before 2020 were similar to those shown in 2021.

approximately 800 years ago in Fujian Province in the south, and moved north, with the species introduced in Zhejiang Province 500 years ago. Eventually, the northern provinces of Liaoning, Hebei, and Shandong began to culture the species as well. Some populations in the north show similarities with southern populations, while some in the central coast of China are in another clade. It is unknown to what degree native populations in northern areas were used when culture of the species began, versus seed transported north either through larval dispersion or human transport; however, these authors hypothesize that anthropogenic activities resulted in the mixing of genes between southern and northern populations (Niu et al., 2012). But, it is unclear to what degree, if any, current farming activities affect the health of wild populations. Populations are relatively isolated from each other and, although some have genetic similarities seemingly due to anthropogenic factors hundreds of years ago, the geographic barriers in place effectively limit gene flow between populations.

Of the farmed clam species analyzed in this report, only two are known to be cultured outside their native range: the northern quahog or hard clam (*Mercenaria mercenaria*) and the Japanese littleneck (*Venerupis philippinarum* or *Ruditapes philippinarum*) (Padilla et al. 2011). The northern quahog, native to the Atlantic coast of North America, was intentionally introduced in France and China for the purpose of aquaculture (Goulletquer et al. 2002) (Weixin n.d.). In Europe and China, no effects on ecosystems or native species have been reported (NOBANIS 2012, Weixin n.d.). *M. mercenaria* has no history of becoming invasive in areas where it has been introduced as a nonnative species. Globally, many attempts at establishing wild, nonnative populations have failed. Populations that are continually restocked, such as the farmed population in the Gulf of Mexico, can be maintained, but have not significantly expanded (SERC, n.d.). The Japanese littleneck, native to Asia, is believed to have been accidentally introduced to the West Coast of North America in the 1930s (Toba 2005) (FAO 2016) (Cordero et al., 2017). Japanese littleneck clam is reported to have been established in the wild on the coast of Hawaii, and it may have been established as early as the late 1800s (Zhu 2013). It was later introduced to Europe and spread through intertidal bottom culture to several European coastal areas (as reviewed in Mortensen and Strand (2000) (FAO 2016) (Cordero et al. 2017)). This species, although nonnative, has become ecologically established. But, the effects on ecosystems and native species are apparently limited to the impact on the surrounding habitat by farming infrastructure and/or biodeposition and harvest of the species in areas where it is cultured, not by escaped clams or clam eggs/larvae; see (Spencer 1997) (Saurel et al. 2014) (Lavoie et al. 2016). There is no evidence to suggest that the escape of farmed clams has had a negative impact on wild stocks.

In most cases where clam species are farmed in their native range, wild populations have maintained a high level of genetic diversity and variation and are considered to be healthy despite the potential for gene flow from broadcast spawning from farmed populations. In areas where nonnative species have been introduced, they have not become invasive and have not had a negative impact on native, wild populations. Therefore, the score for Factor 6.2 is 8 out of 10.

Criterion 6 – Escapes Conclusion
Many farmed clam species are cultured within their native ranges. The risk of escape is considered to be high because, although farmed clams are infaunal and escape mitigation management practices are in place, spawning events occur during the grow-out stage of production. But, the risk of ecological impact is low; where clams are farmed within their native range, wild native populations maintain high levels of genetic diversity and variation. Where clams are farmed outside their native range, they generally do not become ecologically established. Ultimately, there is little evidence available to support negative effects of escaped clams on ecosystems or wild populations. Therefore, the final score for Criterion 6—Escapes is 4 out of 10.

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