Monterey Bay Aquarium
Seafood Watch®

Oysters

Crassostrea spp.*, Ostrea* spp.*, Saccostrea* spp.

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Worldwide
Bottom and Off-Bottom Culture

October 5th, 2020
Seafood Watch Consulting Researchers

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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 Watch Assessment. Each assessment 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." This ethic is operationalized in the Seafood Watch standards, available on our website here. In producing the assessments, 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 assessments 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 Watch assessments in any way they find useful.

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 farms must possess to be considered sustainable by the Seafood Watch program. Sustainable aquaculture farms and collective industries, by design, management and/or regulation, address the impacts of individual farms and the cumulative impacts of multiple farms at the local or regional scale by:

1. **Having robust and up-to-date information on production practices and their impacts available for analysis;**
   Poor data quality or availability limits the ability to understand and assess the environmental impacts of aquaculture production and subsequently for seafood purchasers to make informed choices. Robust and up-to-date information on production practices and their impacts should be available for analysis.
2. **Not allowing effluent discharges to exceed, or contribute to exceeding, the carrying capacity of receiving waters at the local or regional level;**
   Aquaculture farms minimize or avoid the production and discharge of wastes at the farm level in combination with an effective management or regulatory system to control the location, scale and cumulative impacts of the industry's waste discharges.
3. **Being located at sites, scales and intensities that maintain the functionality of ecologically valuable habitats;**
   The siting of aquaculture farms does not result in the loss of critical ecosystem services at the local, regional, or ecosystem level.
4. **Limiting the type, frequency of use, total use, or discharge of chemicals to levels representing a low risk of impact to non-target organisms;**
   Aquaculture farms avoid the discharge of chemicals toxic to aquatic life or limit the type, frequency or total volume of use to ensure a low risk of impact to non-target organisms.
5. **Sourcing sustainable feed ingredients and converting them efficiently with net edible nutrition gains;**
   Producing feeds and their constituent ingredients has complex global ecological impacts, and the efficiency of conversion can result in net food gains or dramatic net losses of nutrients. Aquaculture operations source only sustainable feed ingredients or those of low value for human consumption (e.g. by-products of other food production), and convert them efficiently and responsibly.
6. **Preventing population-level impacts to wild species or other ecosystem-level impacts from farm escapes;**
   Aquaculture farms, by limiting escapes or the nature of escapees, prevent competition, reductions in genetic fitness, predation, habitat damage, spawning disruption, and other

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

impacts on wild fish and ecosystems that may result from the escape of native, non-native and/or genetically distinct farmed species.

7. **Preventing population-level impacts to wild species through the amplification and retransmission, or increased virulence of pathogens or parasites;**
   Aquaculture farms pose no substantial risk of deleterious effects to wild populations through the amplification and retransmission of pathogens or parasites, or the increased virulence of naturally occurring pathogens.
8. **Using eggs, larvae, or juvenile fish produced from farm-raised broodstocks thereby avoiding the need for wild capture;**
   Aquaculture farms use eggs, larvae, or juvenile fish produced from farm-raised broodstocks thereby avoiding the need for wild capture, or where farm-raised broodstocks are not yet available, ensure that the harvest of wild broodstock does not have population-level impacts on affected species. Wild-caught juveniles may be used from passive inflow, or natural settlement.
9. **Preventing population-level impacts to predators or other species of wildlife attracted to farm sites;**
   Aquaculture operations use non-lethal exclusion devices or deterrents, prevent accidental mortality of wildlife, and use lethal control only as a last resort, thereby ensuring any mortalities do not have population-level impacts on affected species.
10. **Avoiding the potential for the accidental introduction of secondary species or pathogens resulting from the shipment of animals;**
    Aquaculture farms avoid the international or trans-waterbody movements of live animals, or ensure that either the source or destination of movements is biosecure in order to avoid the introduction of unintended pathogens, parasites and invasive species to the natural environment.

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.

Final Seafood Recommendation

Criterion	Score	Rank	Critical?
C1 Data	7.00	GREEN	
C2 Effluent	10.00	GREEN	NO
C3 Habitat	7.20	GREEN	NO
C4 Chemicals	9.00	GREEN	NO
C5 Feed	10.00	GREEN	NO
C6 Escapes	4.00	YELLOW	NO
C7 Disease	4.00	YELLOW	NO
C8X Source	0.00	GREEN	NO
C9X Wildlife mortalities	-2.00	GREEN	NO
C10X Secondary species escape	-2.40	GREEN	
Total	**46.80**		
Final score (0-10)	**6.69**		

OVERALL RANKING

Final Score	6.68
#REF!	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 global farmed oysters is 6.69 out of 10, which is in the green range. There are no red or critical critera. The overall rating for global farmed oysters is a green Best Choice recommendation.

Executive Summary

This Seafood Watch assessment involves ten different criteria covering impacts associated with: effluent, habitats, wildlife and predator interactions, chemical use, feed production, escapes, introduction of non-native organisms (other than the farmed species), disease, the source stock, and general data availability.

The species under consideration here are oyster species, produced globally and available to consumers in the US. In 2018, global oyster production was 5,994,895 mt. Countries in Asia dominate global production: namely, China (5,139,760 mt, 85% of global production), South Korea (303,200 mt, 5%) and Japan (176,000 mt) which together account for 94% of global production. The United States accounts for approximately 2.6% of global production, with miscellaneous other countries contributing the remainder. In the US market, approximately 93% of oysters consumed are produced domestically. Oyster production in the United States is practiced in most coastal states. The most commonly farmed species of oyster are *Crassostrea gigas* (Pacific oyster), *Ostrea edulis* (European flat oyster), and *Crassostrea virginica* (Eastern oyster). Production methods used in oyster culture include on-bottom and off-bottom techniques.

Data

Data on the biology and global production of oyster farming are generally accessible. While there is a large body of research relating to interactions between oysters and surrounding ecosystems, gaps remain in our understanding of dynamics between oyster aquaculture and surrounding environments. Available research is not evenly spread globally, and generally finds variations in regional and local ecological impacts from oyster farming. The overall data quality is moderate-high, resulting in an overall data criterion score 7.0 out of 10.

Effluent

As effluent data quality and availability are good (i.e. Criterion 1 score of 7.5 out of 10 for the effluent category), the Evidence-Based Assessment methodology was utilized. As filter-feeders, farmed oysters are not supplied external feed or nutrient fertilization for a majority of their life cycle. Though rare and specific examples of a reduction in nutrients available to native species have been found, oyster farming has largely been shown to improve water quality through removal of excess nutrients. Overall, oyster farming is considered highly unlikely to result in negative nutrient-related impacts, particularly beyond the immediate vicinity of the farm. The score for Criterion 2 – Effluent is 10 out of 10.

Habitat

Oyster culture generally occurs in coastal intertidal areas or in coastal inshore subtidal areas, which are considered to be of moderate to high habitat value. Oyster aquaculture can alter sediment processes, community composition, seston resources, nutrient cycling, and hydrodynamics. However, the impact of farmed oyster operations on habitat functionality is considered to be minimal, as oyster culture is also associated with a host of ecosystem services and ecological benefits to water quality, nutrients, provision of habitat and shoreline stabilization. The score for Factor 3.1 is 9 out of 10. Assessing the management of oyster farm siting globally is challenging, but overall, the regulatory and enforcement of licensing and site selection appear reasonably effective. The score for Factor 3.2 is 3.6 out of 10. The combination of Factors 3.1 and 3.2 result in a final Criterion 3 – Habitat score of 7.20 out of 10.

Chemical Use

Oyster production does not typically rely on the use of chemicals. Best management practices employed for oyster farming worldwide designate manual labor (e.g., pressure-washing, hand removal, freshwater baths and/or air drying) to prevent and remove predators and fouling organisms from gear and from oysters themselves. While antibiotics may be used in the hatchery phase, they are rarely used to treat disease during growout, as their application is not practical given the production systems used. Overall, the use of physical and non-chemical methods of biofouling control are effective and widely utilized in oyster culture. Given the global scope of this report, there may be some circumstances in which chemicals are used for fouling, disease, or predation control, but the majority of evidence suggests chemicals used, if any, have no impact on non-target organisms. The final numerical score for Criterion 4 – Chemical Use is 9 out of 10.

Feed

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

Escapes

As sessile organisms, direct escape of farm population oysters is implausible. However, oysters are often harvested after reaching sexual maturity and grown in fully open production systems, allowing for larval dispersal. The use of triploid seed partially mitigates the risk of spawning-related escape, but its use on a global scale cannot be considered common. The overall risk of escape is high, and the score for Factor 6.1 is 2 out of 10. The risk of impact, however, is moderate. Where oysters are farmed within their native range, they typically have high genetic similarity to their wild counterparts due to wild collection of spat or broodstock, and where they are farmed outside their native range, they have typically been ecologically established for several decades. However, it is still possible that both native and non-native cultured oysters can impact populations of wild oysters, and non-native oysters have been shown to compete with native populations for food and habitat. The score for Factor 6.2 is 6 out of 10. Combining Factors 6.1 and 6.2, the final score for Criterion 6 – Escapes is 4 out of 10.

Disease, pathogen and parasite interactions

Without a robust understanding of how on-farm disease impact wild organisms (i.e. Criterion 1 score of 5 out of 10 for the disease category), the Seafood Watch Risk-Based Assessment methodology was utilized. Oysters are susceptible to disease during every stage of production and there is a risk of impact to wild species through the amplification and retransmission, or increased virulence of pathogens or parasites. Across the global industry, biosecurity measures, including genetic selection for disease resistance, have been put in place at the farm, government, and international levels help reduce the risk of parasite and pathogen transmission to wild populations. However, the existence of biosecurity measures does not guarantee successful mitigation of all disease risk, and incidents of disease outbreaks in farmed oysters are not uncommon. Importantly, knowledge gaps still exist for disease transmission and impacts to wild species. Ultimately, farms experience disease challenges and are fully open to the introduction and discharge of pathogens. The final score for Criterion 7 – Disease is 4 out of 10.

Source of Stock

Seed for oyster farming is either collected through natural settlement of spat on cultch or through the use of broodstock in land-based hatcheries. Passive collection techniques allow for spat to settle, and then be collected and reared in nursery. In regions where there is a reliable and abundant supply of wild spat, passive collection is often used. Land-based hatcheries may be utilized where wild spat supply is not reliable or abundant. As the global industry is not reliant on wild caught broodstock or growout stock, the final score for Criterion 8X – Source of Stock is 0 out of -10.

Wildlife and predator mortalities

Oyster culture utilizes bags, mesh and other passive exclusionary devices to control for predation. The use of passive, non-harmful barriers yields no evidence of direct or accidental mortality of predators or wildlife. Dredge harvest techniques result in mortality of wildlife beyond exceptional cases, but due to rapid recovery and some potential benefit to predators, there is no expectation of long-term significant impact to the affected species' population size, and best management practices are in place to minimize effects. Therefore, oyster aquaculture has a low impact on predators or other wildlife and the final numerical score for Criterion 9X--Wildlife and Predator Mortalities is a deduction of -2 out of -10.

Escape of secondary species

It is assumed that 50% of the global oyster industry relies on movements of animals. Best management practices for both the source and destination of oysters are established, however due to the global scope of this assessment, it is assumed that their implementation and efficacy are varied. Typically, hatcheries use larval tanks, while growout sites are open systems using BMPs. International and national biosecurity measures vary with regard to oyster aquaculture, however trade and movement of oysters and seed is regulated at state, national and international levels. The final score for Criterion 10X – Escape of unintentionally introduced species is –2.4 out of –10.

Summary

The final numerical score for global farmed oysters is 6.69 out of 10, which is in the green range. There are no red or critical critera. The overall rating for global farmed oysters is a green Best Choice recommendation.

Introduction

Scope of the analysis and ensuing recommendation

Species: *Crassostrea* spp., *Ostrea* spp., *Saccostrea* spp.
Geographic Coverage: Global
Production Method(s): Bottom and Off-bottom (suspended or floating systems, longlines, racks/bags) culture

Species Overview

Oysters are sessile, filter-feeding bivalves in the phylum Mollusca. Oysters are often described as ecosystem engineers because they form reef structures which serve as habitat for other species in coastal estuarine environments. Oysters begin their life cycle as larvae and float for approximately two weeks before developing a foot and eventually attaching to the substrate (Figure 1). Once attached, the juvenile oyster (called "spat") will begin to secrete a calcium 'glue' that will cement it to the substrate as it develops into a mature adult. Oysters are hermaphrodites and reproduce via broadcast spawning. The sex of an oyster can change depending on environment and life stage, and spawning can be induced with temperature change.

Oysters are farmed worldwide for human consumption, with 97% of production occurring in China, South Korea, Japan, and the United States. The most commonly farmed species of oyster are *Crassostrea gigas* (Pacific oyster), *Ostrea edulis* (European flat oyster), and *Crassostrea virginica* (Eastern oyster).

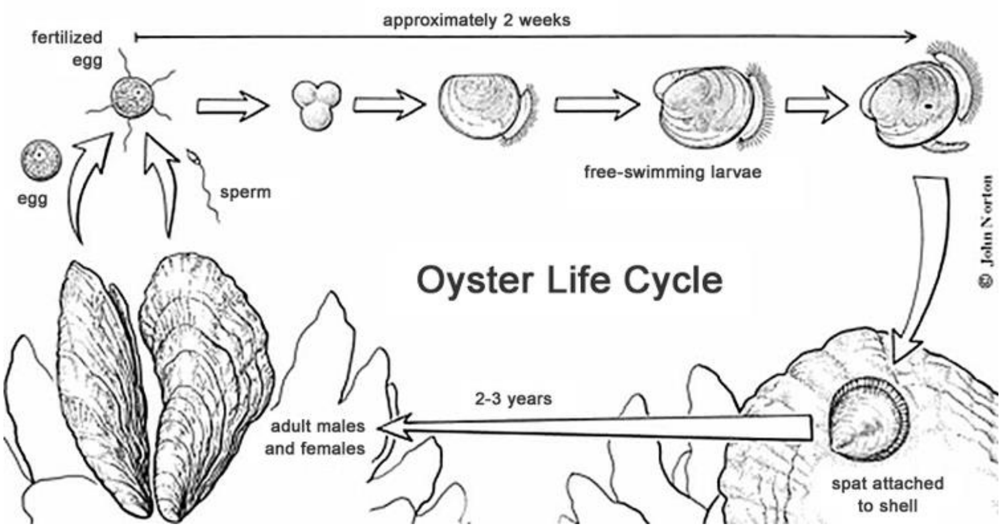

Figure 1. Oyster lifecycle: adult oysters spawn, releasing eggs or sperm into the water column; fertilized eggs become free-swimming larvae; larvae develop a foot and attach to the substrate where they remain as they grow and mature. Image from: https://www.pangeashellfish.com/blog/oyster-life-cycle-on-farm

Production system
This assessment considers both types of oyster farming production utilized globally: bottom and off-bottom systems. The decision to utilize bottom or off-bottom culture depends on a variety of environmental factors, such as wave and wind action, salinity, natural food supply, availability of broodstock or seed, water quality, predator assemblage, stability and condition of sediments, and depth. Other reasons include market preference for shapes of shells, which can be influenced by production on- or off-bottom.

Recruitment
Seed is collected either passively via natural settlement of spat on cultch (a material, typically old oyster shell, that is provided as a settlement point for larvae) or via hatchery and nursery production. Passive collection techniques include different types of material for spat to settle on, including sticks, drain pipe, oyster and scallop shells placed in bags and strung on wires, and plastic tubes (Doiron 2008, Queensland Government 2018). Land-based hatcheries may be utilized where wild spat supply is not reliable or abundant. Hatcheries may also be used to obtain greater quantities of spat (Doiron 2008), to control for the health of spat, or when farming a non-native species, as well as when regions have been previously chellenged by disease (Element Seafood 2013).

Growout
Oyster growout occurs in open marine and estuarine environments using a variety of techniques, which include plastic or wire-mesh containers, cages, trays, and bags, deployed on-bottom or from floating or fixed structures (Doiron 2008). Figure 2 outlines different configurations of cages for oyster growout in both bottom and off-bottom culture (note all these production systems are covered by this Seafood Watch assessment).

Oysters may be grown directly on the bottom of intertidal and subtidal substrates. Bottom culture (Figure 3) entails sowing the young oysters on the ground, either unattached or attached to collectors for a period of 1-2 years, after which they are scraped from cultch (if applicable) and sown on maturing beds, often surrounded by protective fences in intertidal or shallow subtidal areas. In deeper waters, oysters are often planted only after dredging the area to remove stones, predators, and competitors (Pangea Shellfish Company 2015, Doiron 2008, Garrido-Handog 1990, Héral and Deslous-Paoli 1991).

In areas where there is a lack of hard substrate or significant wave action, oysters may be grown in suspension (i.e., off-bottom) using (among others) raft, rack, and stake methods (Figures 4 and 5). In raft culture, oysters are suspended from a raft in which single oysters are placed on trays and allowed to grow until they reach a marketable size or they are suspended from a raft in which seeds are threaded onto a length of wire, rope, or cord. In rack culture, racks of various materials are used as a superstructure to hold oysters housed in trays or on strings. The racks are typically deployed so that oysters are only exposed to air during a low tide. Stake culture is generally used in lagoons that are too shallow for raft and rack techniques.

This method holds oysters in a vertical position and the stakes may also serve as collectors themselves (Pangea Shellfish Company 2015, Doiron 2008, Garrido-Handog 1990).

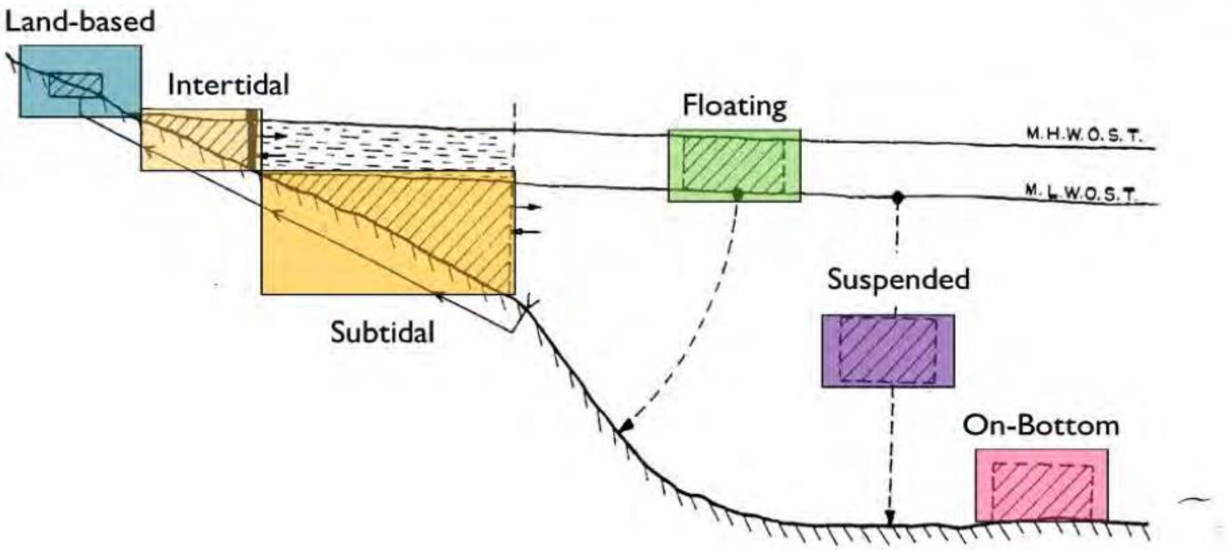

Figure 2. Examples of different zones in which oyster aquaculture growout methods can be located: Land-based, Intertidal, Subtidal, Off-Bottom (Floating, Suspended) and On-Bottom methods are all depicted (Cerino 2016).

Figure 3. Example of on-bottom oyster cages. Oyster cages are placed directly on the seabed to prevent predation and sinking into the substrate (Cerino 2016).

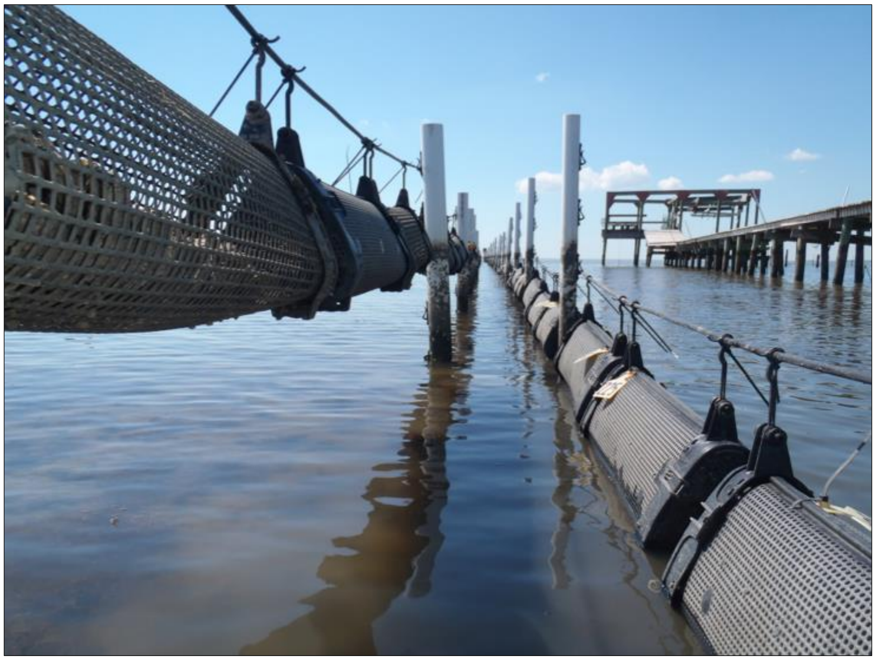

Figure 4. Adjustable suspended longline culture system on the Gulf Coast of the US. Baskets hanging from lines are adjusted vertically in and out of the water column to control the amount of water they are exposed to, which is a tactic used to reduce biofouling. This is one method of off-bottom culture (Walton et al. 2012).

Figure 5. An off-bottom oyster culture method using floating cages. Cages can be flipped up onto floats occasionally to control for biofouling through periodic drying. Floating systems are considered off-bottom culture methods (Walton et al. 2012).

Production Statistics

In 2018, global oyster production was 5,994,895 mt (FIGIS 2020). Over 95% of global oyster production was in Asia: specifically China (5,139,760 mt), South Korea (303,200 mt) and Japan (176,000 mt) which together account for 94% of global production. The United States accounts for approximately 2.6% of global production, with miscellaneous other countries contributing the remainder (ibid.).

Table 1. Global farmed oyster production by species in 2018 (FIGIS 2020).

Species	Quantity (mt)	% of Total Production
Crassostrea spp.	5,171,065	86.3
C. gigas	643,549	10.7
C. virginica	134,939	2.3
Ostreidae	7,627	0.1
Total	**5,957,180**	99.4

China:

Chinese production of oysters consists mainly of *Ostrea denselamellosa*, *Crassostrea gigas*, *Crassostrea angulata, Crassostrea rivularis*, *Crassostrea plicatula, Crassostrea hongkongensis*, and *Pinctada martensii* (Mao et. al. 2019). In 2018 China produced 85.7% of the total global volume (FIGIS, 2020). The main production method used in oyster culture is suspended longlines, and the majority of production occurs in Bohai Bay, Liaodong Bay, Laizhou Bay, the Shandong Peninsula, Guangdong Province, Guangxi Province, Hainan Island, and Fujian Province (Mao et. al. 2019). The Pacific oyster (*C. gigas*) is mainly produced in the northern provinces, while other species are produced in the south.

South Korea:

South Korea produced 303,200 mt (5.1% of global production) in 2018 (FIGIS 2020). Although 14 species of native oysters are found in South Korea, the only oyster species that is commercially important in Korea is *C. gigas* (ibid.). Wild, native oysters are harvested to some extent along the western coast (Choi 2008), while culture of oysters in South Korea is concentrated along the southern coast (Choi 2008).

Japan:

Japan has a long history of oyster farming, with a majority of the production centered in Hiroshima Bay. Oysters are also produced in smaller quantities in the Iwate, Miyagi, Niigata, Mie and Okayama prefectures (Japan Atlas 2019). The species most commonly grown is the native *C. gigas*, with minor production of *C. nippona* (common name Iwagaki oyster) in the summer (Little Creek Oyster Farm 2016, FAO 2018a). Many oyster farms were destroyed in the 2011 earthquake and tsunami, resulting in a rebuilding effort, with the help of French oyster producers and French oyster aquaculture technology (The Japan Times 2019, Japan Atlas 2019, Thefishsite.com 2016). Production decreased over the 6-year period 2010-2016 from 200,298 mt to 158,925 mt. Decreased domestic production, coupled with increased consumer demand led to a 49% increase in Japanese oyster imports in 2016 (FAO, 2016).

United States:

In the United States, oyster aquaculture accounted for 81% of the total mollusk aquaculture production by volume in 2016 (FAO, 2018g), and 2.1% of total global production in 2018 (FIGIS 2020). Approximately 83% of the oysters produced are *C. virginica* (American cupped oyster), and approximately 15% were *C. gigas* (Pacific cupped oyster) (FIGIS 2020).

In the US market, approximately 93% of oysters consumed are produced domestically (FAO 2018b). Oyster production in the United States is practiced in most coastal states, with Massachusetts producing approximately 68% of the domestic farmed oysters by volume, Rhode Island 16%, Maine 15% and New Hampshire 0.4% of oysters farmed in the Northeast region in 2015 (Sackton 2018). Most oyster operations are small, privately owned, family businesses (Pers. comm., B. Rheault 2019).

France:

France has seven main regions in which oysters are farmed, including Normandy, North Brittany, South Brittany, Vendée, Charente-Maritime, Arcachon, and the Mediterranean (which includes Thau, Leucate, and Corsica) (Driver 2018). France produced an estimated 64,910 mt of oysters in 2016, a decrease from the 80,650 mt in 2010. The vast majority of these were *C. gigas*, however *O. edulis* are also farmed (FAO 2018a, Buestel et al. 2009). Nearly all of the oysters produced in France are sold live, raw and eaten fresh (Buestel et al. 2009).

Percent of industry represented by each different production system

While it is not entirely clear what percentages of off-bottom and on-bottom production are used in global oyster production, the majority of production in the top 5 producing countries (China, South Korea, Japan, United States, and France) is done in suspended, off-bottom systems.

In China, oysters are most commonly grown on longlines and in “mudflat aquaculture” (Mao et. al. 2019), although it is unclear whether this term refers to on-bottom or suspended production.

Growout methods are primarily off-bottom culture in South Korea with longlines being the most popular method used (FAO 2005b, Choi 2008, Lovatelli 1988).

The oyster farming industry in Japan dates to the 16th century, and traditional methods, such as suspended hanging rafts, were typically used until the 2011 earthquake and tsunami, which destroyed many oyster farms (Thefishsite.com 2016). Since then, production methods have shifted to longlines, and suspended bags. The suspended raft method is also currently used. (Thefishsite.com 2016).

In the US, both bottom and off-bottom culture are used in production. Floating and suspended systems such as rack and bag and bottom cages (often a few inches from the ground) are more widely utilized on the east coast, while bottom culture methods (wild spat collected on cultch and free planted on leases) are more popular in the Gulf of Mexico. In Canada, the prevalent production methods used are both on-bottom methods and off-bottom suspension (holding bags, cages, trays or rope lines).

In France, 65% of the oyster industry uses off-bottom culture methods, while the remaining 35% uses bottom culture either in intertidal or deep-water environments (Beustel, 2009).

Import and Export Sources and Statistics

The worldwide total oyster trade is approximately 70,000 mt (FAO 2018). France exports more oysters than any other country, by volume, but ranks only fifth in overall production (FAO 2018). From 2016 to 2017, French exports grew by 20% to 12,000 mt. France is also a major importer with 8,000 mt imported in 2017 (FAO 2018). The vast majority of oysters are sold live, fresh, frozen, or dried, with a small percentage of the industry represented by canned or preserved products (WHO 2010).

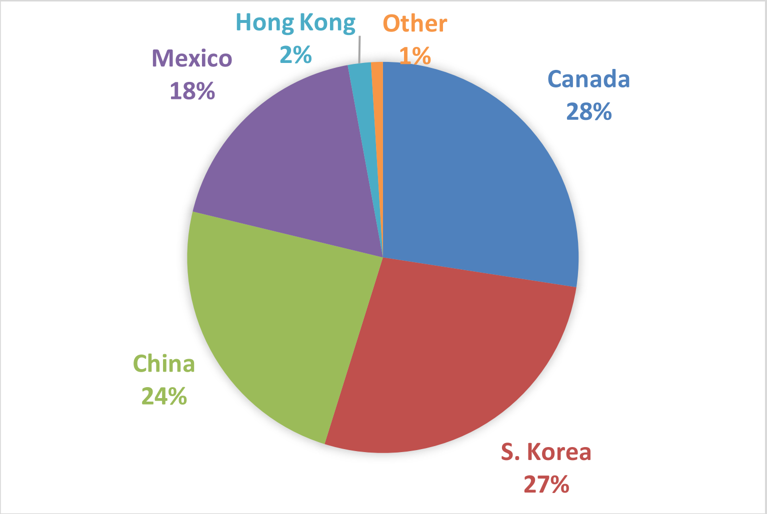

Figure 6. US oyster imports in 2019 (NOAA 2020).

The US imported a total of 10,964 mt in 2019, of which 916.2 mt were designated as wild or seed (NOAA, 2020). The remaining 10,048.1 mt were either designated as farmed, or were not differentiated (e.g. canned, canned smoked). In 2019, the US imported 2,757.2 mt from Canada, 2,751.2 from South Korea, and 2,406.8 from China, with other, smaller volumes coming from Asia, South America, and New Zealand (ibid.).

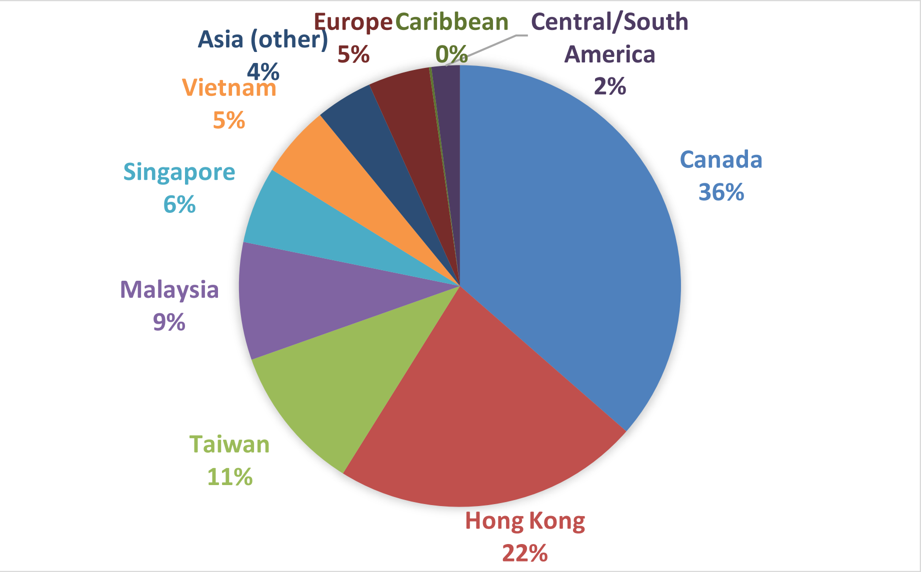

Figure 7. US oyster exports in 2019 (NOAA 2020).

The volume of oysters, live or prepared, that were exported from the US in 2019 was 3,540 mt, of which 143.4 mt was seed. The remaining 3,396.6 mt do not differentiate between farmed and wild(ibid.). The largest export volumes went to Canada, Hong Kong, Taiwan, Malaysia, Singapore and Vietnam (1237.2 mt, 762.3 mt, 363.6 mt, 292.7 mt, 191.0 mt, 178.8 mt respectively).

The US is the largest importer of oysters, with growing demand. Domestic production is growing, with the industry rapidly expanding. Oyster demand is currently higher than the available supply, and this trend is expected to continue (FAO 2018a).

Common and Market Names

Farmed oysters are available on the U.S. market as "oysters." Species include:

Common Name	Scientific Name
European flat oyster	*Ostrea edulis*
Pacific oyster (also known as the Japanese oyster and Giant oyster)	*Crassostrea gigas*
Eastern oyster (also known as the Atlantic or Virginia oyster)	*Crassostrea virginica*
Sydney rock oyster	*Saccostrea glomerata (formerly S. commercialis)*
Kumamoto oyster	*Crassostrea sikamea*
Olympia Oyster (also known as the West Coast Native oyster)	*Ostrea lurida*

Angasi/ Australian flat oyster	*Ostrea angasi*

Product forms

Live whole, Frozen in the half shell, Shucked- Preserved, Shucked- Frozen

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 available for analysis.

Criterion 1 Summary

Data Category	Data Quality	Score (0-10)
Industry or production statistics	7.5	7.5
Management	7.5	7.5
Effluent	7.5	7.5
Habitat	7.5	7.5
Chemical use	7.5	7.5
Feed	Not Applicable	n/a
Escapes	7.5	7.5
Disease	5	5
Source of stock	7.5	7.5
Predators and wildlife	7.5	7.5
Introduced species	5	5
Other – (e.g. GHG emissions)	Not Applicable	n/a
Total		**70**

C1 Data Final Score (0-10)	**7**	**GREEN**

Brief Summary

Data on the biology and global production of oyster farming are generally accessible. While there is a large body of research relating to interactions between oysters and surrounding ecosystems, gaps remain in our understanding of dynamics between oyster aquaculture and surrounding environments. Available research is not evenly spread globally, and generally finds variations in regional and local ecological impacts from oyster farming. The overall data quality is moderate-high, resulting in an overall data criterion score 7.0 out of 10.

Justification of Rating

Production

Data describing the size of the global oyster industry in terms of volume and value, as well as general breakdown of production by country and species are available through the FAO's website. Information describing the production systems used and locations of farms are generally found in grey literature and journal articles. These data and information may vary, but at the highest level, data are available describing the regions within a country that are most productive. Overall available data are considered to give a reliable representation of the production of global oyster farming, and are considered good, scoring 7.5 out of 10.

Management

Data on aquaculture management are generally easy to find on government resources and websites. National, regional and local laws and regulations and industry management measures for China, South Korea, Japan and the United States are clear and accessible. Management within and across countries and regions is analyzed through a variety of secondary sources and published papers. However, reliable information on the effectiveness of enforcement is lacking. The data are considered moderate-high and score 7.5 out of 10.

Effluent

There is broad literature available to describe the effluent-related impacts of oyster farming on the waterbodies in which the industry is sited. Multiple studies are available investigating the effects of oyster presence on nitrogen cycling, however conclusions on the effects of biodeposition are inconsistent across these studies leading to knowledge gaps for this topic, and these effects are predicted inconsistently among sources. There are no monitoring records available for effluent discharge from oyster farming nationally or regionally, though the lack of nutrient-related impacts typical of fed aquaculture is well understood. The data are considered moderate-high and score 7.5 out of 10 for effluent.

Habitat

Habitat data is accessible in European and North American countries, where extensive research has investigated the effects of the physical presence of oysters on bottom composition, tidal flush and changes in sediment size and makeup. Data relating to habitat effects are available, however there are gaps in data regarding enforcement of habitat protection regulations, including data on carrying capacity, baseline water quality, and effectiveness of multitrophic aquaculture systems. Information on enforcement and relevant laws and regulations is accessible for China, South Korea, Japan and the United States, where 97% of oyster aquaculture occurs. This results in moderate data quality and confidence, and a data score of 7.5 out of 10.

Chemical Use

Historically, the use of chemical treatments (pesticides, parasiticides, disinfectants, antibiotics, antifoulants, anaesthetics and herbicides) in mollusk aquaculture is minimal. Communication with oyster farmers show that non-chemical methods of antifouling are the most widely used in the industry. The data and research that has been collected is easy to access, and relatively thorough and complete, though the global nature of the assessment presents some uncertainty in a fully comprehensive understanding of chemical use. The data score is 7.5 out of 10 for chemical use.

Feed

This criterion is not directly applicable to the scope of this assessment, as oysters are not provided external feed in the growout portion of their life cycle.

Escapes

Information and data on escape risk are readily available. General understanding of oyster biology (e.g. broadcast spawning) and open production systems combined with research on oyster gene flow and invasiveness has increased the amount of data available on escapes in recent years. Precise numbers of escapes and scale of impact is impossible to accurately measure given the nature of the oyster life cycle, though the impacts of non-native farmed oyster escapes have also been well-documented and there is a large body of research continuing to investigate these interactions. This results in good data quality and confidence, and a score of 7.5 out of 10 for escapes.

Disease

Information on disease prevention, identification, and biosecurity measures is available and well-documented in reports and literature. There has been extensive research on the spread of disease and regional transmission, with knowledge gaps on international transmission identified in the literature. Information surrounding the content and use of Best Management Practices is available. Peer reviewed literature provided some information on transmission of disease between wild and farmed oysters, though there are gaps in knowledge for many of these impacts. Current knowledge of OsHV-1 is incomplete and the effects are not well-understood at this time. The knowledge gaps that exist create uncertainties about key information. This results in moderate data quality and confidence, and a score of 5 out of 10 for disease.

Source of Stock

The sources of stock are known to generally come from wild sources, either via passive settlement or broodstock from hatcheries. This has been discussed in peer-reviewed literature. It is difficult to quantify the source of stock for all areas, particularly in Asian countries. The data quality and availability can be considered good overall, resulting in a score of 7.5 out of 10 for source of stock.

Predator and Wildlife Mortalities

Understanding of mortalities of predators and wildlife is primarily informed by the use of passive exclusionary measures. Communications with experts and information from peer-reviewed literature provide high confidence in the data quality surrounding the use of exclusionary measures and the limited resulting predator interactions. Due to the global scale of this assessment, it in unknown what true mortality rates are, and how any negative impacts to wildlife are balanced out by potential benefits associated with providing habitat. Therefore, the data score for predator and wildlife mortalities is 7.5 out of 10.

Escape of Secondary Species

Research is available with some limitations for this criterion. Data on international and trans-waterbody live animal movements, species and domestication status, and biosecurity are available, however it is unclear what portion of the global industry relies on international or trans-waterbody animal movements. Information describing biosecurity measures at the source and destination of animal movements is available, however given the broad scope of this assessment, it is unclear whether and how best management practices that are described are met. This results in moderate-high data quality and confidence, and a score of 5 out of 10 for escape of secondary species.

Conclusions and Final Score

The overall data on the impacts of oyster farming worldwide are generally available and relatively high quality. There are knowledge gaps in some areas where research is either being continued or needs to be done in order to better understand the impacts and interactions between oyster aquaculture and the surrounding ecosystems. The final score for Criterion 1 – Data is 7.0 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

Evidence-Based Assessment

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

Brief Summary

As effluent data quality and availability are good (i.e. Criterion 1 score of 7.5 out of 10 for the effluent category), the Evidence-Based Assessment methodology was utilized. As filter-feeders, farmed oysters are not supplied external feed or nutrient fertilization for a majority of their life cycle. Though rare and specific examples of a reduction in nutrients available to native species have been found, oyster farming has largely been shown to improve water quality through removal of excess nutrients. Overall, oyster farming is considered highly unlikely to result in negative nutrient-related impacts, particularly beyond the immediate vicinity of the farm. The score for Criterion 2 – Effluent is 10 out of 10.

Justification of Rating

As effluent data quality and availability are good (i.e. Criterion 1 score of 7.5 or 10 of 10 for the effluent category), the Evidence-Based Assessment methodology was utilized. The effluent criterion considers the impact of effluent beyond the immediate boundary of the farm; benthic impacts directly beneath the farms are considered in Criterion 3 – Habitat. Farmed oysters are not provided external feed or nutrient fertilization (Ward 2016, Helm et al. 2004, Nuffield Australia 2012), limiting or eliminating the concern for nutrient-related impacts often observed in fed aquaculture.

Oyster farms remove phytoplankton and organic detritus from the water column through filtration (Ward 2016, Wiedenhoft 2017, Mote.org 2018). Some of the available literature asserts that this reduction in nutrients may stimulate trophic cascades by removing nutrients that would otherwise be available to benthic filter feeders, or that would be passed up to higher trophic levels (Gallardi et al. 2014). A notable example was the demonstrated depletion of phytoplankton due to oyster farming in Daya Bay in the South China Sea, where there was a 60% reduction in Chl-a during the culture period (Jiang, et. al, 2016). However, this and other examples are rare, notable exceptions, as ecological carrying capacity modelling broadly suggests that the current farming densities are not high enough to cause this concern (Ross et al. 2013, Byron et al. 2011). Reducing the amount of phytoplankton and detritus in the water column is generally thought provide a key ecosystem service by reducing the primary symptoms of eutrophication (Duball et al. 2019, Silva et al 2017, Smith et al. 2016, Weidenhoft 2017, Ward 2016, Dumbauld et al 2009). Rose et al. (2015) examined the effects of nitrogen removal by shellfish farms across 9 countries and 4 continents as it relates to coastal eutrophication and best management practices for agricultural and stormwater runoff. The study concluded that shellfish farms should be included in nutrient management programs due to their high nitrogen-removal capabilities on a per-acre basis.

Oysters remove inorganic N and P from the water column through filtration of phytoplankton and incorporate these nutrients into their tissues and shells (Duball et al. 2019, Rose et al. 2015, Kellog et al. 2013). They remove these nutrients from the system permanently when harvested (Pollack et al. 2013). However, impacts to nutrient budgets and primary production from oyster production will vary according to their abundance, location, system flushing rate, and residence time (Gallardi 2014). This active filter feeding results in the excretion of undigested material (feces or pseudofeces[2]), which can lead to enhanced biodeposition (Huang et al. 2018, Oyster BMP Expert Panel 2016, Solomon and Ahmed 2016, Ward 2016, Gallardi 2014, Forrest et al. 2007, Newell et al. 2005). However, biodeposits generally settle in the immediate vicinity of the farm (and are therefore considered in Criterion 3 – Habitat), and localized benefits of filter feeding and subsequent biodeposition can include a net decrease of nutrients in the water column through sequestration of N and P into oyster tissues and through denitrification, which improves water quality and combats eutrophication (Duball et al. 2019; Rose et al. 2015).

Conclusions and Final Score

The extractive nature of shellfish, including oysters, is widely known to have the capacity to improve water quality and clarity through the removal of suspended particulate matter in the water column. The final score for Criterion 2 – Effluent is 10 out of 10.

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[2] Pseudofeces are undigested particulates, such as grit and sand, that are taken in by oysters while filter feeding and not used as food. These particulates are coated in mucus and ejected from the oyster. Once ejected, the particulates and grit that are contained in the pseudofeces will settle on the bottom and become buried beneath the surface layer of sediment.

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 SummaryHabitat 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		3.6
C3 Habitat Final Score (0-10)		**7.20**
Critical?	NO	**GREEN**

Brief Summary

Oyster culture generally occurs in coastal intertidal areas or in coastal inshore subtidal areas, which are considered to be of moderate to high habitat value. Oyster aquaculture can alter sediment processes, community composition, seston resources, nutrient cycling, and hydrodynamics. However, the impact of farmed oyster operations on habitat functionality is considered to be minimal, as oyster culture is also associated with a host of ecosystem services and ecological benefits to water quality, nutrients, provision of habitat and shoreline stabilization. The score for Factor 3.1 is 9 out of 10. Assessing the management of oyster farm siting globally is challenging, but overall, the regulatory and enforcement of licensing and site selection appear reasonably effective. The score for Factor 3.2 is 3.6 out of 10. The combination of Factors 3.1 and 3.2 result in a final Criterion 3 – Habitat score of 7.20 out of 10.

Justification of Rating

Factor 3.1. Habitat conversion and function

Habitat conversion is measured by the effect of aquaculture activities on ecosystem services. Oyster farming can provide valuable ecosystem services, however there are some concerns regarding habitat impacts. The greatest concerns raised about habitat-related impacts oyster culture are alteration of epibiont abundance and diversity (Smith et al. 2018) and contribution to hypoxic benthic conditions (Smyth et al. 2016). Additional factors include modification of nutrient exchanges such as increased denitrification and microbial respiration under farms (Smyth et al., 2016, Forrest et al., 2007), and broader ecological effects such as the creation of novel habitat leading to shifts in species abundance (Solomon and Ahmed 2016, ASC 2012, Shumway 2011, Forrest et al. 2007). There may also be evidence that biodeposition underneath shellfish farms could have positive impacts on nutrient load and ecosystem functioning (Huang et al. 2018). The interactive effects of these observations on habitat are still unknown. Definitive data on the effects of oyster aquaculture on ecosystem functions are insufficient, and further research is needed to address the current knowledge gaps of broader ecosystem effects. Figure 9 outlines several effects of oyster aquaculture on the immediate and surrounding habitat.

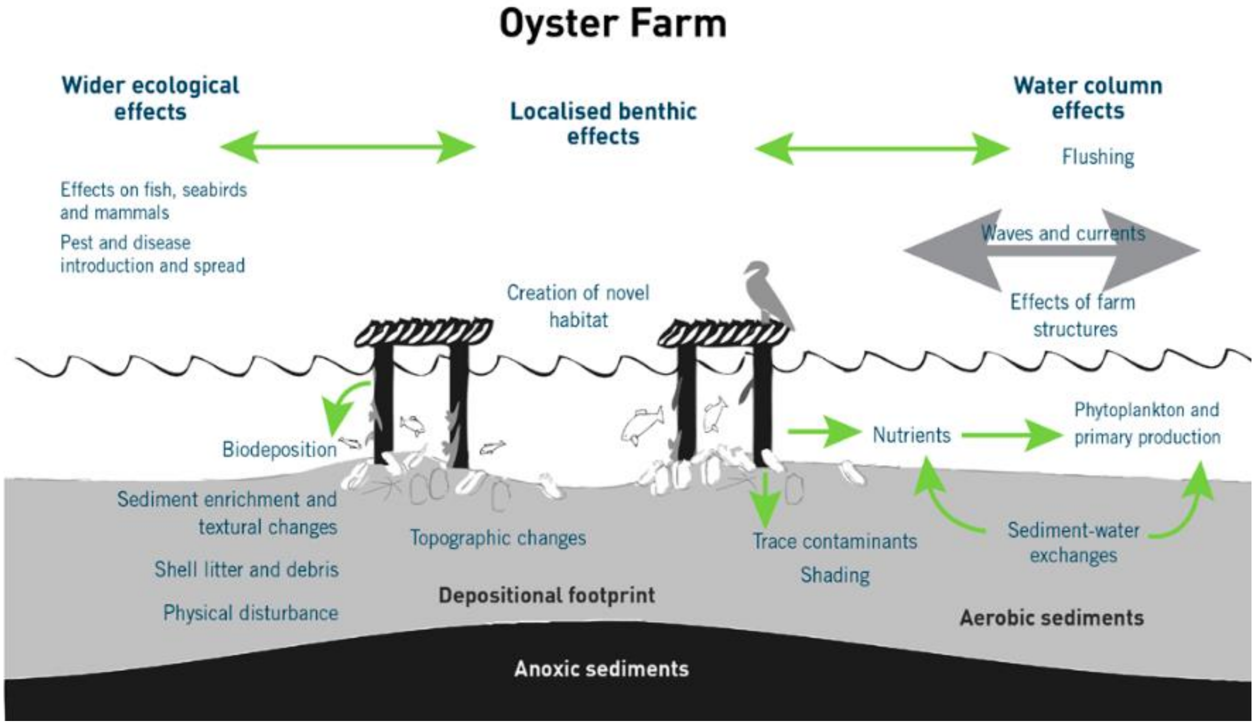

Figure 8. Diagram illustrating actual and potential ecological effects of off-bottom oyster culture. (MPI 2013).

Benthic effects

Effects on Submerged Aquatic Vegetation

Oyster aquaculture operations can both positively and negatively affect seagrass beds that are within close proximity to the farms. Studies on the effects of oyster presence on submerged aquatic vegetation (SAV) suggest that a reduction in phytoplankton and sediment in the water can provide benefits such as an increase in the amount of underwater light and extension of the euphotic zone (Sandoval-Gil et al. 2015, Oyster BMP Expert Panel 2016, Dumbauld et al. 2009, Ward 2016, Rose, Bricker and Ferreira 2015, Gallardi et al. 2014, Rice 2008). Eelgrass beds located in close proximity to oyster aquaculture operations may have increased denitrification and nitrogen uptake abilities, which further improves water quality (Sandoval-Gil et al. 2015). This suggests that the biosedimentation associated with oyster aquaculture could be beneficial to the eelgrass habitats located in close proximity to farms. Conversely, some studies have also shown highly localized effects such as decreased density on seagrass beds directly beneath oyster aquaculture infrastructure, though these effects do not extend beyond the farm boundary and do not seem to impact surrounding ecosystems (Bulmer, Kelly and Jeffs 2012, Barillé et al. 2010, Martin et al. 2010).

Effects on benthic conditions

Oyster aquaculture may also reduce the potential for hypoxic or anoxic conditions in the benthos. Without other forms of removal, dead phytoplankton settle on the seafloor and can contribute to hypoxic and anoxic conditions through biochemical processes (Rice 2008). Oyster filtration exerts top-down control on phytoplankton populations and reduces the amount of dead phytoplankton settling on the bottom (Sandoval-Gil et al. 2015). Assessment of the effects of biodeposition on nutrient cycling and habitat functionality show conflicting findings in relevant literature. Some studies assert that biodeposition from oyster aquaculture creates increased sedimentation which can negatively affect water flow around the farm (Solomon and Ahmed 2016) and contribute to hypoxic conditions (Rice 2008), however this concern is directly related to stocking density and may not be likely given the actual stocking density of most farms (Rice 2008). Additionally, biodeposition beneath bivalve farms may improve ecosystem functioning by providing nutrients to the meiobenthos, as illustrated in a study involving scallop aquaculture (Huang et al. 2018). These nutrients may support organisms in lower levels of the food web and enrich the benthic ecosystem. The results of this study may be extended to other filter-feeding organisms, such as oysters.

Concerns about the effects of localized biodeposition can be mitigated in off-bottom culture by controlling stocking density and ensuring proper farm siting (Rice 2008). Some off-bottom culture systems can limit the broad dispersal of pseudofeces and increase sedimentation by inhibiting tidal currents (Solomon and Ahmed 2016, Forrest et al. 2007). The ecological impacts of these biodeposits are largely unknown, however they may undergo denitrification by nitrifying bacteria, which converts the biologically active N in the biodeposits into inert nitrogen gas (N_2), a form of N that cannot be utilized for primary production (zu Ermgassen et al. 2017, Smyth et al. 2016, Kellog et al. 2013, Newell et al. 2005). Oyster biodeposits have been shown to enrich sediments and increase rates of denitrification as compared to other coastal habitats (zu Ermgassen et al. 2017, Smyth et al. 2016, Sandoval-Gil et al. 2015).

Effects of competition

Oysters may compete with other benthic species that occupy the same space, or through trophic competition. Oysters remove phytoplankton from the water, effectively competing for the same food source as wild populations of other filter feeders, such as mussels (Solomon and Ahmed 2016). The effects of trophic competition, however, would be reduced in areas with high levels of nutrients in the water column, and depend on the stocking density of the farmed population. Oysters may also outcompete other species for space (habitat exclusion) (Solomon and Ahmed 2016), however several studies have shown that the effects of competition would not occur outside of the farm footprint (Ward 2016, Wiedenhoft 2017, Dumbauld et al. 2009). While these studies assert that the effects of competition for space would not extend beyond the farm boundary, this does not account for cumulative impacts in an area with a high density of farms.

Effects of physical infrastructure

Physical infrastructure from oyster farms can create habitat and refuge for species, as environments with more complex three-dimensional structure generally support greater species abundance and biodiversity (Rice 2008, Muething 2015). Off-bottom oyster farms could potentially provide more three-dimensional structure than natural reefs or estuarine environments (Muething 2015). Given the dynamic nature of the system, and the fact that pelagic effects are dependent upon the specifics of each study site, it is difficult to compare findings among studies or to find consensus on whether these effects can be beneficial.

Oyster aquaculture may also induce community shifts towards species that are better adapted to the new environments that oyster farms create, such as polychaetes and other marine worms (Smith et al. 2018, Kwan et al 2018, Huang et al. 2018). . Aquaculture may indirectly influence seagrass epibiont communities by shifting the composition of benthic species abundances beneath the farms (Smith et al. 2018). Furthermore, epibiont communities beneath farms in this study showed higher abundances of isopods and sessile polychaete worms. While shifts in species abundance and composition have been observed, the effects of these shifts on ecosystem productivity are uncertain.

The physical infrastructure associated with oyster culture can raise habitat-related concerns; including the alteration of hydrodynamics and current velocities, as well as reduced flow rates (Kraft 2017, Solomon and Ahmed 2016, MPI 2013, Dumbauld et al. 2009 and Padilla, McCann and Shumway 2011). Reduced currents may increase sedimentation, and reduce sediment turnover rates. One concern in the literature is that this could stimulate hypoxic conditions, which has been observed in mussel farms (Gallardi et al. 2014) . "Sediment fouling" can occur if the carrying capacity of oysters in a given area is exceeded, and nitrifying bacteria within sediments cannot effectively fix the nitrogen coming from oyster biodeposits, however the current densities of oysters in farming operations do not exceed carrying capacity (Rice 2008). Siting farms in areas of high tidal exchange can mitigate potential issues found with physical infrastructure (Rice 2008). For instance, constructing oyster culture structures parallel to the direction of the current will reduce siltation (MPI 2013).It is unknown, however, what percentage of global oyster production follows these best management practices.

Harvest

Oysters grown off-bottom are typically harvested by hand, however the strings or trays employed could be heavy enough to require mechanical power. In this case, marketable oysters are harvested by small vessels equipped with mechanical washing and grading equipment. These methods are increasingly preferred for their improvement of oyster survivorship, growth rate, and overall product consistency and aesthetic (Muething 2015).

Oysters grown on-bottom are typically harvested by hand (raking or picking), but they can also be harvested by either a mechanical or suction dredge, both of which increase the potential for negative impacts on the benthic environment (Muething 2015, Stokesbury et. al. 2011). Dredging is becoming less prevalent, however, as off-bottom culture becomes more popular.

A mechanical oyster dredge is operated by a winch and penetrates soft sediments to remove oysters and shell directly from the surface. Additionally, suction dredges operate by pumping water from the seafloor through a hose to remove or move sediments containing oysters (Mercado-Allen and Goldberg 2011). Suction dredges can be used for transplanting oysters for growout, relocating shell and cultch material, and removing benthic predators, such as oyster drills (Mercado-Allen and Goldberg 2011).

Dredging at harvest can result in an initial decline in abundance and biomass for all species that occur on in oyster cultivation areas (i.e., predators, target species and other benthic organisms), but the decline is often followed by rapid benthic recovery (Mercaldo-Allen and Goldberg 2011, Stokesbury et al.,2011). Oyster habitats are generally found in high energy shallow waters, and the organisms that reside in them are well adapted to frequent disturbances (i.e., storms) (Stokesbury et al. 2011). While changes in sediment structure associated with oyster dredging are reversible or dissipate over short periods of time, these time periods may be variable (as reviewed in Dumbauld 2009 and Mercado-Allen and Goldberg 2011).

Scavengers and opportunistic predators may also be attracted to the area due to the effects of dredging. They may feed on exposed prey or colonize newly exposed seafloor. For example, the density of fish and crustaceans in the vicinity of clam dredges increases after dredging (Mercaldo-Allen and Goldberg 2011), and original communities of infaunal species return within a year of harvesting via dredge, as shown in studies with clams (Rice 2008). Common practices like replanting shell and spatted shell following dredging have the capacity to improve or restore habitat and biodiversity (Dumbauld 2009, Mercado-Allen and Goldberg 2011).

When on-bottom oysters are harvested by hand, the potential for negative habitat effects decreases. Habitats in which oysters are farmed and then harvested by dredge are subject to changes in sediment structure and reduction in species diversity and biomass. Harvest impacts are considered to be local, reversible and minimal in areas well adapted to frequent disturbance (Pers. comms., B. Rheault, 2019, Stokesbury et al. 2011, Rice 2008).

Overall, the effects to habitat function from oyster culture are expected to be minimal, reversible and mitigated by the ecosystem services that oysters provide. The score for Factor 3.1 is 9 out of 10.

Factor 3.2. Farm siting regulation and management

Aquaculture management varies country-to-country, and existing strategies to assess environmental impact can be lacking or inapplicable to individual circumstances and needs of a given country (Ross et al. 2013). Farm site selection tools have been developed to encourage an ecosystem-based approach to site selection (Ross et al. 2013, Silva et al. 2011). Historical decisions of site selection were based on available space and productivity limits; however, there is a push towards an ecosystem-based approach to global aquaculture management (EAA), which focuses on ecosystem services, social impacts, governance, carrying capacity and long-term aquaculture effects to ecosystems (Ross et al. 2013, Silva et al. 2011). One 10-year study of the incorporation of EAA in aquaculture management found that EAA may be raising awareness of, and steering aquaculture towards greater sustainability. However uptake of EAA by different user groups varies (Brugère et al. 2018). EAA is a new focus for aquaculture that was not considered earlier than a decade ago and this is a step towards sustainability, however further development and refinement of EAA approaches may be necessary. Each oyster-producing country regulates aquaculture and enforces aquaculture policies differently, but often with the same goal of minimizing environmental impact. The following is an overview of habitat and farm management measures in several countries with significant oyster aquaculture production.

China

There are no specific laws for aquaculture site selection, however, there are many other comprehensive laws dealing with fisheries and the environment. The Fisheries Law of the People's Republic of China allows states to designate plans for different uses of surface waters including aquaculture. Permits for aquaculture are granted under this law (FAO, 2004a; Zhu and Dong, 2013). In addition, there are other legislative tools applicable to aquaculture including the Regulator Law for Sea Area Usage, and laws around water quality, marine protected areas, and water discharge (among others) (Zhu and Dong, 2013). Although there is a legal framework present for aquaculture, enforcement remains an issue, particularly due to the large number of rural and small aquaculture operations in China and the government's desire to maintain or grow production in the industry (Zhu and Dong, 2013).

South Korea

South Korean aquaculture activities are regulated by both the central government through The Ministry of Maritime Affairs and Fisheries (MMAF), as well as provincial governments (FAO 2005a). The Fisheries Act (1990) and The Fishery Resources Protection Act (1953, as amended) make up the regulatory framework of Korean aquaculture, and cover aquaculture licensing and planning, natural resource management, and conservation (FAO 2005a). The Aquaculture Ground Management Act (2000) regulates how sites increase productivity and encourages environmentally responsible aquaculture over the long-term (FAO 2005a).

Additionally, the Framework Act on Marine Development (1987, as amended) deals with the economic development of the aquaculture industry, as well as the preservation and management of marine ecosystems (FAO 2005a). The Framework Act on Marine Development calls for science-based policy and management of aquaculture through research subsidies and support of research facilities. It is unclear whether formal environmental impact assessments are required.

South Korea utilizes a co-management system between local governments and groups of fishermen to implement and encourage responsible fishing practices. These groups self-regulate and are responsible for creating measures and practices that adhere to the conservation and sustainability laws and regulations put in place by government (FAO 2005a). Information on specific enforcement measures and regulatory practices was not available.

Japan

In Japan, aquaculture legislation is regulated by the Ministry of Agriculture, Forestry and Fisheries (MAFF), but in practice many tasks have been delegated to the prefecture governments (FAO 2004-2019). Japan is politically separated into different territories, or prefectures, with distinct Sea Areas. Each Sea Area has a designated Sea Area Fisheries Adjustment Commission as set forth in The Fisheries Law (1949, revised 1962), which also regulates licenses and fishing rights (FAO 2004-2019).

The Central Fisheries Adjustment Council, as well as Sea Area Fisheries Adjustment Commissions (under the joint jurisdiction of the prefecture governments and the MAFF) regulate policy, and implement and enforce laws within the national framework (FAO 2004-2019). Aquaculture is regulated under the Law to Ensure Sustainable Aquaculture Production (1999) and the MAFF Basic Guidelines to Ensure Sustainable Aquaculture Production (1999) (FAO 2004-2019).

The Fisheries Agency (FA), under the MAFF, manages Japan's marine resources and fisheries, as well as marine research institutes that contribute to the management of these resources (FAO 2004-2019). The MAFF enacted the Law to Ensure Sustainable Aquaculture Production (1999) to mitigate environmental degradation due to fish farming. In addition to this law, the MAFF put forth “Basic Guidelines to Ensure Sustainable Aquaculture Production” (1999) and "Aquaculture Ground Improvement Programmes" were designed and implemented by the FCAs (FAO 2004-2019).

Other laws pertaining to aquaculture include The Water Pollution Control Law (1970, as amended) which regulates effluent discharge, the Basic Environmental Law which establishes Environmental Quality Standards (EQS) and criteria for environmental indicators such as water quality, sediment condition beneath aquaculture operations, health of cultured animals, and the Law to Partially Amend the Law on the Protection of Fishery Resources (1996) which addresses the spread of disease by permitting imports (FAO 2004-2019). The Basic Environment Law also established the “aquaculture ground improvement program” which requires farms to report on farm population density, feeds and other materials used on the farm, and measures taken to improve environmental conditions. The program is enforced through prefecture government oversight (Takeda 2010).

Policy, implementation and enforcement are handled by Sea Area Fisheries Adjustment Commissions and a Central Fisheries Adjustment Council for each prefecture. The prefecture governments coordinate efforts under the national framework outlined in the Fisheries Law (FAO 2004-2019). The program is enforced through prefecture government oversight and can result in loss of the aquaculture lease if there is non-compliance (Takeda 2010). Specific information on enforcement, sanctions and policies was not readily available.

United States

In the US, oyster aquaculture occurs along each of the coasts, and is regulated at the federal and state level (Farquhar et al. 2017), though local regulations can also impact oyster aquaculture permits.

The U.S. Army Corps of Engineers (ACoE) issues aquaculture permits before a farm can be established, and these permits require consultation with the ACoE, the National Marine Fisheries Service (NMFS) and the US Fish and Wildlife Service (USFWS), as well as approval by states to ensure the farm is consistent with the coastal zone management programs. The ACoE also issues permits for harvest activities such as dredging, under the Nationwide 48 permit (NWP48). Additionally, state and local agencies are involved in permitting, however legislation varies from state to state. Each state must develop a Coastal Zone Management Plan (CZMP) that is consistent with (or more stringent than) the requirements of the federal Coastal Zone Management Act. CZMPs are implemented through local level Shoreline Master Programs (SMP) which are specific to individual coastal counties. Counties are not required to coordinate SMPs to account for cumulative impacts.

If aquaculture activities will impact protected or endangered species, NOAA, or a designated agent for NOAA, may issue permits pertaining to the Endangered Species Act (ESA) and the Marine Mammal Protection Act (MMPA) (Fisheries.noaa.gov 2018). Consultations for new farms also seek to ensure compliance with the ESA and Essential Fish Habitat before aquaculture activities commence (NMFS 2016). Permits are re-authorized every 5 years, dependent on re-assessment (NMFS 2016). The National Environmental Policy Act (NEPA) regulates the process of conducting an Environmental Impact Assessment (EIA). Parameters assessed include protection of critical habitat (e.g. compliance with water use planning) and essential fish habitat (EFH), impact on historic resources and navigation, and impact on migratory fish and submerged aquatic vegetation (ECSGA 2018).

Europe

The EU, including main oyster producers Italy, Spain and France, employs a Common Fisheries Policy that was amended in 2014 and includes regulations for oyster aquaculture (European Commission, 2019). While the EU Common Fisheries Policy does not explicitly name environmental sustainability as a priority area within the policy, Environmental Impact Assessments, as well as coordinated spatial planning efforts are identified as important steps in aquaculture planning and regulation (Ec.europa.eu, 2019). Much of the licensing and siting decisions for aquaculture are decided at a state-level, and an EU-wide collaboration is identified as an area of improvement (European Parliament, 2009). European aquaculture siting management is often state-specific, generally robust and utilizes an ecosystem-based approach (Ross et al., 2013). Europe has relatively strict water-quality standards and understanding of ecological impacts of aquaculture as well as knowledge of specific waterbodies (Ross et al., 2013).

While management in European countries is well regulated and enforced, there are currently minimal aquaculture licensing procedures for the entirety of the EU, nor a well-developed standard EU procedure for administering Environmental Impact Assessments (EIAs). Licensing and siting are the responsibility of member-states (European Parliament 2009). This leads to uncertainty and lack of uniformity in regulation and environmental protection measures (European Parliament 2009). Often, this regulatory variance leads to the use of the precautionary principle, which relies on stronger regulation when there is a lack of information. The use of the precautionary principle effectively blocks many aquaculture activities from occurring, however newer technology in aquaculture is allowing for a more informed approach to regulation and enforcement (European Parliament 2009). Additionally, the EU has taken steps to address the fragmentation of policy and enforcement via the Common Fisheries Policy and the Blue Growth agenda (European Commission 2019). These new standards are being developed to standardize aquaculture licensing, siting, regulation and enforcement among all EU member-states (European Commission 2019).

European oyster producers have started to utilize remote sensing technology and collaborative processes between government, stakeholders, non-governmental organizations and the scientific community to inform management and farm siting decisions (Pastres 2017). This new technology is also being used to estimate the impacts of biodeposition and sedimentation from farms, and the amount of nitrogen and phosphorous that are removed from the ecosystem (Pastres 2017). Other modeling technologies, such as Life Cycle Assessment (LCA) are also becoming more widely-used in siting decisions, which improves the ability of government bodies to minimize environmental impacts from farming through informed decision-making (Lourguioui et al. 2017).

Conclusions and Final Score

Oyster aquaculture typically has minimal impact on habitats within the farm sites. It is associated with the potential to alter sediment processes, community composition, seston resources, nutrient cycling, and hydrodynamics. Oyster culture is also associated with ecological benefits to benthic composition, provision of habitat, and shoreline stabilization. The Factor 3.1 score is 9 out of 10. Regulations governing oyster aquaculture globally are generally based on ecological principles and environmental considerations (e.g. impact assessments, inspections, etc.), however the degree to which cumulative impacts are accounted for varies. Enforcement of habitat management measures is partially effective, with organizations identifiable and largely appropriate to the scale of the industry. Licensing processes are generally publicly shared, however the transparency of these processes is variable. The final Factor 3.2 score is 3.6 out of 10. While there are minimal ecological impacts associated with oyster aquaculture, the variations in the content and effectiveness of the management regimes may not account for cumulative impacts. Factors 3.1 and 3.2 combine to result in a final Criterion 3 – Habitat score of 7.20 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)	**9**	
Critical?	NO	**GREEN**

Brief Summary

Oyster production does not typically rely on the use of chemicals. Best management practices employed for oyster farming worldwide designate manual labor (e.g., pressure-washing, hand removal, freshwater baths and/or air drying) to prevent and remove predators and fouling organisms from gear and from oysters themselves. While antibiotics may be used in the hatchery phase, they are rarely used to treat disease during growout, as their application is not practical given the production systems used. Overall, the use of physical and non-chemical methods of biofouling control are effective and widely utilized in oyster culture. Given the global scope of this report, there may be some circumstances in which chemicals are used for fouling, disease, or predation control, but the majority of evidence suggests chemicals used, if any, have no impact on non-target organisms. The final numerical score for Criterion 4 – Chemical Use is 9 out of 10.

Justification of Rating

Biofouling is a significant challenge in oyster culture; both physical farm infrastructure and cultured oysters themselves are prone to fouling. Consistent manual cleaning is required to remove fouling organisms. Current management of biofouling typically relies on manual methods of removal or raising growout infrastructure out of the water where many fouling organisms will either die or release. Air drying, brine or freshwater dips, power washing, and scrubbing/scraping are not only more successful, but environmentally innocuous antifouling methods that are widely used worldwide (Pers. comm., H. Pearson, Island Creek Oysters 2018, PEIFARD 2014, Fitridge et al. 2012, Doiron 2008).

Pesticides

Historically, the use of pesticides (e.g. copper sulfate, calcium oxide, sand coated with trichloroethylene, and insecticides) was pioneered for oyster culture in the 1930s (Loosanoff et al. 1960, Jory et al. 1984, Shumway et al. 1988). While chemical control methods proved effective, the concern for potential environmental and public health risks of copper sulfate, trichloroethylene, and insecticides outweighed the benefits, and farms began to utilize manual methods of biofouling control instead. The use of many pesticides has been discouraged for shellfish aquaculture by industry "Best Practices" in the US (ECSGA 2010, Creswell and McNevin 2008, Sapkota 2008), or completely banned, as recently demonstrated in the case of imidacloprid (approved in the U.S. in 2016, has now been banned in the state of Washington) (Mayer 2018, The Aquaculturists 2015, US EPA 2019).

Calcium oxide (lime) is used widely to control fouling and predation, as well as to control for pH fluctuations in systems (PEIFARD 2014). The effects of liming include limiting algal growth via phosphorous sequestration, pH buffering, and increasing productivity and adding important nutrients (e.g. calcium and magnesium) to the production system (Boyd 2017). Studies involving the application of hydrated lime in shellfish aquaculture show minimal effects on the habitat and non-target species, and liming is considered a safe practice in aquaculture (PEIFARD 2014). While liming is a common practice, manual methods are most common in oyster aquaculture.

Leaching and Marine Debris

Oyster aquaculture can often involve bottom-conditioning with treated and recycled material. This has raised concerns for chemical leaching and has prompted research in recent years. Research on the use of Recycled Concrete Aggregate (RCA) in aquaculture in the Chesapeake Bay showed no cause for concern over hydrocarbon contamination (Maryland DOT 2016). Treated timber used in spat collection and grow-out may leach chemicals into the environment over time, although deleterious effects are expected to decrease over time and have not been confirmed (Huckstep 2015, MPI 2013).

Antibiotics

While antibiotics may be used in the hatchery stage to control bacterial disease, their use is not practical in the growout stage of oyster culture due to the nature of the production systems. Instead, culling and maintaining appropriate stocking densities are relied on more heavily to manage the presence and spread of disease (Pernet et. al. 2016).

Conclusions and Final Score

Evidence suggests that oyster farming does not typically employ the use of chemicals, and non-chemical methods to control biofouling and disease prevention and management are often preferred. Non-chemical methods of control include air drying, brine or freshwater dips, power washing, and scrubbing/scraping, while disease management techniques include culling and management of stocking density. Given the global scope of this report, there may be some circumstances in which chemicals are used for fouling, disease, or predation control, but the majority of evidence suggests chemicals used, if any, have no impact on non-target organisms. Therefore, the final score for Criterion 4 – Chemical Use is 9 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**
Critical?	NO	**GREEN**

Brief Summary

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

Justification of Rating

Oyster aquaculture occurs in open-water environments. Because oysters are filter-feeders, they consume naturally occurring phytoplankton and other particulate matter for food (Pangea Shellfish Company 2015, Doiron 2008). The culture of bivalve shellfish in open systems therefore does not require the provision of feed for the vast majority of the production cycle (MPI 2013), except in the hatchery setting (Doiron 2008), which is outside of the scope of this report. No marine or terrestrial crop ingredients are involved in feeding bivalve shellfish. As such, there is zero reliance on marine or terrestrial resources that are typical in the culture of fed species.

Conclusions and Final Score

There is no external feed provided to farmed oysters. The final numerical 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

Escape parameters	Value	Score
F6.1 System escape risk	2	
F6.1 Recapture adjustment	0	
F6.1 Final escape risk score		2
F6.2 Competitive and genetic interactions		6
C6 Escape Final Score (0-10)		**4**
Critical?	NO	**YELLOW**

Brief Summary

As sessile organisms, direct escape of farm population oysters is implausible. However, oysters are often harvested after reaching sexual maturity and grown in fully open production systems, allowing for larval dispersal. The use of triploid seed partially mitigates the risk of spawning-related escape, but its use on a global scale cannot be considered common. The overall risk of escape is high, and the score for Factor 6.1 is 2 out of 10. The risk of impact, however, is moderate. Where oysters are farmed within their native range, they typically have high genetic similarity to their wild counterparts due to wild collection of spat or broodstock, and where they are farmed outside their native range, they have typically been ecologically established for several decades. However, it is still possible that both native and non-native cultured oysters can impact populations of wild oysters, and non-native oysters have been shown to compete with native populations for food and habitat. The score for Factor 6.2 is 6 out of 10. Combining Factors 6.1 and 6.2, the final score for Criterion 6 – Escapes is 4 out of 10.

Justification of Rating

Factor 6.1. Escape risk

Oyster culture inherently poses a high risk of escape due to that fact that all production systems for growout are open to the environment. As sessile organisms, direct escape of farm population oysters is, realistically, impossible. However, oysters are broadcast spawners, and as oysters are often harvested after reaching sexual maturity, unrestricted broadcast spawning is a potential source of escapes from the farm (Anglès d'Auriac et al. 2017, Pers. comm. F. Chen, 2018, MPI 2013, Doiron 2008).

One important safeguard against spawning escapes is the use of triploid oysters. Triploid seed use lowers the concern for genetic interaction with wild populations because the these oysters rarely spawn (Element Seafood 2016, Pers. comm., B. Rheault 2019, Pers. comm,. L. Cruver 2019). The use of triploid seed was originally developed and patented in the US, and it is more widely used in US production than in other parts of the world (Moore 2012, Hollier 2014, Pacific Shellfish Institute 2015). Most of the hatcheries providing tetraploid seed for triploid production are in the US, however hatcheries in Australia and France are also producing this seed (Hollier 2014). Triploid females typically have approximately 2% of the fecundity of female diploid oysters, and offspring resulting from triploid parents have high rates of mortality (Miller 2014, Oregon State University 2019, Go Deep Shellfish Aqua 2019). It is unknown what percentage of global production uses polyploid seed.

The escape risk for farmed oyster larvae is high due to the inherent risks of open production systems and broadcast spawning; the use of triploid seed partially mitigates this risk, though it is uncertain how common – across the global industry – triploid oysters are used. The score for Factor 6.1 is 2 out of 10.

Factor 6.2. Competitive and genetic interactions

While many areas farm native species, production of spat in hatcheries and subsequent selection of traits beneficial to farming has the potential to modify the genetic integrity of wild populations if those farmed oysters spawn (Harwell et al. 2010). The degree to which hatchery-produced spat may affect wild oyster populations is not fully known, and likely varies widely with species and geographic location. Hatchery seed can be selectively bred to have disease resistance, and sterile triploid seed is also commonly used (Oregon State University 2019, Go Deep Shellfish Aqua 2019). However, passive collection of oyster spat is still heavily utilized in many regions (Manley, Power and Walker 2008, Pers. comms, B. Rheault, 2019, Oysterguide.com 2018).

While most oysters are cultured within their native ranges, others are cultured in areas where they were introduced by various means (i.e., shipping, aquaculture or escape) (British Antarctic Survey 2018, Rice 2008). Robust data on numbers of escapes and the scale of impact are not sufficient to determine the impact of these introductions, and thus, impact is mostly theorized in the available literature. The impact of farmed oyster escape is likely dependent on the scale of the farming operation, location of the farm, tidal flushing and subsequent larval dispersal and scale of historic oyster depletion (MPI 2013, Rice 2008).

As noted in the Introduction, the majority of global oyster aquaculture falls within the genus *Crassostrea* (85.9%), and *C. gigas* accounts for 11% of total global production. Of the total global *C. gigas* production, 80% occurs in Asia, where it is native, and 12.4% in Europe and 6.5% in the Americas where it is non-native. *C. virginica* production accounts for 2.07% of global oyster production, and the vast majority of production is in its native range along the eastern coast of the United States and the Gulf of Mexico.

For oysters cultured in their native regions, farmed stock is either naturally settled from the same waterbody, or hatchery raised. While some research suggests that wide use of genetic selection for disease resistance and other traits and the possibility of genetic mixing of farmed and wild oysters may affect wild oyster fitness, adaptability, diversity and survivorship (MPI 2013), these conclusions cannot be considered the global norm.

In areas where non-native oysters were introduced and are currently fully established, there is evidence that recipient ecosystems have been altered to some extent by such introductions due to competition for resources and habitat modification (Federal Agency for Nature Conservation 2018, Herbert et al. 2016). Non-native species could outcompete native oysters for habitat and food or alter ecosystem dynamics such as native oyster settlement (Wilkie et al. 2013). Newer genetic techniques to analyze gene flow and recombination in oyster populations may be able to address some of the knowledge gaps that exist regarding interbreeding and genetic impact on wild stocks (Anglès d'Auriac et al. 2017).

C. gigas is cultured both within and outside of its native range of the Pacific Coast of Asia (Ojaveer et al. 2018, Anglès d'Auriac, et al., 2017), and is now fully established worldwide (GISD 2019). Establishment of *C. gigas* has led to shifts in benthic community structure, outcompeting native species for space and food, leading to changes in the structure of communities, and potentially creating trophic cascades in the regions in which *C. gigas* was introduced (ibid.). In addition, introduction of *C. gigas* may change substrates, overgrow other benthic species, change suspended particle concentrations, change flow and sedimentation patterns (Padilla et al. 2011), and impact larval settlement (Wilkie et al. 2013). For instance, farmed Pacific oysters in Denmark have been shown to outcompete the native Limfjord oyster (*O. edulis*) population for food and space (Zhen 2018, Chen 2018, Tang 2018). *C. gigas* has been introduced to over 66 regions globally (not all for aquaculture purposes) and is considered invasive in 24 of these (Wilkie at al. 2013).

C. virginica is native to the North Atlantic and was introduced to Europe, Japan, and the west coast of the US. The species is not considered invasive in either the US or Japan (Kemp and Hansen 2018), and the Global Invasive Species Database (GISD) has marked it as having unknown invasiveness (GISD 2019).

Oyster mortality estimates from broadcast spawning are highly variable and therefore are not entirely reliable for understanding the impacts of oyster larval escape. However, they provide some context for understanding the percentage of larvae from farms that may survive and establish new reefs. In general, there is a 70% or higher mortality rate for larvae (Anglès d'Auriac et al. 2017; Levinton, Doall and Allam 2013), however there is some evidence that increasing ocean temperatures may facilitate the growth and survival of oyster larvae (Anglès d'Auriac et al. 2017).

In some locations, oysters grown in their native range are hatchery-raised and the progeny of wild-selected broodstock parents or of multiple generations of hatchery production. In others, spat is collected passively from both wild and farm-origin oysters. In other locations, non-native oysters are cultured and – either through aquaculture or other means – those species are fully ecologically established. However, it is still possible that both native and non-native cultured oysters can impact populations of wild oysters, and non-native oysters have been shown to compete with native populations for food and habitat. The score for Factor 6.2 Competitive and Genetic Interactions is 6 out of 10.

Conclusions and Final Score

While the direct escape of farmed oysters is implausible, farm stock may spawn before being harvested, and the use of culture systems fully open to the environment allows for larval dispersal. The use of polyploid oysters in modern oyster farming can decrease the risk of escape and establishment, though the escape risk remains high. The species examined in this report are largely well-established where they have previously been introduced, or have some genetic selection from native parents, and it is still common practice for spat to be passively collected in the environment. Factors 6.1 and 6.2 combine to result in a final numerical score of 4 out of 10 for Criterion 6 – Escapes.

Criterion 7: Disease; pathogen and parasite interactions

Impact, unit of sustainability and principle

- Impact: amplification of local pathogens and parasites on fish farms and their retransmission to local wild species that share the same water body
- Sustainability unit: wild populations susceptible to elevated levels of pathogens and parasites.
- Principle: preventing population-level impacts to wild species through the amplification and retransmission, or increased virulence of pathogens or parasites.

Criterion 7 Summary

Risk-Based Assessment

Pathogen and parasite parameters	Score	
C7 Disease score (0-10)	4	
Critical?	NO	**YELLOW**

Brief Summary

Without a robust understanding of how on-farm disease impact wild organisms (i.e. Criterion 1 score of 5 out of 10 for the disease category), the Seafood Watch Risk-Based Assessment methodology was utilized. Oysters are susceptible to disease during every stage of production and there is a risk of impact to wild species through the amplification and retransmission, or increased virulence of pathogens or parasites. Across the global industry, biosecurity measures, including genetic selection for disease resistance, have been put in place at the farm, government, and international levels help reduce the risk of parasite and pathogen transmission to wild populations. However, the existence of biosecurity measures does not guarantee successful mitigation of all disease risk, and incidents of disease outbreaks in farmed oysters are not uncommon. Importantly, knowledge gaps still exist for disease transmission and impacts to wild species. Ultimately, farms experience disease challenges and are fully open to the introduction and discharge of pathogens. The final score for Criterion 7 – Disease is 4 out of 10.

Justification of Rating

As disease data quality and availability is moderate (i.e. Criterion 1 score of 5 out of 10 for the disease category), the Seafood Watch Risk-based assessment was utilized.

Infectious diseases have the potential to occur in all aquaculture systems, including hatcheries, nurseries, and growout systems, and may be associated with the transfer of broodstock, larval and seedstock. Many of the infectious diseases associated with shellfish in hatcheries, nurseries, and concentrated growout systems are caused by opportunistic agents that become pathogenic at high temperatures or salinities (e.g. seasonally). Mass mortality events resulting from oyster disease can have economic and environmental impacts, as large quantities of stock can be lost. For many of these diseases there is no curative measure, but control methods include avoidance of stock transfer from infected regions, restricted culture practices and seasonal avoidance (VIMS 2019, Neindorf 2018, NAEC 2017, Prado-Alvarez et al. 2016, Green et al. 2011, Connecticut Bureau of Aquaculture 2018).

In some cases, farming methods have been modified in attempts to avoid disease problems. For example, the US oyster industry has modified production practices to avoid mudworms; the industry, which initially began with on-bottom and dredge bed culture, has transitioned to an intertidal system that enables oysters to be periodically exposed to air, wind, and sun, which prevents parasitism from mudworms (Morse, Rawson and Kraeuter 2015). The same methods of controlling for immersion are used to reduce proliferation of the herpes virus OsHV-1 on oyster farms in Europe, reducing mortality by up to 50% (Pernet et al. 2016). There is evidence that oysters grown in culture with other species, either other oysters species or other shellfish (e.g. mussels), also have a reduced risk of disease transmission (Pernet et al. 2016).

Other forms of disease management require knowledge of transmission vectors and disease progressions. For some diseases, disease-resistant oysters, bred to withstand outbreaks and mass mortality events, can be an effective method for disease control (Connecticut Bureau of Aquaculture 2018, VIMS 2019, Neindorf 2018, NAEC 2017, Prado-Alvarez et al. 2016, Green et al. 2011). For diseases and parasites exhibiting density-dependent transmission, culling to eradicate disease is a successful method and has been suggested as a control for OsHV-1 to reduce oyster density (Pernet et al. 2016). Progressive diseases in which mortality occurs after a period of weeks or months can be less of a concern to farmers because oysters can be harvested prior to mortality which prevents the release of infectious agents into the water (Pers. comms., B. Rheault, 2019).

Outside of the U.S., the World Organization for Animal Health (formerly the Office International des Epizooties (OIE)) exists as the international body responsible for setting animal health standards. The OIE adopted the Aquatic Animal Health Code and the Manual of Diagnostic Tests for Aquatic Animals, inclusive of mollusks (Pernet et al. 2016, World Organization for Animal Health 2018, OIE 2012). These documents are used by World Trade Organization (WTO) member country authorities to develop individual country standards for all matters related to aquatic products that carry risk of disease (Manual of Diagnostic Tests for Aquatic Animals 2018, World Organization for Animal Health 2018). Furthermore, the OIE maintains a list of 117 animal diseases that helps to inform country bans and restrictions on aquaculture trade to limit disease spread (Rheault and Kehoe 2019). These preventive measures aim to limit imports to those countries where no outbreak of diseases were caused by notifiable pathogens (World Organization for Animal Health 2018). This indicates that oyster movements may be subject to legal regulations on notifiable diseases on a federal and international level (World Organization for Animal Health 2018, Allshouse et al., 2004).

In the UK, restrictions on the movement of oysters from areas with disease outbreaks are in place to limit transmission of disease and pathogens between regions. Similarly, in Australia, a disease response plan and movement restrictions limit the spread of disease (Pernet et al. 2016). In European countries, one challenge to disease management is lack of oyster traceability to production and harvest location (Hastein 2001), which can impede swift and effective management (Pernet et al. 2016). In Canada, the *Health of Animals Act* outlines reportable diseases in aquaculture and mandates the immediate notification of disease outbreak to the Canadian Food Inspection Agency (CIFA), which then notifies the OIE international body (DFO Canada 2018).

Diseases associated with oyster aquaculture

Several diseases that affect farmed oysters can cause mortality or decreased flesh quality. A plethora of information is available on diseases, and the management measures in place to control them. There are some knowledge gaps around disease source, modes of transmission and vectors, as well as the impacts of disease to wild populations. The following diseases are known to impact farmed oysters worldwide:

Table 2. Diseases and parasites associated with oyster aquaculture

	Disease	**Causative Parasite or Pathogen**	**Susceptible Species**	**Geographic Distribution**	**Signs and Symptoms**	**Management Measures**
1.	Dermo	*Perkinsus marinus*	*C. virginica*	Eastern USA, Central America, South America	Emaciation, shell lesions, retarded growth, mortality	Selective breeding
2.	Pacific Oyster Mortality Syndrome (POMS)	Ostreid Herpes Virus (OsHV-1)	*C. gigas*	USA, Japan, Europe, China, Australia and New Zealand	Lesions, pale digestive gland, cessation of feeding and swimming in larvae, summer mortality	Minimize movement, specialized handling procedures and regulate stocking densities, selective breeding
3.	Multinucleated Sphere Unknown (MSX)	*Haplosporidium nelsoni*	*C. gigas* *C. virginica*	USA, Canada, and in Korea, Japan and France	Eventual mortality	avoiding infected areas, growout in low salinity areas, and proper timing for movements and growout, selective breeding
4.	Seaside Organism (SSO)/ high salinity disease	*Haplosporidium costale*	*C. virginica* *C. gigas* (rare)	USA, Canada, and parts of China	Rapid mortality	Maintain low salinity, harvest prior to mortality, avoid transportation from infected areas,

						filter/sterilize water used in hatcheries
5.	Roseovarius Oyster Disease (ROD)/ Juvenile Oyster Disease (JOD)	*Roseovarius crassostreae*	*C. virginica*	North eastern USA and France	Reduced growth, abnormalities in tissues and shell, mortality	Low density of seed, increased flow in nursery systems, selective breeding, and properly timing transplantation
6.	Queensland Unknown (QX)	*Marteilia sydneyi*	*S. glomerata.*	Australia	Emaciation, discolored digestive tract, stunted growth, mortality	Selective breeding

The most prevalent diseases in oyster aquaculture are briefly discussed below.

Dermo

Dermo disease affects *C. virginica* and is caused by protozoan parasite *Perkinsus marinus*. The disease proliferates at high temperatures and high salinities. The disease was first observed in the Gulf of Mexico in the 1940s and spread to Delaware Bay by the mid-1950s due to the importation of seed from the Chesapeake Bay (VIMS 2019b). Following a seed embargo, the disease was eliminated from Delaware Bay until a recurrence in 1990 (VIMS 2019b). Dermo is geographically distributed along the east coast of the US from Maine to Florida, the Gulf of Mexico, and South America (VIMS 2019b, Bower 2013). Geographic range of the disease is increasing with higher winter temperatures, coupled with unintentional introduction of disease through shucking waste and drought conditions which affect salinity (VIMS 2019b). It can take up to three years to kill an oyster, during which time the oyster is able to be harvested (Connecticut Bureau of Aquaculture, 2018).

Mortalities can be avoided by harvesting oysters within three years before the disease becomes fatal, and by fallowing infected grow areas (Connecticut Bureau of Aquaculture, 2018). For this reason, dermo is less of a concern for oyster farmers than other diseases that cannot be managed through timed harvest (Pers. comms., B. Rheault, 2019).

The disease is spread from oyster-to-oyster when dead oysters disintegrate and release water-borne parasites that are then ingested by healthy oysters, or when spread by scavenging hosts such as snails (Connecticut Bureau of Aquaculture 2018). The impact of dermo in wild oysters in the Chesapeake Bay is still “significant”, however it seems that wild, native oysters are developing resistance to the parasite that is the causative agent (VIMS 2020).

Ostreid Herpes Virus (OsHV-1)/ Pacific Oyster Mortality Syndrome (POMS)

OsHV-1 is a variant of oyster herpesvirus that causes mass mortality in *C. gigas*. The virus has been recorded in the USA, Japan, Europe (with exceptionally intense outbreaks in France), China, Australia and New Zealand, and was first observed in 2008 in France (Ugalde et al. 2018, NEAC 2017, The Fish Site 2019, Neindorf 2018). While oysters are susceptible to the disease at any life stage, most mortalities occur in juvenile oysters (The Fish Site 2019).

Spread of the disease is at least in part due to oyster translocation for aquaculture, however there are uncertainties surrounding the causes of transmission, and the source of the disease is unknown (The Fish Site 2019, Pernet et al. 2016). Wild oyster populations are often susceptible to this disease, and outbreaks are often seen in wild populations (Pernet et al. 2016). It is recognized that there is far less information and knowledge around diseases in wild oyster populations than there is around the impacts of disease on farmed oyster populations (ibid.). Given this, it is currently unknown whether the infection of farmed oysters with OsHV-1 causes an amplification of disease in the environment. Current research suggests that while disease could originate in farms and spread seaward, wild oysters can often be asymptomatic carriers of disease and may contribute to the spread as well (Pernet et al. 2018). High water temperatures increase transmission and prevalence of the disease may increase with warming ocean temperatures (The Fish Site 2019, Prado-Alvarez et al. 2016, Ugalde et al. 2018).

Management in farms previously infected involves minimizing movement, specialized handling procedures and regulation of stocking densities (Ugalde et al., 2018). While there is currently no cure for OsHV-1 herpesvirus, minimizing the movement of stock and seed and refraining from moving infected oysters to areas where the disease is not present are effective ways to mitigate its spread (The Fish Site 2019).

MSX (Multinucleated Sphere Unknown)

MSX is caused by the spore-forming protozoan *Haplosporidium nelsoni* and affects both *C. gigas* and *C. virginica.* It occurs as a co-infection with the SSO (seaside organism) parasite. MSX is found in Pacific oysters in the west coast of the USA, Canada, and in Korea, Japan and France, where it has caused fewer mortalities than in eastern oysters (VIMS 2019, DFO Canada 2018). MSX was first observed in eastern oysters starting in the 1950s, and since then it has caused mass mortalities in the Chesapeake Bay and Delaware Bay, and can be found on the east coast from Maine to Florida (DFO Canada 2018). The complete lifecycle and mode of transmission are still unknown, but it is not believed to be directly transmitted from oyster to oyster (VIMS 2019, Connecticut Bureau of Aquaculture, 2018). MSX affects oysters in nearly every life stage, and transmission is suppressed at low temperature and salinities (VIMS 2019). Infected oysters can be harvested prior to mortality.

There is evidence that effective selective breeding for resistance in hatcheries can reduce mortalities in native oysters (Connecticut Bureau of Aquaculture 2018), and that wild populations have developed resistance as well (VIMS 2020). A study by VIMS scientists between the 1960s to 2000s shows an increase in prevalence of *H. nelsoni*, but a levelling of instances of infection of wild oysters moved from a disease-free location to an area known to have *H. nelsoni*, suggesting developed resistance in wild populations (VIMS 2020).

Additional mitigation methods include avoiding infected areas for oyster growout, siting growout in low salinity areas, and timing oyster movements and growout to avoid summer infection season (VIMS 2019). Additionally, holding oysters at salinities of less than 15 ppt appears to suppress the disease (DFO Canada 2018).

SSO (Seaside Organism, also known as high salinity disease)

SSO is caused by the parasite *Haplosporidium costale.* The disease affects *C. virginica* in the USA from Virginia to Maine (first observed in Virginia), Canada, and *C. gigas* in parts of China, with some detection in California (Stokes and Carnegie n.d). SSO can cause significant and rapid mortality, within one or two months of histological detection (DFO 2018c). Peak infections occur in March to June, with most mortalities occurring in May and June (Stokes and Carnegie n.d). The disease is only found in areas of high salinity (>24ppt) (DFO Canada 2018, ICES 2011). The complete lifecycle and mode of transmission are still unknown, but it is not believed to be directly transmitted from oyster to oyster (DFO Canada 2018) without an intermediate host.

Management of disease outbreak and spread can be controlled by maintaining low salinity, harvesting prior to mortality, avoiding the transportation of oysters from infected areas into uninfected areas, and filtering/sterilizing water used in hatcheries and nurseries to eliminate infective stages (DFO Canada 2018, ICES 2011). High infection rates do not necessarily result in high mortality rates, and the parasite can be eradicated from an area if temperatures increase or salinity decreases (Banrie 2013).

Conclusions and Final Score

There are several diseases affecting farmed oysters worldwide, and disease transmission and full life cycles of some of the associated parasites are unknown. Genetic selection for disease resistance is a widely-used measure of management for oyster diseases and has reduced the likelihood of transmission and outbreak. Biosecurity and disease-management measures have been effective for many diseases in the past, however further study is needed to assess modes of transmission for others, such as OsHV-1. While biosecurity measures may be in place and implemented, current knowledge gaps regarding disease transmission and risk factors may prevent biosecurity measures from removing all risk of spreading disease. Without robust understanding of how on-farm diseases impact wild populations, the Risk-Based Assessment methodology is used; ultimately, farms experience disease-related mortalities and are fully open to both the introduction and discharge of pathogens. The final numerical score for Criterion 7 – Disease is 4 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	
C8X Independence from unsustainable wild fisheries (0-10)	0	
Critical?	NO	**GREEN**

Brief Summary

Seed for oyster farming is either collected through natural settlement of spat on cultch or through the use of broodstock in land-based hatcheries. Passive collection techniques allow for spat to settle, and then be collected and reared in nursery. In regions where there is a reliable and abundant supply of wild spat, passive collection is often used. Land-based hatcheries may be utilized where wild spat supply is not reliable or abundant. As the global industry is not reliant on wild caught broodstock or growout stock, the final score for Criterion 8X – Source of Stock is 0 out of -10.

Justification of Rating

Stock for oyster farming is either collected passively via natural settlement of spat on cultch or via hatchery and nursery production. Passive collection techniques rely on spat settlement on different types of material, including sticks, drain pipe, oyster and scallop shells placed in bags and strung on wires, and plastic tubes (Doiron 2008, Queensland Government 2018). In regions where there is a reliable and abundant supply of wild spat, passive collection is used (Manley, Power and Walker 2008). Oyster farming in the US utilizes a wide variety of spat collection and growout methods. States such as Connecticut, Delaware and the Gulf states rely on wild-settled spat, however hatcheries are being developed (Pers. comms., B. Rheault, 2019, Oysterguide.com 2018).

In certain areas, the majority of production is hatchery based (e.g., West Coast and the New England region in the United States). Land-based hatcheries may be utilized where wild spat supply is not reliable or abundant, or where the species being grown is not native. Broodstock is initially selected from the wild and spawned in the hatchery in order to collect spat (Oregon State University 2019, Helm, Bourne and Lovatelli 2004, Wallace et al. 2008), however in many cases the lifecycle is closed, and wild broodstock are no longer collected for hatchery spawning. Certain programs to select and produce broodstock exist to supply the commercial industry with disease-resistant and selectively-bred broodstock. One such program is the Molluscan Broodstock Program (MBP) which supplies West Coast farms with broodstock originally selected from 600 wild oysters (Oregon State University 2019, Pacific Shellfish Institute 2015). After the initial collection of wild stock, oysters were planted in grow-out areas and collected to continue breeding and no further wild individuals were taken (Oregon State University 2019).

While passive collection of oyster spat is still heavily utilized in many regions (Manley, Power and Walker 2008, Pers. comms, B. Rheault, 2019, Oysterguide.com 2018), it is becoming less popular as hatchery seed can provide a more stable and hardier source of stock. Hatcheries may also be used to obtain greater quantities of spat (Doiron, 2008), to control for the health of the spat, or when farming a non-native species, as well as when regions have been previously affected by disease (Element Seafood 2013). In the hatchery, broodstock are spawned and the oyster spat are collected. Seed is then transported to ocean-based nurseries. In Europe, wild spat collection has been common practice since the 1950s, however hatchery spat are becoming more widely used (FAO Fisheries & Aquaculture 2018, Beustel 2009).

Conclusions and Final Score

Oyster aquaculture relies on either natural settlement via passive collection or hatchery production from broodstock. Some regions of Italy, France, Spain, China and Japan rely on natural spat collection, where recruitment levels are high. Much of the current oyster farming relies on hatchery-reared seed. This practice is becoming more commonplace as new hatcheries are established and hatchery-reared seed becomes more accessible. As the global oyster industry relies on passive settlement or hatchery raised broodstock, the final score for Criterion 8X – Source of Stock for farmed oysters is a deduction of 0 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: preventing population-level impacts to predators or other species of wildlife attracted to 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

Oyster culture utilizes bags, mesh and other passive exclusionary devices to control for predation. The use of passive, non-harmful barriers yields no evidence of direct or accidental mortality of predators or wildlife. Dredge harvest techniques result in mortality of wildlife beyond exceptional cases, but due to rapid recovery and some potential benefit to predators, there is no expectation of long-term significant impact to the affected species' population size, and best management practices are in place to minimize effects. Therefore, oyster aquaculture has a low impact on predators or other wildlife and the final numerical score for Criterion 9X--Wildlife and Predator Mortalities is a deduction of -2 out of -10.

Justification of Rating

Oysters have several natural predators including sea birds (e.g. sea gulls, oystercatchers), fish (e.g. black drum, cownose rays, oyster toadfish) and invertebrates (e.g. gastropods, worms, boring sponge, crabs, lobsters, sea stars) (Everblu Capital 2018, Doiron 2008, Leavitt and Burt 2007, Bevin, Chandroo and Moccia 2002). On oyster farms, the predation impact from these species is relatively minimal in comparison with predation in finfish aquaculture (Bevin, Chandroo and Moccia, 2002). Additionally, the impact of shellfish farms on marine mammals and seabirds is considered minimal and while the risk of entanglement and/or migration disturbance is a possibility, these adverse effects are minor (MPI 2013). The use of bag culture minimizes predator interactions via passive exclusion, whereas oysters grown in on-bottom culture are more susceptible to predation (Go Deep Shellfish Aqua 2019, Doiron 2008). Netting can be placed on the seafloor to cover culture areas and prevent predators (Leavitt and Burt 2007). Alternatively, netting can be placed beneath oyster seed on the bottom, and folded over the top of the seed, held in place either by stapling or burial (Leavitt and Burt 2007). The aforementioned passive exclusion measures, and off-bottom methods such as bag culture, are very effective at preventing predation, however predators may still be able to breach these devices by entering during their larval or juvenile stages, and then growing inside the netting or bags alongside the oysters (ECSGA 2010, Leavitt and Burt 2007). Predators that do find their way inside netting or bags can be removed via non-lethal methods, either by hand or via aquaculture exclusionary devices such as conch pots (Pacific Shellfish Institute 2015, Booth 2014, ECSGA 2010, Leavitt and Burt 2007).

During harvest of on-bottom culture, dredging causes the immediate decline in abundance and biomass of resident organisms, such as crustaceans, polychaetes and bivalves. However, these effects are temporary (Mercado-Allen and Goldberg 2011) and the decline is often followed by rapid benthic recovery (Mercaldo-Allen and Goldberg 2011). Additionally, dredging on oyster farms is limited to the boundaries of known growing plots which minimizes damage (Stokesbury et al. 2011), and on-bottom culture is not nearly as common as off-bottom production systems. In addition, changes in sediment structure associated with oyster dredging are reversible or dissipate over short periods of time, although time periods may be variable (as reviewed in Dumbauld 2009 and Mercado-Allen and Goldberg 2011). Replanting shell and spatted shell following dredging is a common practice and has the capacity to improve or restore habitat and biodiversity (Dumbauld 2009, Mercado-Allen and Goldberg 2011).

Conclusions and Final Score

Oyster farms attract predators and other wildlife, but the use of passive, non-harmful barriers on farms yields no evidence of direct or accidental mortality of predators or wildlife. There are documented short-term impacts on wildlife due to dredging during harvest, however these effects are temporary and of low concern using best management practices. The final numerical score for wildlife and predator mortalities is a deduction of -2 out of -10.

Criterion 10X: Escape of secondary species

Impact, unit of sustainability and principle

- Impact: movement of live animals resulting in introduction of unintended species
- Sustainability unit: wild native populations
- Principle: avoiding the potential for the accidental introduction of secondary species or pathogens resulting from the shipment of animals.

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 secondary species parameters	Score	
F10Xa International or trans-waterbody live animal shipments	4	
F10Xb Biosecurity source/destination	6	
C10X Escape of secondary species Final Score	**-2.4**	**GREEN**

Brief Summary

It is assumed that 50% of the global oyster industry relies on movements of animals. Best management practices for both the source and destination of oysters are established, however due to the global scope of this assessment, it is assumed that their implementation and efficacy are varied. Typically, hatcheries use larval tanks, while growout sites are open systems using BMPs. International and national biosecurity measures vary with regard to oyster aquaculture, however trade and movement of oysters and seed is regulated at state, national and international levels. The final score for Criterion 10X – Escape of unintentionally introduced species is –2.4 out of –10.

Justification of Rating

International, national, and regional regulations and permitting requirements are in place to prevent the spread of secondary species. Historically, there is evidence that movements of farmed oysters have unintentionally caused the spread of pathogens and parasites (Brenner et al. 2014); however, there has been a focus on biosecurity for the global farmed oyster trade, as well as improved biosecurity regulation and disease monitoring in recent years. Trans-waterbody movement of live oysters is common, and as such there is concern of unintended introduction of secondary species during oyster movement and shipment. The American whelk tingle (*Urosalpinx cinera*), introduced with *C. virginica*; the slipper limpet (*Crepidula fornicata*), Japanese and Eastern oyster drills (*Ocinebrellus inornatus* and *Urosalpinx cinerea*) and red worm (*Mytilicola orientalis),* introduced with *C. gigas,* are non-target species that have had documented negative impacts to the native *O. edulis* stocks via transmission from introduced farmed species. Pacific Oyster Mortality Syndrome (POMS), caused by the herpesvirus OsHV-1, is an ongoing oyster threat, and current evidence indicates that it is at least partially due to international and trans-waterbody movements.

Factor 10Xa International or trans-waterbody live animal shipments

There are some data gaps regarding the extent to which international or trans-waterbody live animal shipment is utilized in oyster aquaculture. Due to the nature of this global report, there is a known reliance on some trans-waterbody movement, however this is highly variable worldwide. Some oyster-producing regions, such as the US Gulf coast, rely on the passive settlement of native oyster seed which is then collected for growout (Pers. comms., B. Rheault, 2019). These operations do not rely on movements of seed or stock. Additionally, many US farms that do not use wild-collected seed are producing their own seed via hatcheries, which eliminates the concern escape of secondary species (Walker 2017). Farms that do not produce their own seed may rely on trans-waterbody movement of broodstock. When seed is not readily available locally, farmers may have to rely on imported seed (Walker 2017).

Although there are currently trans-waterbody movements of oyster seed and live adults, the amount of seed may vary greatly depending on the region and needs of different farms. Due to the variability of industry reliance on international and/or trans-waterbody movements, it is assumed that 50% of the global industry relies on these movements. Therefore, the score for Factor 10Xa is 4 out of 10, representing a moderate 50-59.9% reliance on animal shipments.

Factor 10Xb Biosecurity of source/destination

There are international and national biosecurity guidelines, agreements and measures in place to limit the movement of oysters from areas with active disease outbreaks, and inform biosecurity standards worldwide (Oidtmann 2011, Pernet et al. 2016, Pacific Shellfish Institute 2015) which are in place to limit the risk of trans-waterbody disease spread. Trans-waterbody movements of juvenile oysters have been associated with the introduction of non-target species; for example, the slipper limpet was unintentionally introduced to Europe with the transfer of *C. virginica* (Padilla, McCann and Shumway 2011) and the oyster drill (*Ocinebrina inornata*) was introduced to the US with the introduction of *C. gigas* (Encyclopedia of Puget Sound n.d.). In the case of OsHV-1, the lack of biosecurity practices and oyster translocations have been identified as likely causes of disease spread around the world (Whittington et al. 2018), however the source of the disease is not entirely understood. At the global level, many national and international biosecurity management measures are in place to manage the risk of disease transmission, with effective Best Management Practices for biosecurity widely available (FAO 2004-2019, FAO 2005a, FAO 2005-2019b, Oidtmann et al. 2011, NOAA 2019, ECSGA 2010, Pacific Shellfish Institute 2015).

Hatcheries generally use tanks during the larval stage, however while best practice for biosecurity at hatcheries is established, given the global scale of this assessment, it is assumed that strategies for meeting these BMPs are highly varied, as well as their effectiveness. For instance, larval tanks may be fully or partially recirculating, with variation in the disinfection techniques used for incoming and/or outgoing water. Given this, the Source score for Factor 10Xb is 6 out of 10.

The destination for live animal shipments is the farm grow-out site. Grow-out systems generally use best management practice techniques for management of risk of disease from transfer, however similar to hatcheries, these practices vary at the global scale. Grow out sites, both on-bottom and off bottom, are fully open to the environment. Therefore, as grow-out sites are open systems which generally employ best management practices, the Destination score for Factor 10Xb is 2 out of 10.

The score for Factor 10Xb is the higher of the two, which is 6 out of 10.

Conclusions and Final Score

The global oyster aquaculture industry relies partially on international and trans-waterbody movement of oyster larvae and live oysters. While some farms prefer to collect from the wild, or produce their own seed, this is not always feasible. Seed shortages often necessitate the transport of seed and broodstock. International agreements, BMPs, and regulations are in place to reduce the risk of introducing unintentional species, however these vary globally. The final score for Criterion 10X – Escape of Secondary Species is -2.4 out of -10.

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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	7.5
Effluent	7.5
Habitats	7.5
Chemical use	7.5
Feed	n/a
Escapes	7.5
Disease	5
Source of stock	7.5
Predators and wildlife	7.5
Secondary species	5
Other – (e.g. GHG emissions)	n/a
Total	**70**

C1 Data Final Score (0-10)	**7**	**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 habiat 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)	**9**	
C4 Chemical Use Final Score (0-10)	**9**	**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)	2	
6.1a Adjustment for recpatures (0-10)	0	
6.1a Escape Risk Score (0-10)	**2**	
6.2. Competitive and genetic interactions score	**6**	
C6 Escapes Final Score (0-10)	**4**	**YELLOW**
CriticaL?	**NO**	

Criterion 7: Diseases

Disease Evidence-based assessment (0-10)		
Disease Risk-based assessment (0-10)	4	
C7 Disease Final Score (0-10)	**4**	**YELLOW**
Critical?	NO	

Criterion 8X: Source of Stock

C8X Source of stock score (0-10)	0	
C8 Source of stock Final Score (0-10)	**0**	**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 secondary species

F10Xa live animal shipments score (0-10)	4.00	
F10Xb Biosecurity of source/destination score (0-10)	6.00	
C10X Escape of secondary species Final Score (0-10)	**-2.40**	**GREEN**
Critical?	n/a	