Monterey Bay Aquarium Seafood Watch

Environmental sustainability assessment of farmed from Pacific geoduck (*Panopea generosa*) the United States and Canada produced in bottom culture

Species: Pacific geoduck (*Panopea generosa*)

Location: United States (Washington), Canada (British Columbia)

Gear: Bottom culture

Type: Wild Caught

Author: Seafood Watch

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

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

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

Farmed geoduck from Washington State, United States

Approximate annual production	**776 mt**		
Criterion	**Score**	**Rating**	**Critical?**
C1 Data	7.96	Green	n/a
C2 Effluent	10.00	Green	No
C3 Habitat	7.33	Green	No
C4 Chemicals	10.00	Green	No
C5 Feed	10.00	Green	No
C6 Escapes	4.00	Yellow	No
C7 Disease	7.00	Green	No
C8X Source	0.000	Green	No
C9X Wildlife	–2.00	Green	No
C10X Introduction of secondary species	–0.80	Green	n/a
Total	53.49		
Final score (0–10)	7.64		

OVERALL RATING

Final Score	7.64
Initial rating	Green
Red criteria	0
Interim rating	Green
Critical Criteria?	0

Final Rating
Green

Farmed geoduck from British Columbia, Canada

Approximate annual production	**30 mt**		
Criterion	**Score**	**Rating**	**Critical?**
C1 Data	7.96	Green	n/a
C2 Effluent	10.00	Green	No
C3 Habitat	7.33	Green	No
C4 Chemicals	10.00	Green	No
C5 Feed	10.00	Green	No
C6 Escapes	4.00	Yellow	No
C7 Disease	7.00	Green	No
C8X Source	0.00	Green	No

C9X Wildlife	–2.00	Green	No
C10X Introduction of secondary species	–0.40	Green	n/a
Total	53.89		
Final score (0–10)	7.70		

OVERALL RATING

Final Score	7.70		
Initial rating	Green		
Red criteria	0		
Interim rating	Green		Final Rating
Critical Criteria?	0		**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 or one Critical criterion result in a Red final result.

Summary

The final numerical scores for Pacific geoduck (*Panopea generosa*) produced in intertidal and subtidal aquaculture plots production systems in Washington, United States and British Columbia, Canada are 7.64 out of 10, and 7.70 out of 10, respectively, which are in the Green range. The final recommendations are both a Green "Best Choice."

Executive Summary

The U.S. state of Washington is the world's foremost producer of farmed Pacific geoduck, with total U.S. production of 776 mt in 2020. The bulk of Washington's geoduck farming takes place in southern Puget Sound, with farms in each of Puget Sound's sub-basins and planned expansion into the Strait of Juan de Fuca and throughout Puget Sound and Hood Canal. The Canadian province of British Columbia (BC) is a comparably small but growing producer of farmed geoduck. Aquaculture production of geoduck is aggregated with other clams in BC government reporting, with a total volume of 1,300 mt and landed value of CAD9.28 million for all species in this category in 2022 (pers. comm., DFO 2023). Geoduck harvests account for a small proportion (<5%) of these sales in BC. Baynes Sound is the most important region for shellfish farming, but geoduck farms are scattered throughout the Strait of Georgia, and expansion throughout the province's extensive coastline has recently been facilitated through the consideration of permit applications. For both Washington and BC, geoduck production is supported by a strong international market, and the industry is eager to expand. Geoduck farming has also been controversial; questions remain concerning the potential environmental impacts of geoduck aquaculture. Published research has been steadily increasing, and regulators in both Washington and BC have worked to improve management of the industry.

This Seafood Watch assessment involves a number of different criteria covering impacts associated with effluent, habitats, wildlife and predator interactions, chemical use, feed production, escapes, introduction of nonnative organisms (other than the farmed species), disease, the source stock, and general data availability. Differences (and similarities) between BC and Washington geoduck farming are discussed in applicable criteria. But many differences were not deemed significant enough to warrant independent scoring for the purposes of this assessment, except for a minor difference in Criterion 10X—Escape of Secondary Species.

The geoduck aquaculture industry is well characterized by published data in government sources and academic studies, in addition to contacts with geoduck farms, hatcheries, researchers, and regulatory authorities. These personal communications provided clarity and context to the evolving culture methods and regulations of the industry. Two areas of uncertainty are: Habitat, where there are knowledge gaps about the full scope of potential impacts over repeated farm cycles or in response to growth of the industry; and Disease, which could be resolved with larger-scale studies of pathogens in the assessment area that include a large sample size of geoduck from culture areas. The final numerical score for Criterion 1—Data is 7.96 out of 10.

Farmed geoduck is not provided external feed for the bulk of the production cycle, and it is given only small volumes of cultivated microalgae in the hatchery setting. Although there have been documented cases of high-density shellfish operations reducing phytoplankton resources, shellfish culture is generally considered to provide an ecosystem service through improving water quality. When sited properly in well-flushed waters, there is no anticipated impact to local nutrient supply. Overall, geoduck 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.

The impacts of geoduck aquaculture on marine habitat appear to be minor to moderate, with impacts largely ephemeral, and limited to the farm site. Habitat on geoduck farms appears to be maintaining functionality, but uncertainty remains, as noted by nearly all the authors cited in this section. The combination of the nature of apparent effects and the remaining uncertainty (such as in the cumulative effects of repeated farm cycles and the impacts of scales larger than existing studies) factors into the score of 7 of 10 for moderate habitat impacts for Factor 3.1.

There are limitations in management and enforcement in both BC and Washington, but both jurisdictions have worked to strengthen their infrastructure, have supported scientific understanding, and have shown evidence of enforcement. The permitting process is extensive, transparent, and reflects robust management of both regions. Overall, management and enforcement are considered robust, with minor limitations to enforcement. Factor 3.2 receives a score of 8 out of 10. Factors 3.1 and 3.2 combine to give a final Criterion 3—Habitat score of 7.33 out of 10.

Chemicals of high concern such as antimicrobials, herbicides, or pesticides are not used at any point during the farming of geoduck (hatchery or grow-out). For a small fraction of the production cycle, government-approved cleaning chemicals are used in the hatchery setting and may be discharged in diluted and/or degraded or neutralized form to the marine environment. There is no evidence of significant environmental impacts from this type of chemical use. Overall, with no evidence of significant chemical use, and a demonstrably low need for chemical use, the final numerical score for Criterion 4—Chemical Use is 10 out of 10.

Geoduck is a filter feeder and is not provided any external feed. Therefore, the final score for Criterion 5—Feed is 10 out of 10.

Geoduck is a sessile animal, so it cannot escape directly; however, farmed geoduck reaches reproductive age and has been observed spawning in the natural environment during grow-out. There is no technology in place (e.g., sterilization techniques) to prevent escaped gametes or larvae from entering the environment and interacting with wild conspecifics. As a highly fecund species, this is considered a high escape risk, and Factor 6.1—Escape Risk scores 0 out of 10. Geoduck populations are largely panmictic at the waterbody scale, and there is a general acceptance that there is a homogenous population of Pacific geoduck across its native range. But there is a phenomenon of microgeographical (patchy) genetic variation among wild populations, and there is uncertainty of the potential impacts that farmed geoduck genetics may have at this scale. Only wild broodstock are used (i.e., all farmed offspring are first-generation), and regulatory measures and best management practices are in place to maximize the genetic diversity of farmed geoduck seed and to maintain wild type genetics as closely as possible. There is inherent modification of normal selective pressures during the capture and conditioning of broodstock and the hatchery rearing environment that cannot be removed from the production cycle—the potential impacts are not well understood on geoduck seed genetics, though they likely result in increased genetic variability retained in the hatchery seed cohort, relative to wild seed, given the more relaxed selective pressures in a hatchery environment. As a native species with high genetic similarity to wild conspecifics (e.g., one generation domesticated), the score for Factor 6.2 is 8 out of 10 for low to moderate risk. Factors 6.1 and 6.2 combine to give a final numerical score of 4 out of 10 for Criterion 6—Escapes.

The geoduck industry has not had major disease issues to date, and risk management infrastructure is in place in both Washington and British Columbia in the form of best management practices used by growers, government regulations, and industry-sponsored risk reduction programs. It is of note that the understanding of geoduck disease is relatively nascent; however, the regulatory mechanisms for monitoring seed health before allowing transfer seem adequate to detect and manage any pathogens that may emerge in the future, as is the significant global infrastructure for notification and containment of reportable pathogens. Most major companies involved in geoduck production in Washington appear to be involved in the strongest industry disease risk-management program available, and BC also has a strong risk-management regulatory framework. Various agencies in Washington and BC have additional requirements and the leeway to manage risk conservatively, and the industry has a vested interest in preventing disease issues. There is no currently known disease risk to wild organisms from geoduck farms, but because farms may operate at higher densities than wild geoduck populations and are open to the environment near wild geoduck populations, a precautionary approach is taken. The final numerical score for Criterion 7—Disease, Pathogen and Parasite Interaction is 7 out of 10.

Geoduck is highly fecund. One animal can produce tens of millions of gametes annually and can spawn multiple times each year (Goodwin and Pease 1989). Thus, small numbers of broodstock are required to produce vast quantities of seed. Though wild-caught broodstock is used for hatchery production of farm animals, this practice promotes genetic diversity of the farm stock, and the taking of small numbers from robust wild populations is not anticipated to have a significant impact. The final numerical score for Criterion 8X—Source of Stock is 0 out of 10, meaning that no reductions have been made for this criterion.

Species of conservation concern have legal protections in both the United States and Canada and are not expected to be significantly affected by geoduck aquaculture. Both countries have requirements for nonharmful exclusion methods by shellfish operators, and best management practices are being used in the industry. Predator exclusion is done passively using HDPE mesh and PVC tubes. At times during the culture cycle, predators or competitors may be removed by hand and relocated in a nonlethal manner. The potential for wildlife to become entangled in the predator exclusion mesh is considered exceptionally rare at most. The species commonly found on geoduck plots by operators are considered to have healthy population statuses, with many supporting commercial fisheries. Thus, the impacts on wildlife populations from geoduck aquaculture are considered low. The final numerical score for Criterion 9X—Wildlife and Predator Mortalities is –2 out of –10.

Both Washington and British Columbia have regulations and permitting requirements in place that aim to prevent the spread of nonnative species within the state/province and across international boundaries. The use of transfer permits and management zones is intended to reduce the risk of spreading nonnative species. Movement of live geoduck is largely limited to the movement of juvenile "seed" from the hatchery to the farm setting. Some movement of aquaculture gear and vessels occurs, and this presents a risk vector to the spread of nonnative species. But industry protocols are in place to dry gear upland to remove biofouling, and it is redeployed in the same water body from which it was removed. Washington and British Columbia are estimated to have 10% and <10% of total seed transported trans-waterbody, respectively. The source hatcheries are the most biosecure segment of geoduck aquaculture, and shellfish hatcheries are classified as moderate risk systems that use active best management practices for design, construction, and biosecurity management. For Washington, the final numerical score for Criterion 10X—Escape of Secondary Species is a minor deduction of –0.8 out of –10. For British Columbia, the final numerical score for Criterion 10X—Escape of Secondary Species is a minor deduction of –0.4 out of –10.

The final numerical scores for Pacific geoduck (*Panopea generosa*) produced in intertidal and subtidal aquaculture plots production systems in Washington, United States and British Columbia, Canada are 7.64 out of 10 and 7.70 out of 10, respectively, which are in the Green range. The final recommendations are both a Green "Best Choice."

Introduction

Scope of the analysis and ensuing recommendation

Species
Pacific geoduck (*Panopea generosa*, Gould, 1850; formerly *Panopea abrupta*)

Geographic Coverage
The U.S. state of Washington and the Canadian province of British Columbia (BC).

Production Method(s)
On-bottom culture

Species Overview

Brief overview of the species
The Pacific geoduck is one of, if not the world's, largest burrowing clams and is a long-lived native bivalve of the west coast of North America. Geoduck can live >100 years, and its wild populations constitute a majority of the benthic biomass naturally occurring in the assessment area (Mcdonald et al. 2015)(Emmett et al. 1991)(WDFW 2015). Geoduck is a broadcast spawner, releasing sperm and eggs synchronously to fertilize in the water column. Spawning occurs from about January to July (Goodwin and Pease 1989), and a female may release up to 40 million eggs over several spawning sessions each season (Beattie 1992). Fertilized eggs develop and graduate to a pelagic larval period that lasts 16 to 47 days. During this time, geoduck larvae move according to a combination of both passive (drift) and active strategies and may disperse great distances from their natal locations. Geoduck larvae then settle to the substrate, where they begin burial and growth. Geoduck is a filter feeder, and the water that it siphons down to the buried main body is filtered for small particles of food, phytoplankton, pelagic crustaceans, and fish larvae.[2] This water is also the source of the animal's oxygen and is actively pumped over the gills. Geoduck has been harvested by indigenous Northwest Tribes for millennia ("geoduck" originated from an indigenous Nisqually word).

Production system
Since commercial harvest of wild geoduck began in the 1970s, international markets have driven the demand for geoduck production. The modern geoduck aquaculture production system was piloted by the Washington Department of Fish and Wildlife in the 1970s, originally to augment wild stocks (Feldman et al. 2004), and methods were adopted for commercial state trials in 1995 (pers. comm., B. Vadopalas, UW 2023) and a BC pilot program in 1996 (DFO 2014).

All farmed Pacific geoduck in the United States and Canada is produced on intertidal or subtidal benthic plots using seed stock produced in land-based hatcheries from wild broodstock. Plot size

[2] https://oceana.org/marine-life/geoduck/

may vary from approximately 1,200 m^2 to 81,000 m^2, with the average farm size for one operator being 5,050 m^2 (pers. comm., E. Ewald, Taylor Shellfish 2023). The minimum individual total farm size for financial viability is estimated to be approximately 4,047 m^2 (1 acre) (pers. comm., E. Ewald, Taylor Shellfish 2023), and smaller growers may operate on plots this size. Subtidal plot sizes may be much larger in BC (e.g., 45 to 80 hectares [ha]), though these are not in full production, and the more common size is roughly 10 ha (pers. comm., Anonymous Industry 2023). Any new subtidal farms in BC are anticipated to be <20 ha rather than the quite large plots that were leased in the earlier days of the geoduck aquaculture industry (pers. comm., Anonymous Industry 2023). Regulatory restrictions are in place that limit the size of new farms in certain locations, based on the Integrated Geoduck Management Framework (pers. comm., DFO 2023). Subtidal planting occurs at lower densities but over larger areas in BC (Vadopalas et al. 2015) and is currently a more common practice in BC than in Washington (pers. comm., Anonymous Industry 2023).

Hatcheries

Hatcheries can be flow-through or circulating in design and rely on intake from open coastal water (pers. comm., E. Ewald, Taylor Shellfish 2023)(pers. comm., Anonymous Industry 2023). Because of their need for direct seawater intake, hatcheries are located near the shore. Generally, geoduck is one of several species produced within a given shellfish hatchery (DFO 2023b).

Nurseries

In the wild and on farms, geoduck is vulnerable to mortality by predation and environmental influences in the post-settlement juvenile stage (herein "seed"), especially in the first 1 to 2 years of life (Goodwin and Pease 1989). To increase the survival of geoduck seed from the hatchery, it may be grown for a period of time in a nursery structure before planting into the substrate on beach plots. This is not always necessary, because depending on the seed size, season, and need, seed may also be planted directly from the hatchery (pers. comm., E. Ewald, Taylor Shellfish 2023). Currently, the nursery methods being used are land-based tank systems outfitted with settling trays that may be at or near hatchery facilities, or trays that are suspended on floating raft systems (pers. comm., E. Ewald, Taylor Shellfish 2023)(pers. comm., Anonymous Industry 2023). Nursery facilities are typically located within the water (or, for land-based facilities, are sourcing water directly from) where the seed will be planted, which would obviate the need for further acclimation at the farm site. Subtidal growers in BC report acclimating geoduck seed in aluminum trays of sand suspended at approximately 12' for 24 months within protected bays near their plots (pers. comm., Anonymous Industry 2023).

Beach preparation

A beach may be prepared by hand-relocating predators or species that would be damaged by the implanting of nursery tubes in the sediment (e.g., sand dollars), though this is not necessary for all plots (pers. comm., three anonymous industry representatives 2013, 2015)(pers. comm., E. Ewald, Taylor Shellfish 2023)(pers. comm., Jim Parsons, Jamestown Seafood, A Jamestown S'Klallam Tribal Enterprise 2023)(pers. comm., Anonymous Industry 2023). During the course of preparation and management, all-terrain vehicles (ATVs, a.k.a. four-wheelers) may be used occasionally when crew need to cover long distances with gear within short tide windows, though this is not the normal mode of operation. If there is land access to the site, crews will access farms via roadways, and boats may be used to ferry gear and equipment if access is only available by water (pers. comm., E. Ewald, Taylor Shellfish 2023). Scows (flat-topped, typically nonmotorized floats that are towed or pushed by boats) may be anchored on the deepwater edge of farm sites, and can be used to stage gear and harvest pumps (pers. comm., E. Ewald, Taylor Shellfish 2023). Beach preparation is not applicable for subtidal sites (pers. comm., Anonymous Industry 2023).

Planting and structure addition

Geoduck seed (and geoduck farming in general) is a sizable investment, from USD 0.16 each for small seed, and potentially ranging between USD 0.42 to 1.25 per planting-sized individual (Lummi Shellfish 2016)(pers. comm., E. Ewald, Taylor Shellfish 2023). Intertidal and subtidal methods for planting and structure addition vary, so they are discussed individually.

Intertidal

To protect against predation and exposure for the first 1 to 2 years of the production cycle, geoduck seed is planted within 10- to 15-cm diameter PVC or (increasingly) HDPE plastic mesh tubes, which may be installed at low tide by shore crew or in some instances by divers, if the work window coincides with a higher tide (pers. comm., E. Ewald, Taylor Shellfish 2023). Tubes are inserted (pushed in, a sand core pulled, mesh tube placed on it and reinserted into the hole, or inserted hydraulically) 23 to 30 cm into the sediment in high-density grids, depending on grower preferences and area conditions (but generally about 10 tubes/m^2, or a distance of 12–18 in., or 30.5–45.7 cm apart) and 2 to 4 geoduck seed are planted within each tube, with roughly one-third to two-thirds surviving to harvest (BCSGA 2013)(Feriss et al. 2015)(Pearce et al. 2019)(pers. comm., E. Ewald, Taylor Shellfish 2023). Seed are only planted by hand, either by “finger poking” into the sediment or by being dropped into the tube and allowed to dig down into the sand on their own (pers. comm., E. Ewald, Taylor Shellfish 2023). Intertidal beds are also planted by divers when the tide is in. The initial planting density may be approximately 20–30 clams/m^2 (VanBlaricom et al. 2015).

To complete the predator-exclusion design, individual PVC tubes may be covered with mesh caps secured with rubber bands (PCSGA 2019). Alternatively, a large array of tubes may be covered with a single large “canopy” net secured with rebar stakes or rocks (Figure 1) (VanBlaricom et al. 2015). Some farms report that they may or may not use antipredator area netting (pers. comm., Anonymous Industry 2023), and that when the site is suitable for the use of mesh tubes, no antipredator netting or capping of the tubes is required (pers. comm., E. Ewald, Taylor Shellfish 2023).

Figure 1: Clockwise from top left: Planting geoduck seed into mesh tubes (Associated Press 2015); geoduck tubes covered with canopy netting (University of Washington 2015); cap mesh-covered PVC tubes (nap.edu); harvest of geoducks following unstructured phase of farming (Washington SeaGrant 2015).

Predator exclusion tubes and mesh coverings are typically removed after the first or second year of the farm cycle, because geoduck size and burial depth is now sufficient to avoid most predation and environmental stressors. Tubes may represent a major expense for a geoduck farmer, so they are removed, cleaned, and redeployed elsewhere once they have fulfilled their usefulness for a particular farm plot, and all geoduck gear is expected to be fully functional for multiple planting cycles (pers. comm., E. Ewald, Taylor Shellfish 2023)(pers. comm., Jim Parsons, Jamestown Seafood, A Jamestown S'Klallam Tribal Enterprise 2023)(pers. comm., Anonymous Industry 2023).

Subtidal

All plantings are done by divers, generally using free-casting of seed from the nursery over anti-predator nets installed on the bottom to protect the animals (pers. comm., Anonymous Industry 2023). In BC, farms report ongoing experimentation with antipredation gear. Area nets are the most common method (100’ x 12’), though experimental use of PVC pipes and flexible HDPE mesh sleeves is also happening (pers. comm., Anonymous Industry 2023). Netting tunnels may also be used over planted seed (Figure 2) (PCSGA 2019).

Figure 2: A subtidal BC geoduck "clam tunnel" consisting of antipredator netting (DFO 2013).

In BC, antipredator nets may stay in place for 4 to 6 years of the 8- to 10-year production cycle (pers. comm., Anonymous Industry 2023). Biofouling on nets can be prohibitive for gear reuse in BC (pers. comm., Anonymous Industry 2023). In some cases, it is possible to do minor repairs and pressure wash gear for reuse, and the industry is actively researching ways to more effectively remove biofouling (pers. comm., Anonymous Industry 2023).

The average density of planted geoduck is 21 individuals/m^2 (Cubillo et al. 2018). This may often result in an average density higher than that found in the wild. Wild subtidal densities may reach 22.5 clams/m^2 in Washington but the average is 1.7 clams/m^2 (Goodwin and Pease 1989). Note that, in contrast, intertidal densities of naturally occurring geoduck are historically low (Goodwin and Pease 1989). Harvest size is 1.1 lb (approximately 500 g) and the survivorship rate can be under 20% (pers. comm., Anonymous Industry 2023)

<u>Unstructured phase</u>

After tubes and antipredator netting are removed, geoduck remains in the sediment and is allowed to continue to burrow and grow to market size over the ensuing 3 to 5 years (Figure 3). During this time, geoduck feeds on naturally occurring phytoplankton and other seston resources.

Figure 3: Geoduck farm, unstructured phase. Photo: Brook Smith.

Harvest

Farmed geoduck generally reaches market size in 5 to 7 years, although this varies by growing area; in BC, it may take as long as 10 years, but in Washington, as few as 4 years (Table 1) (Martell et al. 2013) (VanBlaricom et al. 2015)(pers. comm., Anonymous Industry 2023)(pers. comm, E. Ewald, Taylor Shellfish 2023). Once geoducks in a given farm plot are ready for market, harvest involves the fluidization of the sediment adjacent to geoducks, using a high-volume, low-pressure hose of 40–60 psi, or about the same pressure as a garden hose (WDNR 2008), which has a narrow hand-held pipe called a “stinger” or “wand” that focuses the outflowing water jet (see Figure 1). Both intertidal and subtidal farms use high-volume, low-pressure hose for harvest. Intertidally, work crews mark out locations of the geoduck using bamboo skewers, and then harvest is conducted either wet (with divers) or dry (low tide exposed beach), by the insertion of the harvest wand into the sediment to loosen the sediment around the animal as the harvester reaches underneath to lift it out of the ground (pers. comm., E. Ewald, Taylor Shellfish 2023). Subtidally, it is often harder to see the geoduck, so the planting areas may be harvested repeatedly until few geoducks remain (pers. comm., Anonymous Industry 2023).

Table 1. Typical time to harvest of geoducks by production method and region. Adapted from (CSAS 2012)(Martell et al. 2013)(VanBlaricom et al. 2015).

Time to harvest (years)	Region	Method
4–6	Washington, South Sound	Intertidal
5–8	Washington	Subtidal
6–7	Washington, Hood Canal	Intertidal
6–7	Washington, Strait of Juan de Fuca	Intertidal
7–10+	British Columbia	Subtidal

Once an intertidal farm plot has been harvested, it is available to be replanted within one to two tidal cycles (less than 1 month) (pers. comm., E. Ewald, Taylor Shellfish 2023), thus beginning the next crop cycle. Subtidal plots are replanted within the same season (pers. comm., Anonymous Industry 2023).

Production Statistics

Washington State is the world's foremost producer of farmed Pacific geoduck (Shamshak and King 2015). In Washington, farmed geoduck represents 7% of total farmed shellfish by weight, but 27% of total value (Washington Sea Grant 2015). The United States produced 776 mt of farmed geoduck in 2020 (Figure 4) (FAO 2023), which came from an estimated 22 farms (USDA 2019). The average farmed geoduck is harvested between 360 and 900 g (0.8–2 lb) per individual, including the shell (pers. comm., E. Ewald, Taylor Shellfish 2023). The apparent decline in production after 2018 was due to an exceptionally large harvest in 2018 (with strong growing conditions and a strong export market) followed by a reduced export market in 2019 (affected by trade tariffs in Asia), and then followed by further reductions in both the export and domestic markets due to the COVID-19 pandemic in 2020 (pers. comm., E. Ewald, Taylor Shellfish 202).

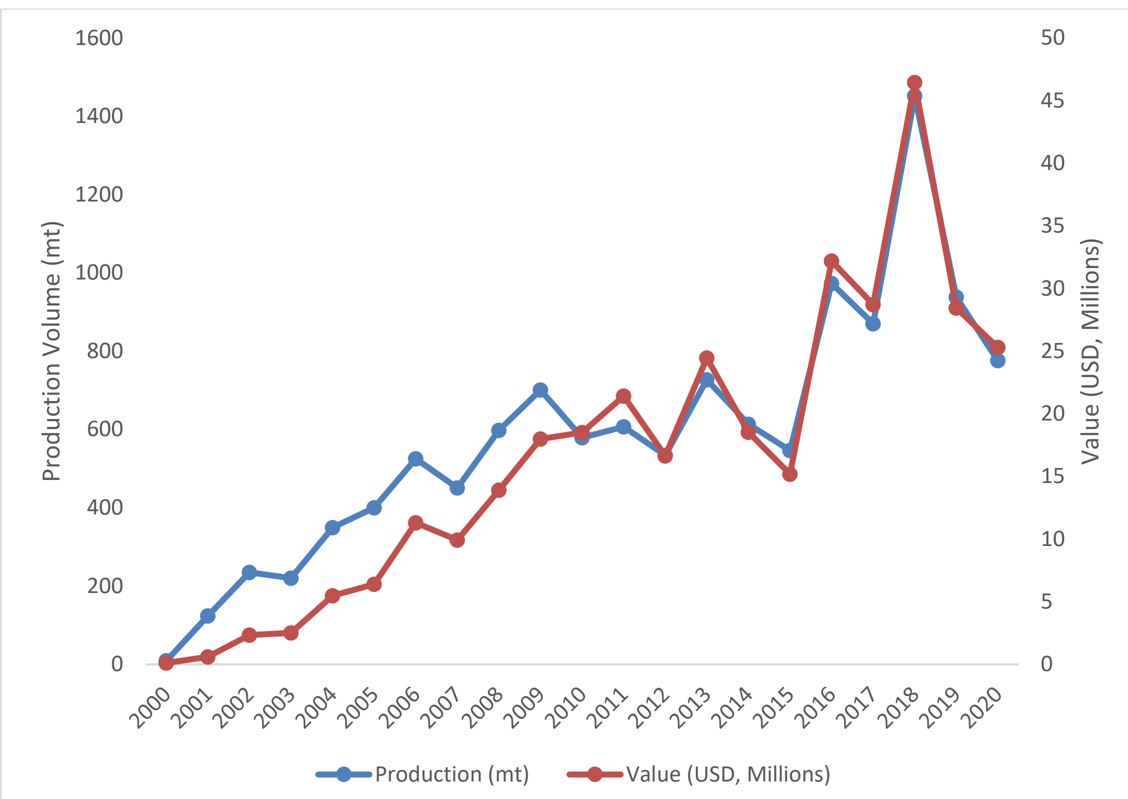


Figure 4: U.S. aquaculture production (mt) and value (USD, millions) of Pacific geoduck by year (FAO 2023).

BC is a comparably small but rapidly growing producer of farmed geoduck. FAO (2023) does not have the same reporting statistic for the species "Pacific geoduck" in the country of Canada as it does for the United States, so total production statistics are less clear. Fisheries and Oceans

Canada (DFO) reported a farmed geoduck harvest in 2022 of CAD 1.3 million from four companies across seven sites (pers. comm., DFO 2023). Although DFO and the British Columbia Ministry of Agriculture (BCMA) report a total of 67 licensed geoduck farm sites (Figure 5), it is clear that most are not currently active (pers. comm., DFO 2023)(pers. comm., C. Matthews, BCMA 2015). In the province's current agricultural statistics, aquaculture production of geoduck is aggregated with other clams, with a total volume of 1,316 mt and landed value of CAD 9.28 million for all species in this category in 2022 (pers. comm., DFO 2023). Assuming a similar price point as received in the United States, an estimated 30 mt of farmed geoduck were harvested in British Columbia in 2022.

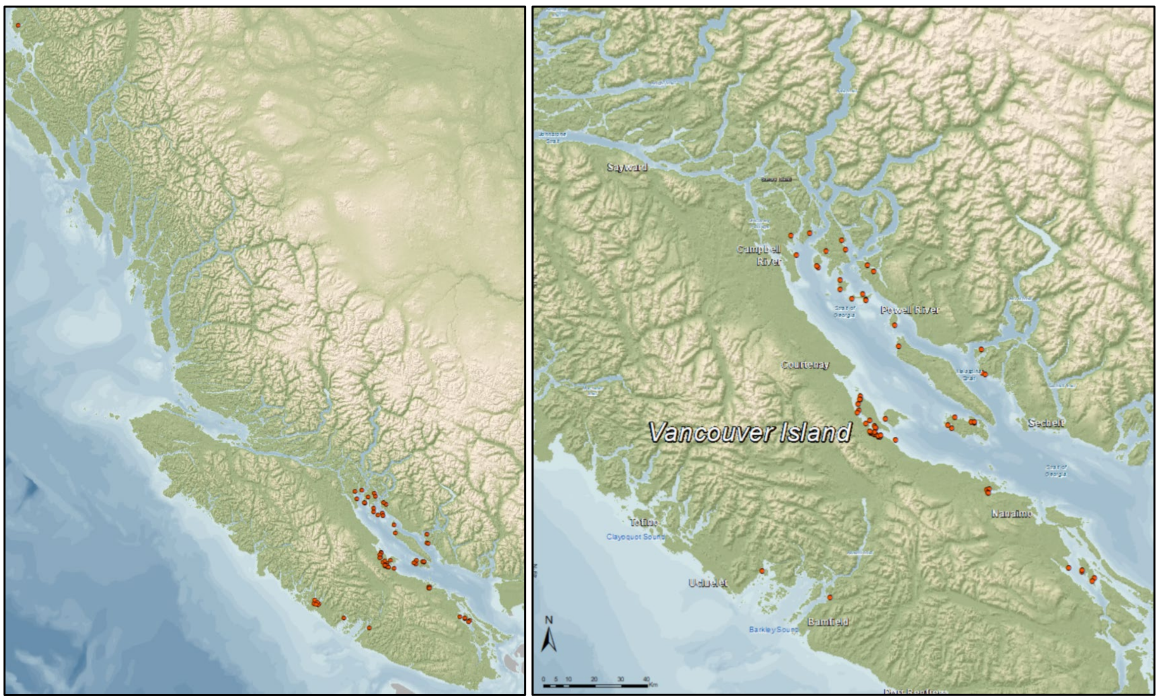


Figure 5: Licensed geoduck facilities in British Columbia, 2023 (pers. comm., DFO 2023).

Import and Export Sources and Statistics

Geoduck is overwhelmingly an export species in both Washington and British Columbia. FAO (2023) only provides trade data classified by the generic category of clams (i.e., aggregated), so the exact export data are not available. British Columbia exported CAD 51.9 million of farmed and wild geoduck in 2020 (the country's fourth-largest seafood export product), with the majority going to China (52%) and Hong Kong (45%) (BCMA 2021), though much of this statistic is represented by wild-harvested product because the commercial geoduck fishery in BC far exceeds the scale of the geoduck aquaculture industry (BCMA 2022).

Common and Market Names

Scientific Names	*Panopea generosa*
Common Names	Pacific geoduck, king clam, elephant-trunk clam
United States	Geoduck clam, giant clam
Spanish	Almeja de sifón
French	Panope du Pacifique
Japanese	Mirugai
China	Xiàngbábàng
Vietnam	Tuhai

Product forms

Whole live.

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	Score (0–10)
Industry or Production Statistics	7.5
Management	10.0
Effluent	10.0
Habitat	5.0
Chemical Use	7.5
Feed	10.0
Escapes	7.5
Disease	5.0
Source of Stock	10.0
Wildlife and Predator Mortalities	7.5
Escape of Secondary Species	7.5
Total	7.5

C1 Data Final Score (0–10)	7.96

Brief Summary

The geoduck aquaculture industry is well characterized by published data in government sources and academic studies, in addition to contacts with geoduck farms, hatcheries, researchers, and regulatory authorities. These personal communications provided clarity and context to the evolving culture methods and regulations of the industry. Two areas of uncertainty are: Habitat, where there are knowledge gaps about the full scope of potential impacts over repeated farm cycles or in response to growth of the industry; and Disease, which could be resolved with larger-scale studies of pathogens in the assessment area that include a large sample size of geoduck from culture areas. The final numerical score for Criterion 1—Data Quality and Availability is 7.96 out of 10.

Justification of Rating
See the relevant sections or criteria within this report for references and/or links to all the information and data sources for which descriptions follow.

Production Statistics
Current U.S. industry production statistics were sourced from the Food and Agricultural Organization (FAO) of the United Nations, and from the Washington State Department of Fish and Wildlife. British Columbia industry statistics were sourced from the British Columbia Ministry of Agriculture, Statistics Canada (Aquaculture Division), and Fisheries and Oceans Canada (DFO), which collects and manages harvest statistics. Production statistics are also self-reported in Washington and BC, but there is evidence that auditing of landings data occurs, and chain-of-custody requirements in both the United States and Canada mean that shellfish landings are reasonably well tracked. Farm size and general location information can be ascertained either directly from listings on government websites, through publicly available permitting information, or through contact with growers. This information ranges in scale, from parcel and farm size information on permit applications to general growing area on published maps and listings. Production statistics in BC are aggregated and reported with either wild-harvested geoduck or "clams" in general. Geoduck export statistics for both the United States and British Columbia are also aggregated and reported with their wild conspecifics and as part of a general "clam" category. Because aggregation limits the applicability of some production data, the final data score for Industry or Production Statistics is 7.5 out of 10.

Management
In Washington State, 11 individual parties oversee the licensing and permitting of geoduck operations across federal, state, and county levels of government. The relevant permits, regulations, and enforcement procedures are readily accessible online. The Army Corps of Engineers and the Washington Department of Ecology both report permitting and enforcement activities and general outcomes on their enforcement websites, as well as making proposals available for public comment. Farm-level inspection and enforcement information was available from the Washington Department of Fish and Wildlife. County-level permitting information is publicly available, and further insight was provided by growers about how they apply for and upkeep these permits (each county upholds individual regulatory authority). In BC, geoduck permitting is led by the Department of Fisheries and Oceans in consultation with First Nations. Canada has created and published a clear management framework for its growing geoduck industry (called the Integrated Geoduck Management Framework), which was informed by a carrying capacity study of BC's coastlines and outlines the governance, regulations, and enforcement procedures for all subtidal geoduck aquaculture operations. The terms and conditions of geoduck license holders are readily available in the Shellfish Aquaculture License authorized by DFO. Statistics on shellfish aquaculture compliance and enforcement are reported on the DFO website[3] and in an annual report. Farm-level enforcement information

[3] https://www.pac.dfo-mpo.gc.ca/aquaculture/regs-eng.html

(i.e., when authorities visit and for what purposes) was verified from discussions with geoduck growers. Overall, the regulatory process in both the United States and British Columbia clearly demonstrates a commitment to preserving ecosystems, and all levels of management information (e.g., regulations, permits, public notices, enforcement authorities and penalties, farm locations, legal proceedings, contact information, and industry best management practices) are generally transparent and freely available. The final numerical score for Management in the data category is 10 out of 10.

Effluent

The production of geoduck in coastal intertidal environments does not require the use of any external feeds or fertilizers that would require intensive effluent calculations. But geoduck culture settings can contain individuals at higher densities than those found in the wild, and the net removal of nutrients was evaluated. There is scientific literature specific to the nutrient cycling of cultivated geoduck in commercially relevant densities, which informed the potential impact of a net removal of nutrients from the system. There is extensive literature published on the beneficial effects of shellfish culture in eutrophic waters. There is a detailed government report on phytoplankton transport in BC that evaluated the potential impacts of industry expansion that provides confidence about the widespread mixing and replenishment of phytoplankton across the region, in addition to several smaller studies conducted within Puget Sound. The final numerical score for data quality for Effluent is 10 out of 10.

Habitat

There is considerable peer-reviewed scientific literature on the habitat impacts of shellfish aquaculture, with some specific to geoduck aquaculture. There are limitations in size, scope, applicability, and the ability to generalize much of the research. The complexity of placing aquaculture animals and gear into the natural environment and the site-specific characteristics that determine the potential for impact (e.g., flushing rate, local background turbidity, phytoplankton availability, proximity to other shellfish culture plots) are difficult to determine. The potential for the degradation or leaching of the PVC and HDPE plastic gear used on geoduck farms is somewhat understood. Habitat regulatory information is extensive and transparently available online, and agencies are readily contacted for clarification where needed. In some cases, dated scientific literature no longer properly characterizes culture practices in response to the way that regulations have evolved in Washington. Much of the "gray" literature (e.g., consultant reports used in permitting proceedings) is speculative, but reliance on some unpublished literature to evaluate habitat impacts has been unavoidable for this assessment. Environmental impact assessments for geoduck farms are readily available online for public comment through regulatory processes. There continue to be considerable uncertainties in the habitat impacts of geoduck farms, and the final numerical score for data quality for Habitat is 5 out of 10.

Chemical Use

Information was available directly from both large and small geoduck farms in Washington State and BC (as well as directly from DFO, which requires reporting of any drug use[4]) to confirm no use of antibiotics, pesticides, or herbicides during the grow-out period. Large and small geoduck hatcheries in Washington also transparently provided information. Hatchery discharge data were unavailable because discharge is not currently required to be monitored, per the authority of the U.S. Environmental Protection Agency (EPA), though this is in the process of changing, with coverage by NPDES permits forthcoming. No geoduck hatcheries in Canada that were contacted for this assessment were able to participate to confirm their practices; however, DFO provided information via phone and email to confirm permitting requirements that clarified hatchery practices to some extent. The cleaning products used in the hatchery were described directly by the industry, and all have publicly available label information and associated documents from the U.S. EPA. The final numerical score for Chemical Use is 7.5 out of 10 in the data category.

Feed

Geoduck is not fed. The final numerical score for data quality for Feed is 10 out of 10.

Escapes

There is robust literature available to describe the age of maturation, spawn size, and relative fecundity of farmed geoduck to understand the potential for escapes during broadcast spawning. Data to describe the potential impact of escapes are less complete. The regulatory structure to describe the spawning requirements to maximize genetic diversity of farmed geoduck in BC is extremely thorough and available to the public (e.g., Geoduck Brood Stock and Hatchery Protocol and Hatchery Licence, Integrated Geoduck Management Framework, and Harmonized Application Guidebooks for Shellfish Aquaculture). The regulatory structure in Washington has more layers and is less streamlined, with no current published spawning requirements (though these are forthcoming, per discussion with WDFW). Information was available directly from geoduck hatcheries and growers in Washington to describe their best management practices, which largely echoed those used in BC. There is literature to describe the genetic population structure of geoduck across its native range; however, there is still uncertainty about the potential impact of repeated F1 generation introductions (i.e., from wild broodstock parents) on wild geoduck at microgeographical scales and more broadly. The final numerical score for data quality for Escapes is 7.5 out of 10.

Disease

Information was available in the literature and directly from geoduck farm operators to describe that there are no known infectious pathogens of Pacific geoduck in the assessment region. But the study of geoduck pathogens and parasites is quite limited, and there is uncertainty about the completeness of the understanding of geoduck disease. Detailed information on reportable diseases is available from the World Organisation for Animal Health (WOAH), and both the United States and Canada are held to agreed-upon international standards for aquatic animal health (Aquatic Animal Health Code as well as the Manual of

[4] https://www.dfo-mpo.gc.ca/aquaculture/management-gestion/overview-eng.htm

Diagnostic Tests for Aquatic Animals). Requirements for information sharing, biosecurity and quarantine requirements, restrictions on the transferring of shellfish, and the use of zoning are readily available. Canada's National Aquatic Animal Health Program (NAAHP) has requirements and procedures readily available online to describe additional layers of regulation related to shellfish disease in Canada. Information was available from published documents, and more details by personal communication, from the Washington Department of Fish and Wildlife to understand their import and disease management procedures. There is an industry-sponsored high-health program for managing disease risk and transfer that many operators voluntarily use in Washington, though there are no public records. A high-health plan was provided by one operator contacted for the assessment, and the practices of smaller growers were available by contacting them directly. There are U.S. federal regulations in place by USDA APHIS that are thoroughly discussed in the new National Aquaculture Health Plan & Standards (NAHP&S) that are robust and readily accessible. The final numerical score for Disease is 5 out of 10 in the data category.

Source of Stock

The source of geoduck broodstock is heavily regulated in both Washington and BC because of genetic concerns. Only first-generation progeny from wild-caught broodstock are allowed to be used by the industry. BC has transparently available, comprehensive regulatory management of all aspects of broodstock collection (allowable zones of collection, number of individuals collected) and individually approves each Introductions & Transfers Licence request to collect and move broodstock to a hatchery facility by a committee to manage genetic risk and disease transfer. All requirements are available in the Integrated Geoduck Management Framework (DFO 2017b) and Shellfish Aquaculture License (DFO 2021). Washington also has requirements for only wild-caught broodstock to be used that are described in Washington Department of Fish and Wildlife documents (WDFW 2021). Information was available for wild geoduck population estimates from BC and Washington (though the Washington data is dated) to understand that there is no impact anticipated to wild populations from the removal of the broodstock quantities used by the industry. The final numerical score for data quality for Source of Stock is 10 out of 10.

Wildlife and Predator Mortalities

Passive predator exclusion methods are described in detail in the literature and were confirmed by the industry. Regulations (the Endangered Species Act in the United States and the Species at Risk Act in Canada)are publicly available in both Washington and BC to protect at-risk wildlife from harm related to aquaculture activities. The permitting processes to receive a shellfish license in both Washington and BC include consideration of the potential wildlife interactions in a robust and publicly transparent way. Reporting requirements for entanglement of marine mammals are strict in both areas, and the U.S. Army Corps of Engineers (ACOE) provided direct information about not receiving any reports related to the geoduck industry. Approved work windows to avoid interactions with any wildlife that has conservation status are transparently outlined in the Conservation Measures related to ACOE shellfish permitting in Washington (Programmatic Biological Opinions for Shellfish Activities in Washington State Inland Marine Waters [U.S. Fish and Wildlife Service {USFWS} Reference Number 01EWFW00-2016-F-0121, National Marine Fisheries Service {NMFS} Reference Number WCR-2014-1502]). The industry provided information via data requests about their beach preparation, planting, and harvest activities, and all procedures for removal and relocation of invertebrates during these phases of geoduck culture. Best management practices from industry representative groups, the Pacific Coast Shellfish Growers Association (PCSGA), and the British Columbia Shellfish Growers Association (BCSGA) are available either online or by request to each respective organization. Nevertheless, a potential for entanglement exists when large areas of netting are used, and there is no formal source of data on the numbers of birds killed. The final numerical score for data quality for Wildlife and Predator Mortalities is 7.5 out of 10.

Introduction of Secondary Species

The industry provided detailed information about practices to minimize the unintentional transfer of secondary species during live animal movements, as well as the transport distances of gear and animals in normal operations. Both the United States and Canada have regulations and shellfish movement license requirements that minimize the transfer of secondary species, and these are readily available online. The transfer of live shellfish and aquaculture gear between the two countries is strictly controlled, and the relevant regulatory approvals and agencies have clear websites and contact information. In Washington, the percentage of industry that is reliant on trans-waterbody shipments was informed by data provided directly by the industry, as well as personal communication with WDFW regarding its shellfish imports. Protocols for the retrieval, biofouling removal, storage, and redeployment of geoduck antipredator gear were provided by the industry. Hatchery protocols (including Biosecurity Plan and high-health plan) were readily provided by direct contact with a large producer in Washington State. Hatchery biosecurity practices of smaller growers were provided by direct communication. The final numerical score for data quality for Introduction of Secondary Species is 7.5 out of 10.

Conclusions and Final Score

The geoduck aquaculture industry is well characterized by published data in government sources and academic studies, in addition to contacts with geoduck farms, hatcheries, researchers, and regulatory authorities. These personal communications provided clarity and context to the evolving culture methods and regulations of the industry. Two areas of uncertainty are: Habitat, where there are knowledge gaps about the full scope of potential impacts over repeated farm cycles or in response to growth of the industry; and Disease, which could be resolved with larger-scale studies of pathogens in the assessment area that include a large sample size of geoduck from culture areas. The final numerical score for Criterion 1—Data Quality and Availability is 7.96 out of 10.

Criterion 2: Effluent

Impact, unit of sustainability and principle

- Impact: Aquaculture species, production systems and management methods vary in the amount of waste produced per unit of production. The combined discharge of farms, groups of farms or industries contribute to local and regional nutrient loads.
- Sustainability unit: The carrying or assimilative capacity of the local and regional receiving waters.
- Principle: not allowing effluent discharges to exceed, or contribute to exceeding, the carrying capacity of receiving waters at the local or regional level.

Criterion 2 Summary

Effluent Evidence-Based Assessment

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

Brief Summary

Farmed geoduck is not provided external feed for the bulk of the production cycle, and it is provided only small volumes of cultivated microalgae in the hatchery setting. Although there have been documented cases of high-density shellfish operations reducing phytoplankton resources, shellfish culture is generally considered to provide an ecosystem service through improving water quality. When sited properly in well-flushed waters, there is no anticipated impact to local nutrient supply. Overall, geoduck 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

Evidence-based assessment

Because the effluent data quality and availability are good (Criterion 1—Data score of 10 out of 10 for the Effluent category), the evidence-based assessment was utilized.

The production of geoduck in coastal intertidal environments does not require the use of any external feeds or fertilizers, because geoduck is an extractive species (see the Species Overview in the Introduction). During the hatchery phase, cultivated microalgae are fed to geoduck seed.

Although external nutrient inputs are not provided, geoduck culture settings can contain individuals at higher densities than those found in the wild. Filter feeding by bivalves influences nutrient dynamics through the transfer of nutrients from the water column to the benthos, the release of dissolved inorganic nutrients to the water column, and the net removal of some nutrients (such as nitrogen) from the system via harvest (Dumbauld et al. 2009). The net nitrogen removal at harvest supports eutrophication mitigation (i.e., in waterbodies that have excess nitrogen), and there is an conversation ongoing about nutrient trading credits—essentially, using bivalves as a nitrogen extraction offset for an environmental benefit (Guyondet et al. 2022b). There can be an increase of dissolved nutrients in the water column immediately around shellfish culture sites related to biodeposits (in the form of feces and pseudofeces) (Straus et al. 2013).

Biodeposition resulting from the production of feces and pseudofeces by densely stocked shellfish increases sedimentation, which in turn can increase sediment oxygen demand, increase denitrification, and increase sediment ammonia concentrations (Straus et al. 2013 and sources within). Anoxic sediment conditions have been linked to deposition from other types of bivalve shellfish aquaculture (Straus et al. 2013), but those results are not specifically applicable to geoduck culture habitat, densities, gear, or methods. Individual flow and site characteristics are also likely to drive sedimentation locally and can reduce or minimize the potential impact (Dumbauld et al. 2009)(Harbin-Ireland 2004)(Straus et al. 2013).

By modeling commercially relevant densities of farmed geoduck, Cubillo et al. (2018) found that, over the span of the entire culture cycle (5 years on average), each individual geoduck will filter approximately 400 m^3 seawater, consume 0.73 kg of oxygen, remove >20 g nitrogen, and filter >845 g suspended organic matter (of which 550 g is algal and 295 g detrital). Of the suspended organic matter that is filtered, 33.6% returns directly to the environment as pseudofeces or feces (7.2% and 26.4%, respectively) and "may contribute significantly to nitrogen regeneration in the benthos" (Cubillo et al. 2018). The estimated loss of dissolved inorganics over the entire life cycle of a cultured geoduck is 12.7 g of NH_4 (Cubillo et al., 2018). Thus, these modeling results suggest that geoduck culture does not have any significant effect on the concentrations of ammonia, dissolved oxygen, or chlorophyll a in surrounding waters (Cubillo et al. 2018). The density of farms in the sound that was modeled (South Puget Sound) is relatively low, and cumulative food depletion effects between bivalve farms were not included.

Nutrient dynamics in natural systems are complex, but with the available knowledge, there seems to be a low risk of geoduck culture at its present scale significantly altering nutrient dynamics. In eutrophic areas, geoduck culture provides a net ecosystem service by contributing to the removal of excess nutrients (Cubillo et al. 2018). There is a general consensus in the literature that aquaculture activities in high-energy, well-flushed intertidal areas generally result in dispersal of biodeposits and lessened impacts to sediments (Galliardi 2014). The potential impacts to subtidal culture plots are not well studied (likely due to the challenge of accessing them), and there may be potential for stronger accumulation impacts in subtidal areas if they are located in low-energy locations (Galliardi 2014).

Effects of competition

Bivalve shellfish feed by filtering suspended particles from the water column, then expelling waste in the form of processed feces and uningested pseudofeces (rejected particles). In the process, there is concern that they may compete for food resources with other wild organisms, although this depends upon the residence time of water in a water body, availability of nutrients, phytoplankton growth, grazing behavior of the bivalves, and the density of bivalves in the system (i.e., culture plot location).

Filter-feeding shellfish can significantly reduce the ambient concentration of phytoplankton in certain circumstances. For example, in estuaries characterized by low flushing or long residence times, phytoplankton density can be significantly reduced as a result of oyster culture (Dumbauld et al. 2009)(Banas et al. 2007). In the estuary of Willapa Bay, Washington, chlorophyll a concentration decreases by 9.6% per half hour as water passes on-bottom adult oysters (Wheat et al. 2013), though there is no similar metric for geoduck. A pilot modeling study by Banas and Cheng (2015) for South Puget Sound suggests that the long residence time and high density of cultured bivalves there potentially affect local phytoplankton concentrations. Decreasing growth rates have been observed at farm sites as a result of an increasing density of bivalve operations (and thus competition for phytoplankton supply) (Dumbauld et al. 2009)(Straus et al. 2013). But the impact is generally confined to the immediate vicinity of the individual aquaculture operation (several examples in Washington are given within Dumbauld et al. [2009]). Although modeling suggests that there may be impacts of expanding geoduck (and other bivalve shellfish) aquaculture on phytoplankton and competitors relying on phytoplankton as a food resource (Reum et al. 2015), it is important to consider the limitations in accuracy of extrapolating system-scale information from models for something as complex as phytoplankton supply.

It seems much more plausible that the impact of geoduck aquaculture to phytoplankton supply is only local at the current scale of the industry. Ferriss et al. (2015) found that a “realistic” increase in cultured geoduck biomass of 120% in Central Puget Sound (which is not as extensively developed for aquaculture as South Sound) resulted in a “nearly negligible” trophic effect on plankton biomass. Ferriss et al. (2015) also suggest resilience at the ecosystem scale despite hypothetical industry growth for one region. A comprehensive ecosystem carrying capacity study of Baynes Sound, BC finds that there is a regular water exchange and replenishment of nutrients from nearby deep waters sustaining high primary productivity, and that “this primary productivity confers a high potential for secondary production to Baynes Sound and in particular the ability to sustain a large bivalve culture production” (Guyondet et al. 2022a). Thus, it is likely that Baynes Sound has nutrients to adequately support the projected shellfish culture growth in the area, and the authors caution that ocean acidification and hypoxia as a result of climate change will be the more critical limitations for future growth (Guyondet et al, 2022a).

It is also important to note that, in some cases, reducing phytoplankton is beneficial to the ecosystem. Filter-feeding shellfish are commonly considered to provide an ecosystem service as they feed. For example, bivalve filter feeding may improve water quality, particularly in areas affected by eutrophication, such as South Puget Sound (Banas and Cheng 2015), and geoduck aquaculture has been modeled to provide a potentially significant reduction in eutrophication (i.e., ecosystem service) when scaled to the whole of Puget Sound (Cubillo et al. 2018). Filter-feeding activity can also reduce turbidity, which can improve light penetration for seagrasses (Newell 2004)(Galliardi 2014).

Conclusion

Farmed geoduck is not provided external feed for the bulk of the production cycle, and it is provided only small volumes of cultivated algae in the hatchery setting. Although there have been documented cases of high-density shellfish operations reducing phytoplankton resources, shellfish culture is generally considered to provide an ecosystem service through improving water quality. Geoduck harvest results in a net removal of nitrogen from the habitat, which appears to be within the ability of natural phytoplankton resources to support at the current intensity of the industry, and is a benefit in areas experiencing eutrophication. When sited properly in well-flushed waters, there is no anticipated impact to local nutrient supply. Overall, geoduck 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.

Criterion 3: Habitat

Impact, unit of sustainability and principle

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

Criterion 3 Summary

Habitat parameters	Value	Score
F3.1 Habitat conversion and function		7
F3.2a Content of habitat regulations	5	
F3.2b Enforcement of habitat regulations	4	
F3.2 Regulatory or management effectiveness score		8
C3 Habitat Final Score (0–10)		**7.33**
Critical?	NO	**GREEN**

Brief Summary

The impacts of geoduck aquaculture on marine habitat appear to be minor to moderate, with impacts largely ephemeral and limited to the farm site. Habitat on geoduck farms appears to be maintaining functionality, but uncertainty remains, as noted by nearly all the authors cited in this section. The combination of the nature of apparent effects and the remaining uncertainty (such as in the cumulative effects of repeated farm cycles and impacts of scales larger than in existing studies) factors into the score of 7 of 10 for moderate habitat impacts for Factor 3.1.

There are limitations in management and enforcement in both BC and Washington, but both jurisdictions have worked to strengthen their infrastructure, have supported scientific understanding, and have shown evidence of enforcement. The permitting process is extensive, transparent, and reflects robust management of both regions. Overall, management and enforcement are considered robust, with minor limitations to enforcement. Factor 3.2 receives a score of 8 out of 10. Factors 3.1 and 3.2 combine to give a final Criterion 3—Habitat score of 7.33 out of 10.

Justification of Rating

Factor 3.1—Habitat Conversion and Function

Habitat Type, Location, and Scale
In Washington State, geoduck culture primarily occurs in South Puget Sound, where it is estimated that approximately 100 ha (247 acres) are under production for farmed geoduck (Preikshot et al. 2015). There are an estimated 100 farms in operation, based upon the known farm count of one operator and a calculation of the remaining area of the industry, divided by the average farm size. The industry in Washington is projected to expand to meet the growing market demand, which would include new tenures as well as conversion of tenures previously used to cultivate other species of shellfish.

In BC, geoduck farming mostly occurs in the Strait of Georgia, though it is now permitted beyond the Strait. The 67 licensed tenures for geoduck aquaculture (intertidal, subtidal, deepwater suspended, or any combination of the three types) total approximately 1,319 hectares; however, only 21 of the tenures have seeded geoduck since 2011 and only 12 of those have ever had a harvest (DFO 2023/2024). The most current permitting registry reflects that expansion is slowly increasing outside the Strait of Georgia, with only 3 of the now 67 licensed tenures beyond the Strait: 2 in Zone 5 (West Coast Vancouver Island) and 1 in Zone 2 (North & Central Coast) (DFO 2023a). In total, an estimated area of 600 ha may be cultivated in BC, but there is uncertainty again whether all the licensed tenures in this number are actively cultivating geoduck (pers. comm., Anonymous Industry 2023). Although a greater area may be under cultivation in BC, total production volume is lower. This may be caused by differing planting densities and the lower survival rate reported in BC subtidal culture.

Geoduck farm plots are located in two habitat types: coastal inshore subtidal (classified as medium value according to the Seafood Watch Aquaculture Standard) and coastal intertidal (classified as high value). In Washington, subtidal culture is less common than in British Columbia, though the proportion of each habitat type under use is difficult to determine with the available data. One large grower in Washington, which represents an estimated three-quarters of the state’s cultivated area, reports no subtidal culture of geoduck (pers. comm., E. Ewald, Taylor Shellfish 2023). But the remaining proportion of farms that may be engaged in subtidal culture is not publicly available in a registry.

BC has a publicly available aquaculture license registry that describes the culture method and permitted species for cultivation. A total of 27 operators are licensed for subtidal culture (either solely or in addition to intertidal/deepwater suspended culture)(DFO 2023a). Subtidal culture represents an estimated two-thirds of the industry, and intertidal culture represents an estimated one-third. Deepwater suspended culture is used only for nursery phases and is not commercially viable for market-sized product (pers. comm., Anonymous Industry 2023).

Impact to Habitat Functionality
Geoduck aquaculture takes place in the benthos of the open environment. Habitat-related concerns specific to geoduck are: the potential for changes to benthic community structure;

interaction with natural ecosystem services (i.e., eelgrass); changes to sediment composition; competition with wild species; disruption of sediment and resuspension during harvest; and the use and fate of plastics used for culture purposes.

Effects on community composition

Unstructured, soft-bottom estuarine sediments are important foraging and nursery habitat for a variety of organisms (such as flatfishes, polychaete worms, birds, bivalves, and Dungeness crab). The structured phase of geoduck culture, in which a high density of predator exclusion tubes and mesh are often used to increase early survival in geoduck production, adds structure to a habitat where there previously may have been none. The concern is that this may exclude or limit organisms adapted to unstructured habitat and favor organisms that seek habitat complexity. For example, antipredator mesh and the associated biofouling are attractive to some sheltering and foraging organisms (Powers et al. 2007).

On-site community composition on geoduck culture plots has been conducted in Puget Sound during three distinct phases of gear use (before gear placement, gear present, and after gear removal), compared with reference areas. The most common resident macroinvertebrates at geoduck culture plots and reference sites were polychaete worms and small crustaceans and bivalves, with echinoids, burrowing sea anemones, sea cucumbers, and larger bivalves as important community components in some areas (McDonald et al. 2015). Although the resident macroinvertebrate taxa abundance was dominated by strong seasonal and site-specific compositions, their overall density was lower at geoduck culture sites (in two out of three culture plots compared to their reference plots). Most resident macroinvertebrate families that experienced changes in abundance (positive or negative) when geoduck aquaculture gear was placed in the environment returned to pregear levels after removal, though some families showed neutral response and two polychaete families showed a persistent negative response (McDonald et al. 2015). In general, the abundance of transient fish and macroinvertebrates increases when geoduck gear is present, and their counts were two times greater at culture sites than at reference sites while geoduck structures were in place (McDonald et al. 2015). Importantly, the diversity of macrofauna was not significantly different between culture and reference sites (McDonald et al. 2015). Although community composition differed from reference areas while geoduck structures were in place, these changes were temporary (1 to 2 years), with composition rapidly returning to background levels after gear and structures were removed (McDonald et al. 2015). The authors caution that other impacts might be occurring that were not captured in the study, including the growth of organisms in the community. Antipredatory structures of geoduck plots have an exclusionary effect on moon snails (predatory gastropods) and flatfish, and the opposite effect (attraction) for demersal fish, sea stars, red rock crab, and small crabs (McDonald et al. 2015), which may be the result of the altered foraging opportunities in the structured habitat or the refuge from predation provided by the structures (Ferriss et al. 2015). Indeed, some growers report an abundance of other species of bivalves that have been able to recruit to antipredatory structures on geoduck farms (pers. comm., E. Ewald, Taylor Shellfish, 2023).

Food web modeling suggests that, under a plausible increase (+120%) in geoduck aquaculture in central Puget Sound over a 50-year period, the ecosystem resilience and the individual species' biomass would undergo "only minor changes" (Ferriss et al. 2015). Habitat modification by the structured phase of geoduck aquaculture may negatively affect the density of some species (such as *Corophium* amphipods and predatory birds) when antipredator structures shelter those species' predators or prey (which were positively affected). The authors also note the importance of needing more research to clarify the potential impact to demersal fish and small crustaceans (important prey items in the food web) and birds (Ferriss et al. 2015); growers have reported the presence of predatory birds, such as great blue heron, predating upon small fish within the farm (pers. comm., Anonymous Industry 2023).

The staghorn sculpin is a ubiquitous local consumer species in the food web of Puget Sound, feeding on invertebrates. Although there were some differences in staghorn sculpin stomach contents between geoduck culture and reference sites, the presence of geoduck aquaculture gear did not affect the food web function or trophic position of sculpin, or the source of carbon at the base of the food web (McPeek et al. 2015).

The available data do not entirely describe the extent of potential community composition changes. Diversity and abundance measures do not necessarily indicate the overall production of some species (Dumbauld et al. 2009), and effects also likely vary in intensity and by location, time, harvest practices, and other factors. Brown and Theusen (2009), McDonald et al. (2015), and VanBlaricom et al. (2015) have all noted the importance of seasonality and site-specific conditions to community composition. Some uncertainty remains regarding potential cumulative effects, such as how a habitat responds to disturbance from multiple, repeated farm cycles in the long term and over a broader ecosystem scale with industry expansion. So far, research points to resilience and the maintenance of ecosystem functions despite these known effects.

Considering all this literature, geoduck aquaculture gear can have an influence on community structure, though the significance thus far is found to be negligible. Modeling suggests that there may be greater impacts at a larger scale, but at the current scale, the effects (both positive and negative) of geoduck aquaculture gear on community structure appear to be short-lived (i.e., 1 to 2 years, per McDonald et al. 2015).

Effects on submerged aquatic vegetation (eelgrass)

Eelgrass and bivalves coexist in the wild and are not inherently antagonistic to each other. Eelgrass is an important primary producer, sediment trap, forage, and biogenic habitat for a variety of organisms, such as waterfowl, crabs, and juvenile fish. Eelgrass is deemed a Habitat Area of Particular Concern (HAPC) on the West Coast; such habitats are "considered high priority areas for conservation, management, or research because they are important to ecosystem function, sensitive to human activities, stressed by development, or are rare" (NOAA 2021).

There are layers of regulation in place that establish a buffer between intertidal geoduck aquaculture and existing eelgrass beds, including Washington State's 401 Water Quality Certification permitting, which requires a buffer of 10–25 ft, and ACOE's 5 m (16.4 ft) buffer requirement for intertidal shellfish aquaculture (WDOE 2017). Washington also requires counties to issue conditional use permits for geoduck aquaculture that assess the concerns about native eelgrass (WDOE 2017) that often appear in public discussion about the industry, and these permits would offer another layer of verification that farms are sited appropriately. Also, conservation measures are required for any U.S. shellfish permit holder, to protect eelgrass from vessels, vehicles, or trampling, and any eelgrass in the vicinity of new shellfish culture activities must be mapped and submitted to the ACOE (Conservation Measures #6, #25, #26 from the Programmatic Biological Opinions for Shellfish Activities in Washington State Inland Marine Waters [U.S. Fish and Wildlife Service {USFWS} Reference Number 01EWFW00-2016-F-0121, National Marine Fisheries Service {NMFS} Reference Number WCR-2014- 1502]). In BC, the DFO's Shellfish Licence Conditions also protect eelgrass (included in the definition of "sensitive habitat") by not allowing the installation of infrastructure in any sensitive habitats, and also address the potential spread of eelgrass into an existing site, stating that, "In the event important and sensitive habitat grows or otherwise moves into an actively cultured area containing existing equipment or gear, the licence holder shall take all reasonable steps to avoid the harmful alteration, disruption, or destruction of that habitat" (DFO 2021). In the context of these required eelgrass protections, it seems highly unlikely that there would be a significant impact to eelgrass from geoduck aquaculture activities.

There have been fairly extensive studies on the potential impacts of shellfish aquaculture to eelgrasses both in the assessment region and globally, such as Brown and Theusen (2009), McDonald et al. (2015), VanBlaricom et al. (2015), and Feriss et al. (2019). But in the context of the current permitting regulations protecting eelgrass, the test parameters in many studies do not seem relevant to evaluating present-day commercial culture practices (e.g., a test of eelgrass regrowth potential after being harvested, when the permitting regulations establish buffers from eelgrass beds that would presumably prevent that interaction).

When antipredation gear is present, there is concern that eelgrass that disperses into the farm site may experience abrasion, displacement, or shading. For example, a study by the Washington Department of Natural Resources (Horwith 2013) documented reduced shoot size and density and an eventual disappearance of eelgrass that had colonized a geoduck farm; these effects were attributed to shading from biofouled antipredator mesh. Anecdotally, growers report that, upon returning to the same site after the study period, eelgrass returned to the farm once antipredator mesh was removed and large cover nets are no longer in use—thus preventing this shading effect from recurring (pers. comm., E. Ewald, Taylor Shellfish, 2023). Dumbauld et al. (2009) and Horwith (2013) have also noted similar shading effects (as well as abrasive and exclusionary effects) on eelgrass in association with gear used to farm other bivalve shellfish. Shading impacts are only found directly under the deployed gear on shellfish farms (Howarth et al. 2022). Robust regulations are in place for bivalve culture to avoid existing eelgrass and any eelgrass that naturally spreads onto the site, which would mitigate any potential interaction between eelgrass and hard gear structures. Geoduck growers are clearly aware of the regulations and report, in some limited and site-specific instances, that if eelgrass naturally disperses across the margins of their sites, they are allowed to harvest their existing planted stock and then must not replant within the mandated eelgrass buffer distance set by WDOE and ACOE (pers. comm., Jim Parsons, Jamestown Seafood, A Jamestown S'Klallam Tribal Enterprise 2023)(pers. comm., Anonymous Industry 2023). This harvest and replanting restriction is not currently required for ongoing and historical commercial farms (pers. comm., E. Ewald, Taylor Shellfish 2023).

Thus, because of the robust regulations in place, geoduck farming is quite unlikely to cause impacts to eelgrass or its habitat functionality during the structured phase (approximately years 0–2 of the farm cycle) or the unstructured phase (approximately years 2–5). The discussion of turbidity related to harvest and its potential impacts follows, under "Harvest Impacts."

Effects on sediment chemistry and composition

The presence of geoduck culture structures (tubes and antipredator mesh) have the potential to affect sediment characteristics on a geoduck farm. (The impacts of harvest activity are addressed separately under "Harvest Impacts.") Note that the potential impacts of biodeposition of the filter feeders is discussed in Criterion 2—Effluent.

Antipredator mesh and culture structures can change flow patterns and sediment characteristics. For example, antipredator mesh used for Manila clam culture (applied over the top of the sediment and weighted or staked at the edges, similar to applications used in geoduck culture) can reduce water flow and increase sedimentation by up to four times (Spencer et al. 1996)(Spencer et al. 1997)(Jamieson et al. 2001). Also, the organic content of sediment was higher underneath antipredator mesh on plots, whether or not clams were present (Spencer et al. 1996)(Spencer et al. 1997), suggesting that the physical structure of the netting is the primary cause of these impacts. Conversely, in Baynes Sound, British Columbia, antipredator netting associated with shellfish aquaculture (Manila clam) was found to have "limited effect on the sediment" (Munroe and McKinley 2007). A Final EIS for a proposed geoduck farm plot in Washington estimated that approximately 0.25 inches per square foot of sediment would deposit on the site during the presence of the nursery gear, and that these accumulated fines and silt would redistribute relatively quickly during the remainder of grow-out after the nursery gear was removed by tides and small-scale wave processes (BLGF Final EIS 2023).

An experiment by Horwith (2013) found evidence of decreased sediment elevation and increased scour from antipredator tubes, as well as a decrease in sediment organic content within the farm, which increased after antipredator mesh was removed. During preharvest phases on the farm site, only minor effects on silt and clay content of the sediment have been observed, with no differences in organic matter or nitrogen content (Sauchyn et al. 2013). Sulfide concentrations were reduced significantly on a farm plot compared to a reference site in one case, which was attributed to disturbances associated with out-planting of geoduck seed, but it was concluded to have an unlikely ecological impact (Sauchyn et al. 2013). Overall, ecologically significant impacts to sediment composition and chemistry (among other measures) resulting from the presence of cultured geoduck after 1 year are unlikely, but the authors caution about this study's limitations in size, scope, and focus on nearby offsite impacts (Sauchyn et al. 2013).

Overall, the effects of bivalves on sediment chemistry are site-specific and depend on local environmental conditions, local hydrography, and culture practices, such as stocking density and infrastructure used (Galliardi 2014). There is also support that, in certain circumstances, there may be no impacts. For example, Straus et al. (2013) reviewed several studies on oyster and mussel farms in which no significant differences in certain parameters (such as sedimentation, carbon content, organic matter, sulfides, and turbidity) were observed between the farms and control sites.

According to what is available to date, it seems that geoduck aquaculture may have some effects on sediment chemistry and hydrodynamics, but the effects have thus far been considered minor and site-specific. In geoduck aquaculture, antipredator structures are only present during the first 1 to 2 years of the production cycle. The findings of McDonald et al. (2015), Liu et al. (2015), VanBlaricom et al. (2015), and others suggest ecosystem resilience and the ability of sites to rapidly return to background characteristics upon the removal of gear.

<u>Effects of plastic gear in the environment</u>

Plastic is currently ubiquitous in the farming of geoduck. The gear is a substantial investment for farmers, and they have a vested interest in maintaining possession of it during the farm cycle. An acre of geoduck culture in Puget Sound contains an estimated 16.5 tons of plastic when using PVC (Bendell 2015), though the use of HDPE is expected to reduce this. Thousands to tens of thousands of tubes (PVC or HDPE mesh) may be deployed to the sediment per farm to protect young geoduck (Schoof and DeNike 2017). Tubes may be topped with individual HDPE mesh, or alternatively, large "canopy" HDPE mesh coverings may be used to cover arrays of tubes at once or to create subtidal "clam tunnels." Anecdotally, the PVC pipe and predator net used in geoduck aquaculture by some operators in Washington has been reported to maintain working condition—that is, resist deterioration—for more than 20 years (Schoof and DeNike 2017). Operators also report expecting full functionality of all geoduck gear for multiple planting cycles, with end-of-life protocols to recycle the gear locally (pers. comm., E. Ewald, Taylor Shellfish, 2023).

The use of HDPE area netting is not necessary on all farms, and growers report installing it only when necessary (pers. comm., Anonymous Industry 2023). Also, nursery tubes (either PVC or HDPE) are not typically used subtidally in BC (pers. comm., Anonymous Industry 2023)(pers. comm., Anonymous 2023). Importantly, growers in Washington report that HDPE area netting is required to facilitate Tribal fishing rights on their leased farm plots upon request (it prevents fishing gear from becoming entangled), such that, even if farmers do not desire to use HDPE netting for predation control on a particular plot, they would need to install it to honor Tribal fishing rights (pers. comm., Anonymous Industry 2023).

The use of these plastics is of potential concern for three primary reasons: if gear is lost, it could become debris to the marine environment; the potential addition of microplastics to the marine environment via degradation and fragmentation of plastic farm gear; and the potential leaching of harmful substances from plastics.

Marine debris

Anthropogenic marine debris, or human-generated trash that enters the marine environment, poses hazards to marine ecosystems. Plastic can be slow to degrade in the marine environment and presents dangers of entanglement, entrapment, and choking to marine wildlife (Ryan et al. 2009). As reviewed in Moore et al. (2001), Ryan et al. (2009), and Thompson et al. (2009), plastics have been extensively implicated in the entanglement deaths of marine mammals, birds, reptiles, and fish, and have been found in the stomachs of numerous and widely distributed taxa.

Geoduck aquaculture has been, and continues to be, criticized by the public and environmental groups in Washington for the potential loss of plastic gear to the marine environment as debris. The concern is that tubes and netting could theoretically become loose and drift from the farm site after stormy weather or other disturbances before they could be retrieved by the operators. Shellfish aquaculture in general contributes to derelict plastic gear in the regions being studied in this report. For example, in Baynes Sound, British Columbia, 6 mt of shellfish marine debris was collected at an annual beach cleanup in 2019 (Bendell et al. 2020). It is not possible to discern geoduck culture's specific role regarding marine debris, including in the Bayne's Sound example, where there is also extensive oyster culture in addition to other clam species (Guyondet et al., 2022). Indeed, a number of growers have indicated that the majority of this debris likely originates from oyster culture (e.g., trays, pouches, floats) and is not associated with geoduck, especially given the limited geoduck culture in the Sound (pers. comm., Anonymous Industry 2023). Government regulations and enforcement have adapted to address the concern of plastic debris from the shellfish industry through mandating gear tags and requiring inspections and maintenance to minimize loss (this is explained in detail in Factor 3.2a), and the industry itself has demonstrated best management practices to mitigate the loss of plastics, through beach clean ups and even setting targets for net negative plastics (PCSGA 2023)(BCSGA 2023). There are clear financial and environmental stewardship incentives for farms to recover their gear to reduce their production costs and maintain their surroundings. Growers stress the importance they give to monitoring for plastics (in some cases even establishing communication networks with the shoreline property owners to report any gear); they describe that growers are actively helping each other to check for gear, and some report that they themselves return to every beach after nursery tubes have been pulled to check for any that may have been uncovered by shifting sands at the subsequent tidal cycles (pers. comm., Jim Parsons, Jamestown Seafood, A Jamestown S'Klallam Tribal Enterprise 2023)(pers. comm., Anonymous Industry 2023).

Microplastics

Microplastics are particles of plastic generally considered to be less than 5 mm in diameter and often resulting from the degradation and fragmentation of larger pieces of plastic. Microplastics are believed to disrupt sediment physical and chemical processes, such as nutrient cycling (Cluzard et al. 2014), and their entry into marine food webs through ingestion is increasingly being demonstrated (Cole et al. 2011) (Cluzard et al. 2014). Microplastics can attract and accumulate toxic chemicals in the marine environment, transfer toxins through ingestion (Cole et al. 2011), and penetrate cellular membranes (Teuton 2009). Thus, the generation of microplastics and their trophic transfer is of significant concern.

Wave action, abrasion, and turbulence are some elements of the marine environment that can fragment plastics (Cole et al. 2011)—all elements likely encountered on a geoduck farm. The potential for the contribution of geoduck aquaculture plastics to the marine microplastic problem has not been thoroughly studied or demonstrated. PVC has been shown to degrade into microplastics in the marine environment (Cole et al. 2011); however, a small study by Schenk (2011) failed to find PVC microplastics in sediments at one geoduck farm and suggests that PVC used in geoduck farming is unlikely to be a major contributor to microplastic pollution, due to lower exposure to UV light. These conclusions were also reached by a Washington State Hearings Board (Coalition to Protect Puget Sound and Case Inlet Shoreline Association v. Pierce County and Longbranch Shellfish 2012). It should also be noted that there is at least some use (and increasing) of HDPE flexible mesh nursery tubes as an alternative to PVC, giving improved fouling and gear retention rates and ease of installation, and that the potential concerns related to this plastic would be similar to that of the antipredator mesh, which is also generally HDPE.

In Baynes Sound, British Columbia, a high amount of microplastic particles were found within intertidal varnish and Manila clams (not geoduck) used to detect biopollution, and the majority of these plastics were high density polyethylene (HDPE) and a polypropylene composite (PPC) (Bendell et al. 2020). Although these plastics are used extensively in the shellfish industry, they are also used in other marine activities (industrial/recreation), which leaves uncertainties about the potential contribution of aquaculture. More recent literature analyzing the polymer composition of microplastics in Baynes Sound indicated that the majority (83%) of confirmed microplastics were fibrous PETE/polyester, and suggestive that “sewage outputs of textile emissions, aerial dust from cities, or coastal landfills” are key sources of this pollution (Mahara et al. 2022). The study further notes that the average concentration of microplastics in Baynes Sound is an order of magnitude lower than that which is the estimated safe concentration threshold for adverse effects to marine invertebrates (Mahara et al. 2022). Shellfish industry representatives have communicated that there is no “significant release of microplastics from shellfish aquaculture operations” (Schoof and DeNike 2017). This is supported by an on-site study of microplastic concentrations in bivalves from commercial shellfish beaches (Manila clam and Pacific oyster) vs. non-aquaculture beaches in coastal BC, where “findings suggest that shellfish aquaculture is not currently a major source of microplastics in BC waters,” with a clarifying note that textile microplastics are dominant and may inhibit the detection of impact from shellfish aquaculture (Covernton et al. 2019).

Leaching of harmful substances

During the manufacturing process, a range of chemicals are added to plastics to manipulate physical characteristics. As plastic degrades, there is evidence of the leaching of such chemicals, some of which may be harmful to humans (Thompson et al. 2009) and the environment (Teuton et al. 2009)(Cole et al. 2011). PVC has widely been considered safe and chemically inert (stable), like many plastics, and is used to transport potable drinking water. The concern in this case is the potential risk for chemical additives from plastics to leach to the marine environment with unknown consequences. For example, phthalates are known endocrine-disrupting chemicals and can make up as much as 50% of PVC by weight (Cole et al. 2011). In general, although leachates are known to enter the marine environment, their activity is exceedingly complex to study at relevant concentrations or in the synergistic setting of the marine environment (i.e., multiple chemicals acting together, not just one in isolation as in many laboratory studies) (Rochman 2015).

Although there is an overwhelming abundance of sources of information on the potential environmental impacts of plastic compounds in marine debris [such as that summarized in Rochman (2015)], there is uncertainty as to what impact geoduck aquaculture may have at its given scale. Without further study into the exact polymers used in the plastic products of the geoduck industry and realistic exposure studies on organisms likely to be affected in locations where geoduck is cultured, it is not possible to discuss this potential impact in greater detail. Future research may provide insights on this topic.

The Pacific Coast Shellfish Growers' Association (PCSGA) encourages members to use plastics with a long life span, or those that are reusable or recyclable (PGSGA 2019), which is echoed in their Environmental Policy framework (PCSGA 2001)(PCSGA 2022). PCSGA also provides a contact on its website for a local plant in Tacoma, WA that will recycle aquaculture plastics (PCSGA 2022). Individual companies may have their own codes of practice to address these concerns; for example, the PCSGA and individual companies in Washington and British Columbia conduct their own periodic beach cleanups, and some have supported studies into concerns on microplastics and leachates (pers. comm., E. Ewald, 2016). The industry is also active in researching ways to reduce the use of plastics and promote marine debris education (PCSGA 2015)(PSI 2015a). PCSGA also encourages members to only use gear that can withstand the elements where it is deployed, and that it be retired and properly recycled or disposed of before breaking down in the environment (PCSGA 2019).

Overall, the use of plastics varies by farm location (intertidal vs. subtidal) and grower preferences. There are uncertainties that cannot be resolved with the available data about the potential for plastics to degrade or leach in the marine environment, within the context of their uses in geoduck nursery structures. A precautionary approach is taken for the cumulative impact potential.

Harvest Impacts

During geoduck harvest, high-volume, low-pressure water hoses (known as "stingers" or "wands") are inserted into the sediment to make the area near a geoduck fluid, to ease the removal of the market-sized clam (Straus et al. 2009) (VanBlaricom et al. 2015). The top 1–2 ft of the culture plot are made fluid by this method at the end of the culture cycle (5–7 years from planting), and the duration of the harvest activities may be approximately 3 hours per day for dry harvest or 4 hours per day for wet harvest, for a given example site in a recently published EIS (22.5 acres total) (BLGF Final EIS 2023). The harvest process has the following potential impacts on habitat: reduction in community diversity; sediment composition and transport; turbidity and total suspended solids (TSS); and interaction with eelgrass.

Harvest: Impacts to Community Diversity

The potential impacts of geoduck harvest to community structure range from insignificant to significant but short-lived. Negative responses in the abundance and diversity of infaunal organisms have been demonstrated to varying degrees in the harvest phases of geoduck aquaculture and other cultured bivalve shellfish (Horwith 2013)(Straus et al. 2013)(McDonald et al. 2015)(VanBlaricom et al. 2015). Harvest activities could potentially expose, injure, or kill nontarget organisms, and the mixing of sediments and their accompanying physical and chemical characteristics may impede recruitment of some species after harvest (Dumbauld et al. 2009)(Straus et al. 2013). VanBlaricom et al. (2015) observed reductions in two infaunal species during and after harvest, but concluded that there were only “modest” effects on infaunal community composition, with no significant shifts.

Natural regimes are likely more influential to community composition. VanBlaricom (2015) concluded that high seasonality and variability by site indicated that the prevailing natural disturbance regimes were far more important in driving infaunal community structure variation than harvest activity, a theme identified by several other studies on the topic of shellfish/geoduck aquaculture and intertidal community structure (Dumbauld et al. 2009)(Sauchyn et al. 2013)(Straus et al. 2013)(McDonald et al. 2015).

Any potential impact to community diversity is likely contained within the farm site. VanBlaricom et al. (2015) investigated geoduck harvest effects on resident intertidal benthic community structure on the farm site and up to 50 m away. Though this study had limitations in terms of replication across multiple farm sites due to spatiotemporal variability, the authors concluded that little evidence of “spillover” effects of geoduck harvest activities on infaunal community structure were detected away from the geoduck farm plot for each individual farm site. Liu et al. (2015) found no change to infaunal community structure (as measured via 6.5 cm core sample) on harvested vs. nonharvested subtidal and intertidal plots in the Strait of Georgia, BC.

Many studies have shown that recovery after geoduck and other on-bottom shellfish (i.e., oyster) culture harvest is fairly rapid, but there are some studies in which recovery has taken longer than 4 years, and it appears that site specifics and harvest intensity are, again, important factors (Straus et al. 2013). Zajac and Whitlatch (2003) caution that recovery at the community level (for example, in terms of measures of abundance and diversity) does not mean that population-level characteristics of the species within the community have recovered. Recovery of infaunal assemblages after on-bottom oyster harvest in the studies reviewed by Straus et al.

(2013) was shown to be rapid—on the order of 2 to 7 months, an observation that was also made after wild subtidal geoduck harvest [recovery after 2 months (Goodwin 1979); 9 days to 7 months (Palazzi et al. 2001)]. Rapid recovery from disturbances related to other cultured shellfish in the Northwest (Simenstad and Fresh 1995) and intertidal communities in general (Zajac and Whitlatch 2003) have also been documented. These results suggest that the impacts of harvest activity on community diversity are likely limited to the farm site, with indication of rapid recovery.

<u>Harvest: Change to sediment elevation and composition</u>
As sediment is made fluid and the geoducks are removed, there is a temporary reduction in the elevation of sediment. Price (2011) observed that intertidal geoduck harvest holes refilled and were nearly indistinguishable from surrounding sediment within several days. A recent EIS for a geoduck farm site in Washington describes that geoduck harvest holes likely infill to 95% within a few seconds of harvest and that the sediment elevation returns to preharvest condition within "a few tidal cycles (up to a few days)" (BLGF Final EIS 2023 and sources within).

When sediment is disturbed and left to settle, there is a potential concern that the sediment composition (i.e., the ratio of fine to coarse particles) at the farm site would be altered from repeated harvests over time. At one proposed geoduck farm site in Washington (22.5 acres total), a Final EIS noted that a senior coastal geomorphologist reviewed the potential impact and "found no apparent physical reason why geoduck HARVEST cycles repeated on a sediment body at multi-year intervals would cause a significant change in the fractional sediment concentration of a harvest bed" (BLGF Final EIS 2023). It is important to note that this analysis was specific to the site being evaluated, which has >80% sand-sized particles, though this is likely representative of the composition of many geoduck farm site sediments. During wet harvesting, coarse sediments are estimated to settle within 33 to 66 ft of the harvest hole, and fine sediments within approximately 80 ft of the harvest hole (BLGF Final EIS 2023). Given these estimated dispersion distances (and their direct influence from the site characteristics), it is possible that, among the entire geoduck industry, certain site configurations and environmental conditions allow sediments to settle outside the farm plot. In the case of the proposed geoduck site, an annual accumulation of <0.5 mm of fine sediment was estimated to fall outside the farm site, described as equal to "a layer of one grain of medium sand, which would be indistinguishable to an observer" (BLGF Final EIS 2023 and sources within).

The best available literature to understand the potential impact to sediment composition is published by Liu et al. (2015). The authors examined the impacts of intertidal and subtidal commercial-scale geoduck harvest on sediment composition (such as grain size, percent organics), sediment chemistry (total nitrogen, carbon, sulfides, and redox potential), eelgrass (shoot length, density, and biomass), and infaunal and eelgrass community structure on and away from harvest sites over time. The findings are most accurately described by a direct quotation:

Suspended sediments were increased by harvesting, but generally limited to the footprint of the harvested area, and were not greater than those created by wind/storm conditions. No changes *were observed, however, in any of the measured sediment or infaunal variables on or near the harvested plot or in adjacent eelgrass. In addition, no significant response in eelgrass parameters was observed. This study indicated little effect of commercial geoduck harvesting practices beyond short-lived resuspension of sediment on the two harvested plots.* (Liu et al. 2015)

<u>Harvest: Turbidity and TSS (via sediment resuspension)</u>
Sediments and organic materials are known to be resuspended as a result of shellfish harvest activities in both the intertidal and subtidal (Dumbauld et al. 2009)(Stokesbury et al. 2011, as reviewed in Sauchyn et al. 2013). The resuspension of sediments during harvest raises concern for impact to turbidity and TSS in the environment. In subtidal harvest, coarser sediments settle immediately, but fine sediments may be transported by currents.

The plume generated at typical geoduck harvesting activities at a hypothetical 22.5 acre geoduck plot in Washington is modeled to be about 0.2 acres and to exist for about 150 minutes (BLGF Final EIS 2023). Short and Walton (1992) found that sediment plumes varied in density and range with prevailing current conditions, with attenuation away from the harvest site, and had potential for further resuspension due to subsequent wave action. In weak currents, most sediment settles within 0.3 m of a harvest hole, and virtually all deposition is limited to within 100 m downstream of the harvest site. At higher current speeds, most deposition occurs within 1.5 m downstream of the harvest site, with small quantities of sediment deposited greater than 200 m away from the harvest site (Short and Walton 1992, and as reviewed in Palazzi et al. 2001). Sauchyn et al. (2012) found no significant discharge of fine sediments beyond 5 m from the farm site following intertidal geoduck harvest (the 5 m sample was the most proximal off-farm site sample in this study), observing that it instead settled close to harvest holes on-site. No significant changes in organic carbon content, redox potential, or sulfide content away from the farm site were attributed to geoduck harvest, nor were there any obvious effects on eelgrass.

For turbidity or TSS to cause impact, they would need to be raised significantly above background levels. Modeling at one proposed geoduck farm site finds that the maximum TSS in the vicinity of the site comes from creek discharges, which discharge TSS an estimated five times greater than that from the proposed geoduck harvesting activities (BLGF Final EIS 2023). Of course, this is a site-specific assessment, and there are limitations to broadly applying this finding to all geoduck sites in all locations. High turbidity and TSS can be associated with creek/stream discharges or erosion over land in locations where geoduck culture occurs, and these may be much more significant in affecting the background levels than any geoduck farm activities (BLGF Final EIS 2023). Liu et al. (2015) conclude that sediment resuspension is short-lived. Direct observations concur that the turbidity associated with harvest events is “short-lived and returned to background levels within approximately one hour” (BLGF Final EIS 2023).

The fate of resuspended sediments is highly dependent on the location, currents, and tidal cycle. There is some agreement that geoduck harvest does not increase sedimentation rates above normal regimes in Puget Sound. Short and Walton (1992) note that the transport and fate of suspended sediment plumes is specific to site and harvest practice, but found that geoduck harvest-related sediment transport is relatively localized, short-lived, and without significant impact—findings shared by Sauchyn et al. (2012) and Liu et al. (2015). It also varies spatiotemporally. Palazzi et al. (2001) state that turbidity is a common characteristic of water in Puget Sound and Hood Canal—driven by wave action, river runoff, and algal blooms—and point out that geoduck harvest, unlike other human activities (such as logging and development) does not add any new sediments to the marine environment. Both papers suggest, with several example calculations, that sedimentation rates resulting from liberally intense subtidal geoduck harvest would still fall far below natural sedimentation rates in Puget Sound. Liu et al. (2015) adds that sediment suspension from intertidal and subtidal geoduck harvest falls below what is typically observed during wind and wave events. Similar conclusions have been reached by analysts in the consulting field (Fisher et al. 2008).

There are specific U.S. federal and state regulations about sediment disturbances, and voluntary best management practices are also applied in the geoduck industry. Turbidity associated with geoduck farming and harvest is restricted by the U.S. Army Corps of Engineers (ACOE) pursuant to water quality standards in the Environmental Protection Agency's Clean Water Act Section 401. As stated by the Corps, turbidity plumes must be "normally limited to the immediate vicinity of the disturbance and should dissipate shortly after the activity." Similar language appears in Washington's Shoreline Master Plan (WAC Part III Guidelines 173-26-241—Shoreline uses), written as a requirement for the "[u]se of the best available methods to minimize turbid runoff from the water jets used to harvest geoducks" (WAC 2023). Intertidal geoduck harvest can be restricted by local government to protect forage fish spawn and herring spawn (WDOE 2017) (see also Factor 3.2a). The Pacific Coast Shellfish Growers' Association (PCSGA) instructs member growers to minimize off-site sedimentation. In addition, policy guidelines in Washington, such as the Department of Ecology's Shoreline Master Program, aim to preserve critical ecosystem services by managing for "no net loss" of shoreline ecological functions (WDOE 2017). Most of these limits are not well defined or monitored, but as outlined previously, sediment effluent resulting from geoduck harvest activities is considered by the scientific literature to be of low concern.

Sediment resuspension may be considered a concern to eelgrass beds. But in the context of the multiple layers of regulatory restrictions about siting a minimum buffer distance away from eelgrass beds, the likely low dispersion of fine sediments during harvest (see previous discussion), and the ethereal nature of a turbidity plume that has been modeled at one geoduck farm site (about 150 minutes) (BLGF Final EIS 2023), it seems unlikely that major impacts are happening under these conditions. It appears that careful siting consideration can minimize any potential interaction of farm harvest activities to eelgrass beds, and that this consideration is reflected in the current laws, which authorize permits to new geoduck operations.

The potential suspension of contaminants within sediments disturbed by geoduck harvest is not considered a significant concern because of the robust permitting process. Shellfish growing and harvest areas are directly dependent on sediment and water quality. Both the Washington

Department of Health and Department of Fisheries and Oceans (Canada) classify and monitor shellfish growing areas for water quality, marine biotoxin, and pollution parameters—prohibiting the growing and harvesting of shellfish meant for human consumption in polluted and unsafe areas (WDOH 2023)(DFO 2023d). Also, the geoduck market itself has recently shown sensitivity toward contaminant concerns (arsenic in particular), which was the focus of a brief 2014 ban that China placed on geoduck imports. Washington's DOH monitors geoduck for inorganic arsenic and marine biotoxins, and mandates that local governments map aquatic-contaminated sediments and restrict the development of aquaculture in areas of known sediment contamination (WDOE 2017). The suspension of contaminants related to the harvest of farmed geoduck is therefore considered a low risk.

<u>Harvest in the context of natural disturbance</u>
Geoduck farming takes place in shallow coastal areas, which experience a high frequency of disturbances (e.g., storms, currents, boat wakes) and have shown the ability to recover from these disturbances rapidly. As noted by Dumbauld et al. (2009), West Coast bivalve aquaculture has not been linked to shifts in larger-scale ecological functioning. Similarly, Simenstad and Fresh (1995) argue that disturbances related to shellfish aquaculture in the Pacific Northwest fall within the scale of natural disturbance regimes (see also Dumbauld et al. 2009). In addition, intertidal and nearshore subtidal species inherently tend to be opportunists that tolerate the highly turbid conditions characteristic of these habitats. It has been demonstrated that these species are capable of rapidly recolonizing disturbed seafloor habitats (see Stokesbury et al. 2011).

Researchers such as Liu et al. (2015) note the need for further study, particularly regarding the roles of culture practices, seasonality, disturbance scale, and spatial variability. Dumbauld et. al. (2009) also warn that multiple novel disturbances can exceed a system's resilience, and geoduck farming typically occurs in repeated cycles. But effluent in the form of suspended sediments from geoduck harvest has demonstrated to date only minor and temporary effects (or no effects) to areas outside geoduck farm boundaries.

Factor 3.1—Conclusion and Scoring
Geoduck farm plots are located in two habitat types: coastal intertidal and coastal inshore subtidal, with the former being more common in Washington State, and the latter more common in British Columbia. The potential habitat impacts of geoduck aquaculture are primarily associated with beach preparation and the installation of predator protection devices in the structured phase of intertidal production, the use of predator nets in subtidal production, and various potential impacts associated with the harvest phase in both systems. Presently, the impacts of geoduck aquaculture on marine habitat appear to be minor to moderate, with impacts largely ephemeral, and limited to the farm site. The harvest phase is a clear disturbance to the farm plot, but effects appear to be temporary and limited to the farm plot. Such effects are likely to vary spatiotemporally—including with local disturbance regimes and harvest practices—and strong seasonal effects have been noted as important drivers in community structure. Plastic loss from geoduck farms is considered an infrequent occurrence, with regulations and best management practices aimed at loss prevention in place. Because of

the reliance of the industry on placing plastics in the environment and the remaining uncertainty of their holistic impacts (considering debris, microplastics, leachates, etc.), this gear is considered to have a potential cumulative impact at the waterbody and regional (or greater) scale, and warrants a precautionary approach. Overall, the affected habitats are considered to be maintaining functionality, and the combination of apparent minor to moderate impacts and remaining uncertainty (such as in the cumulative effects of repeated farm cycles, impacts on scales larger than in existing studies, and impacts to certain species) results in a score of 7 of 10 for Factor 3.1—Habitat Conversion and Function.

Factor 3.2—Farm Siting Regulation and Management
Two different regulatory environments are under assessment: the United States and Canada. They are described separately for Factors 3.2a and 3.2b, but because the differences between the two systems are considered insignificant for the purposes of this assessment, Factors 3.2a and 3.2b are scored together for British Columbia and Washington.

Factor 3.2a: Content of habitat management measures

Washington
A suite of federal, state, tribal, and local agencies are involved in issuing aquaculture permits before a farm can be established, expanded, or renewed (Table 2). At the federal level, the U.S. Army Corps of Engineers (ACOE) is a lead agency in permitting, by overseeing its Individual and Nationwide 48 (NWP 48) permits. Permitting requires consultation with the National Oceanic and Atmospheric Administration Fisheries and the U.S. Fish and Wildlife Service, pursuant to the Endangered Species Act, to ensure protection to threatened and endangered species and their habitats (such as some subpopulations of salmonids, bull trout, and seabirds), and to the Magnuson-Stevens Fishery Conservation and Management Act ,to ensure protection of essential fish habitat, such as eelgrass, kelp, and aquaculture structure itself.

Table 2: Agencies involved with geoduck farm permitting in Washington, United States and British Columbia, Canada. Table adapted from (WDOE 2016)(DFO 2023/2024)(DFO 2017b).

Agency	Requirement	Purpose
Washington Department of Agriculture	Identification requirements for any sale or movement of private sector cultured aquatic products	Protect the public from unsafe, or misbranded, or adulterated foods while promoting the private aquaculture sector.
Washington Dept. of Fish and Wildlife (WDFW)	Aquatic Farm Permit and Registration + annual renewal	Authorize commercial farming on private tidelands.
	Disease outbreak reporting	Protect native and important species from pathogens and invasive species.
	Disease controls, importation, and transfer of species. Protection from pathogens and invasive species.	Promote health, productivity and well-being of aquaculture products and wild-stock fisheries.
Washington Dept. of Ecology (WDOE)	Individual 401 Water Quality Certification	Ensure new geoduck aquaculture is consistent with state water quality standards and other aquaculture resource protection requirements.

	General National Pollution Discharge Elimination System (NPDES) Permit	Provide state oversight of pollution discharge into state waters; sets limits to ensure protection of receiving waters.
	State Waste Discharge General Permit	Provide state oversight of pollution discharge into state waters; sets limits to ensure protection of receiving waters.
	Coastal Zone Management Act Consistency	Allow the public and state, local, and Tribal agencies to review federal actions affecting WA's coast.
Each Washington County	Conditional Use Permit following the guidelines of the Washington Shoreline Management Act	Requirements specific to new geoduck farms. Promote cohesive statewide coastal management standards.
Washington Department of Health (WDOH)	Operator's License, Harvest Site Certificate, Export Certificate	Establish minimum performance standards for growing, harvesting, processing, package, storage, and transport of shellfish for human consumption.
Washington Department of Natural Resources	Aquatic Use Permit and Aquatic Lands Lease	Has mandate to provide balance of public benefits for all citizens of the state when administering its responsibilities for state-owned aquatic lands.
United States Army Corps of Engineers (Corps)	Section 10 Rivers and Harbors Act Permit	Preserve navigation of U.S. waters.
	Section 404 Clean Water Act Permit	Regulate discharge of dredged fill material into U.S. waters
National Oceanic and Atmospheric Administration (NOAA) Fisheries	Endangered Species Act Section 7	Consultation for the protection of threatened and endangered species for any permit issued by ACOE.
	Essential Fish Habitat consultation	Protection of habitat essential to maintenance of fish populations.
US Fish and Wildlife Service	Endangered Species Act Section 7	Consultation for the protection of threatened and endangered species for any permit issued by ACOE.
Fisheries Commission (NWIFC)	Corps notification regarding natural and cultural resources	Protection of Tribal cultural and natural resources.
Individual Tribes	Tribal harvest agreement	Protection of Tribal rights to naturally occurring shellfish.

The ACOE is required to take cumulative impacts of permitting activities into consideration under its obligation to consult with the Endangered Species Act and the National Environmental Policy Act, as reflected in its Biological Opinion (ACOE 2016). The ACOE also regulates the discharge of dredge and fill material into waters of the United States through Section 404 of the Clean Water Act. This is required for ground-disturbing activities, such as the placement of nursery pools on tidelands.

ACOE requires a 16-ft buffer distance of any new shellfish operations from existing eelgrass beds, which would prohibit the planting of any geoduck within this buffer zone (ACOE 2021). Mitigation is required in the events of impacts, and such mitigation "in all its forms (avoiding, minimizing, rectifying, reducing, or compensating for resource losses) will be required to the extent necessary to ensure that the individual and cumulative adverse environmental effects are no more than minimal" (ACOE 2021). Pacific herring sometimes attaches eggs to aquaculture structures or vegetation on or nearby such structures. Herring spawn is protected via the use of approved work windows for activities such as harvest and removal of tubes or mesh, to avoid disturbance to herring spawn, or via surveys for herring spawn for work outside of approved work windows. Approved work windows are also used to protect threatened species such as bull trout. The Endangered Species Act consultation, which is required as part of the ACOE approval process, protects the continued existence of threatened or endangered species (ACOE 2021). Geoduck aquaculture poses a limited risk to Critical Habitat for species listed under the Endangered Species Act (USFWS 2009).

Presently, the nationwide permit (ACOE 2021) is under litigation, and the only vehicle ACOE has to permit shellfish aquaculture is by standard individual permit (SIP) or Letter of Permission (LOP) (ACOE 2023). An Electronic Permit Guidebook is readily available online to the public to understand the SIP process and review (found in the ACOE Permit Guidebook Chapter IX: Aquaculture). Because the laws and regulations governing aquaculture, as they pertain to ACOE jurisdiction, are reviewed on an individual case basis, this is considered to be at least as robust as the nationwide permit process.

The Washington Department of Ecology (DOE) oversees the EPA's Clean Water Act Sections 401 and 402, which ensure consistency with state water quality standards, and takes cumulative impacts into consideration. Washington DOE has the authority to require permits for geoduck aquaculture and to take enforceable actions (WDOE 2017). Federal permitting is also subject to state policy consistency requirements pursuant to the Coastal Zone Management Act and provides the opportunity for public comment and transparency.

Geoduck farms may also need a Substantial Development Permit, Conditional Use Permit, State Environmental Program Act review, or other approval by county or municipal governments under the Shoreline Management Act as outlined in the state's Shoreline Management Program Handbook, which is followed by all counties in developing their shoreline management plans (WDOE 2017). The Shoreline Master Plan Handbook includes guidance on determining locations for geoduck aquaculture and directs for minimal alteration of habitat, the use of the best available science, expert consultation, consideration of cumulative impacts, and employing a precautionary approach where information is lacking (WDOE 2017). This guidance also includes direction to identify environmental limits and conditions to protect critical habitats (such as eelgrass and forage fish spawning areas), conduct site-specific baseline surveys, and manage for no net loss of ecological function. Chapter 12 of the Plan Handbook outlines design and siting locations for overwater structures (such as floating nurseries) to limit the impacts to submerged aquatic vegetation (WDOE 2017). There are currently 39 individual county Shoreline Master Plans that have been developed and approved by the state using the described guidance, and all are publicly available on the DOE website. Also, under the State Environmental Policy Act (SEPA), permitting of geoduck farms requires an opportunity for public comment.

Other state agencies involved include the Washington Department of Fish and Wildlife, which manages farm registrations, live-animal transfers, invasive species, and shellfish disease risk management; the Department of Health, which assures that shellfish are grown and harvested in clean waters and sediments; and individual Tribes, which have the opportunity to comment on all Army Corps permits (WDOE 2008)(pers. comm., WDOE 2015).

On tidelands leased from the Washington State Department of Natural Resources (WDNR), farms are subject to WDNR management provisions, such as an Aquatic Use Authorization and a lease for use of public tidelands. A lease is subject to a set of best management practices (BMPs). Site-selection BMPs are directed at avoiding and minimizing the potential impacts of aquaculture operations on aquatic (or terrestrial) resources and the interactions with other users of marine resources (Dewey et al. 2011)(Getchis and Rose 2011)(WDNR 2015), as well as wild geoduck populations (WDNR 2015). WDNR does not currently authorize geoduck culture leases on subtidal state-managed aquatic land (WDOE 2017), but did initiate a pilot program in 2015 that would allow for assessment of the effects of geoduck aquaculture on the nearshore environment. No public information about the pilot is available at the time of this reporting. It should be noted that relatively small volumes of geoduck will be cultivated on WDNR tidelands initially, compared to production occurring on private tidelands, where the BMPs are at the discretion of the grower and tideland owner.

Each individual county in Washington has regulatory authority over the siting of geoduck farms and has mandated Shoreline Management Plans. Part of county authority is the issuing of conditional use permits for geoduck aquaculture. Growers report that this process in their counties has involved preparing permit justification documents (statement of consistency with the County Shoreline Management Plan, cumulative impact statement, public interest statement, and description of how they will not interfere with the normal use of the shoreline), presenting in front of a hearing examiner, and a public comment period, as well as the addition of other county conditions (e.g., providing updated copies of all ACOE permits as they are issued) (pers. comm., Anonymous Industry 2023).

All geoduck aquaculture in Washington presently occurs on private land, and the Pacific Coast Shellfish Growers Association (PCSGA) has developed an Environmental Code of Practice (ECOP) for member shellfish growers. The ECOP is extensive and echoes regulatory requirements, highlights the importance of compliance, and includes additional guidelines such as training employees on minimizing the impact of cultivation work (PCSGA 2019). The PCSGA has 13 members that farm geoduck, and such Codes of Practice are voluntary, with periodic surveys conducted to assess adherence to the ECOP (pers. comm., PSGA,2023). Individual shellfish companies may also have their own BMPs that promote environmental stewardship of farm sites.

A Marine Spatial Plan for Washington’s Pacific Coast was published in 2018 and aims to provide “a baseline of scientific information, a consistent way of evaluating future proposals, and a framework to coordinate decisions around human uses of the sea” and notes geoduck culture as a potential expansion opportunity in the region (Bates et al. 2018).

Counties in Washington, guided by the WA DOE’s Shoreline Master Program, have language in their Shoreline Management Plans to control plastic litter through various means, including equipment marking or litter patrols (WDOE 2017). The ACOE mandates conservation measures for shellfish activities, which require that beaches in the vicinity of geoduck farms be patrolled at least once every 3 months and that records of such patrols be kept; that areas of aquaculture debris accumulation be identified; that mesh are tightly secured to prevent the release of materials; that tubes and nets are marked with identifying labels (ACOE 2016); and that materials used in aquaculture must be free from pollutants in toxic amounts (ACOE 2021). Geoduck aquaculture gear labeling is required by the ACOE (pers. comm., PCSGA 2013).

British Columbia

Fisheries and Oceans Canada (DFO) is the regulatory authority of finfish and shellfish aquaculture. DFO commits to integrated and ecosystem-based management principles, inclusive and transparent processes, and responsible development of the aquaculture industry, and it calls its aquaculture environmental standards "some of the strongest in the world" (DFO 2017a). When reviewing shellfish proposals, DFO consults with First Nations in advance of issuing licenses. DFO has also stated its commitment to developing area-based management of shellfish aquaculture in BC to both preserve the environment and find socially suitable ways to locate shellfish operations where First Nations and local communities are supportive (DFO 2020).

Table 3: Agencies involved with geoduck farm permitting in British Columbia, Canada. Table adapted from (DFO 2023/2024)(DFO 2017b).

Agency	**Requirement**	**Purpose**
Department of Fisheries and Oceans	Fisheries Act	Develop and execute Pacific Aquaculture Regulations; licensing; conditions of license; enforcement; reporting; research.
	Species at Risk Act	Protect species from extinction or extirpation and provide recovery.
	National Aquatic Animal Health Program	Provide screening for aquatic animal health.
	Canadian Environmental Assessment Act	Protect the environment (natural, social, cultural, built, and economic).
Canadian Food Inspection Agency		Establish minimum performance standards for growing, harvesting, processing, package, storage, and transport of shellfish for human consumption
Environment and Climate Change Canada	Shellfish Water Quality Monitoring Program	Monitor water quality of shellfish growing areas pursuant to the Canadian Shellfish Sanitation Program
Transport Canada	Canadian Navigable Waters Protection Act	Maintaining public right of navigation
BC Ministry of Water, Land and Resource Stewardship		Ensure stronger provincial role in management of fisheries and ocean resources
BC Ministry of Environment and Climate Change Strategy		Provide permitting for wastewater, effluent, and discharge authorizations under the Environmental Management Act
BC Ministry of Agriculture and Food	Aquaculture regulation	Role in enforcement, export reporting
BC Ministry of Forests		Issuance and administration of Crown land tenures
First Nations	Aboriginal and treaty rights Foreshore Management adjacent to First Nations Communities and Treaty Settlement Lands	Fisheries protections are in place for First Nations. Regulatory agencies must consult with local First Nations before issuing any aquaculture licenses or leases.

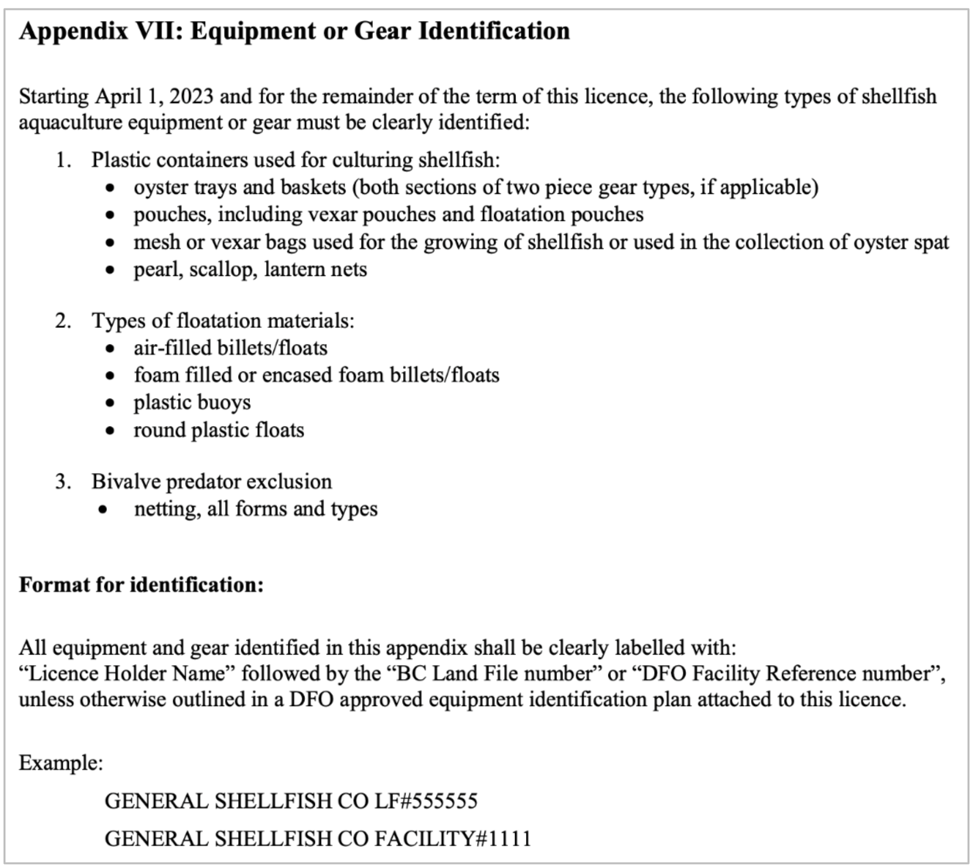
The geoduck aquaculture industry is subject to federal regulations within the Canadian Environmental Assessment Act (1992) and the Navigable Waters Protection Act (1985). Applicable provincial regulations include the Fisheries Act (1996), the Aquaculture Regulation (2002), and the Environmental Management Act (SCBC 2003 C.53).

The primary federal legislation for the regulation of aquaculture is the Fisheries Act Regulations (1995, as amended in 2012), under which the Pacific Aquaculture Regulations (2010) were developed. The Fisheries Act provides broad powers to DFO and guidelines that, among others, prohibit the degradation of water and habitat for fish, require recordkeeping of harvest and cultivation activities, and mandate conducting compliance evaluations for environmental protection. Eelgrass, as a critical fish habitat, is protected by the Fisheries Act, which precludes the future siting of aquaculture (and harvesting of geoduck) in eelgrass beds, protects eelgrass from disturbance and destruction without authorization (Liu et al. 2015), and requires overwater structures to be designed to maximize light penetration for submerged aquatic vegetation. The Fisheries Act also issues protections for herring, sand lance, and squid spawn, as well as intertidal stream channels, rocky reefs, and sponge/coral complexes. All protections and conditions for shellfish aquaculture licensing are transparently available online (DFO 2021). Implementation and day-to-day management of the regulations (such as authorization for use of tidelands for shellfish aquaculture) is supported by the British Columbia Aquaculture Regulatory Program, also established under the Fisheries Act.

DFO has authority under The Oceans Act to lead the development and implementation of integrated management activities in coastal waters. The Integrated Aquaculture Management Plan (DFO 2017b) sets the policy framework for DFO’s management of aquaculture, including its approach to deconflicting wild geoduck harvest and aquaculture. It describes a commitment to using the best available science to guide the industry expansion, and outlines specific hatchery protocols (quarantine protocol, minimum number of broodstock in spawning population, source and replacement rate of broodstock, and prohibition on nonwild or imported broodstock) to limit the potential impacts to the health and genetic diversity of wild geoduck (DFO 2017b). Geoduck aquaculture was previously limited to the Strait of Georgia from 2006 to 2017 (DFO 2017b), but through the multistakeholder committee process of creating the Integrated Geoduck Management framework, and other science-based decision-making [e.g., a carrying capacity assessment for Baynes Sound (Guyondet et al. 2022) that reflects a cumulative approach to the growth of the industry], geoduck aquaculture is now expanding beyond the Strait.

DFO’s licensing conditions for geoduck aquaculture require a written harvest plan to be submitted for approval at least 120 days before the first intended harvest, which includes a summary of husbandry activities at the site, the planned harvest dates, and the amount and size of the individuals to be harvested, and the Harvest Plan must be available for inspection by a Fishery Officer at all times (DFO 2021). Subsequent harvests require 72 hours’ written notice; any notice of an amendment is to be provided to the agency; and strict harvest container tagging requirements apply to all harvests (DFO 2021). The tags must clearly identify the lincense holder name, DFO Facility Reference number, BC Land File number, aquaculture facility location, Pacific Fishery Management Area and Subarea, harvester name, harvest date, the words “Aquaculture” and “Geoduck Clam,” and the tags must “remain in the containers of harvested Geoduck until delivered to a facility licensed by the Canadian Food Inspection Agency with the appropriate shellfish processing permission” (DFO 2021).

As it pertains to the habitat discussion about plastic marine debris, the DFO now requires that, as of April 1, 2023, most shellfish aquaculture equipment must be labeled with the facility identification, which will aid in the enforcement of marine debris permitting conditions; notably, PVC tubes are exempt from this requirement, and DFO staff note that this stems from the lack of consistent PVC tube debris in BC to date, whereas netting must be labeled or tagged (DFO, 2021)(pers. comm., DFO 2023). The shellfish license conditions also require a Seafloor Inspection and Clean-up Protocol with mandatory recordkeeping, which must include an itemized description of what was found, photographs of all items, location coordinates, and the name of each disposal facility the debris was taken to (DFO 2021—Appendix VI) (Figure 6). DFO has also partnered with BCSGA and the Aboriginal Aquaculture Association (AAA) to sponsor collection depots for end-of-life shellfish gear, and to fund the removal of abandoned shellfish gear (DFO 2020).



Appendix VII: Equipment or Gear Identification

Starting April 1, 2023 and for the remainder of the term of this licence, the following types of shellfish aquaculture equipment or gear must be clearly identified:

1. Plastic containers used for culturing shellfish:
   - oyster trays and baskets (both sections of two piece gear types, if applicable)
   - pouches, including vexar pouches and floatation pouches
   - mesh or vexar bags used for the growing of shellfish or used in the collection of oyster spat
   - pearl, scallop, lantern nets
2. Types of floatation materials:
   - air-filled billets/floats
   - foam filled or encased foam billets/floats
   - plastic buoys
   - round plastic floats
3. Bivalve predator exclusion
   - netting, all forms and types

Format for identification:

All equipment and gear identified in this appendix shall be clearly labelled with:
“Licence Holder Name” followed by the “BC Land File number” or “DFO Facility Reference number”, unless otherwise outlined in a DFO approved equipment identification plan attached to this licence.

Example:

GENERAL SHELLFISH CO LF#555555

GENERAL SHELLFISH CO FACILITY#1111

Figure 6: Excerpt from the Canadian Shellfish Aquaculture License requirements for gear identification set forth by the DFO (DFO 2021).

The BC Shellfish Growers Association employs Environmental Codes of Practice to protect marine resources that echo regulatory statements, as well as the importance of compliance (BCSGA 2023). The BCSGA represents 297 shellfish aquaculture facilities and about 60% of the BC shellfish industry by value. Its Shellfish Farm Environmental Plan (SHEP) program aims for net negative debris, and all BCSGA members must have a debris management plan (a 10-page template is available on its website) that outlines the organizational roles and responsibilities to prevent gear loss from the farm into the environment (BCSGA 2023). In addition, the BCSGA ECOP covers gear labeling (mandatory per DFO regulations as of April 1, 2023), bottom surveys, shellfish movements, and species interactions (BCSGA 2023).

Overall, the content of habitat management measures in both British Columbia and Washington is considered to be robust, with area-based, cumulative, and ecosystem-principle-based frameworks within lengthy and extensive permitting systems that appear to be science-based and inclusive of a broad group of stakeholders.

The score for Factor 3.2a is 5 out of 5.

Factor 3.2b: Enforcement of habitat management measures

Washington

The permitting process in Washington is extensive, with as many as 11 federal, state, Tribal, and local agencies involved in the permitting for a single farm—a process that may take years and thousands of dollars (see Table 2, or see WDOE 2017 for permitting requirements). The regulatory and permitting system for geoduck aquaculture in Washington is transparent, and regulatory agencies are easily identified. Government reports, records, leases, and permitting documents are readily available on agency websites or via Freedom of Information Act (FOIA) requests, and standards and rules are clearly laid out in documents such as WDOE's Shoreline Master Plan and accompanying county-level plans.

The ACOE provides transparent and publicly available information on its Permit Decisions and Appeals (published monthly) and Public Notices for Permit Applications to solicit public comments, which are all easily navigable on its website (ACOE 2023b). Details of enforcement activities are also on its website and, though details may be somewhat limited, additional information can be provided by contacting ACOE, which has Aquaculture Leads assigned by district with contact information on its website. The ACOE has been known by the industry to follow up on complaints or potential violations to permitting (pers. comm., Anonymous industry 2015). The ACOE has a general national goal of conducting site visits to 10% of the number of the previous year's permits, which includes shellfish aquaculture. Most site visits have occurred during the grow-out phase of production, with fewer during planting and after harvest (pers. comm., R. Lee 2023). Native American Tribes have the opportunity to review permit applications and policy decisions.

The Washington DOE published a chapter in its Shoreline Management Act (SMA) Guidelines (Chapter 173-26 WAC) specific to enforcement of its policies, which require cooperation with local authorities on ensuring compliance (WAC 2017). Detailed records of DOE enforcement activities (including fines) are available on DOE’s Enforcement webpage (WDOE 2023). Also, records of legal proceedings related to geoduck aquaculture are readily available on applicable municipal websites.

The DOE’s Shoreline Guidelines require counties to monitor eelgrass buffers to ensure that they are adequate to protect eelgrass, but guidance is vague in details in some areas. In a policy review, Ward (2014) called the SMA “clear and cohesive” in its position on commercial aquaculture, balancing “aquaculture as a preferred use of the water area while prohibiting its being located where it would impair ecological functions.” The review praises the “improved structured process for obtaining geoduck harvesting permits” and for “farming requirements” for local project applications, but also criticizes the SMA for not being detailed enough in some of its guidance to local governments and giving “broad latitude” to the economic interests of commercial shellfish farmers. The review concludes that existing laws are in place to protect the ecological functions of Puget Sound, but that policy initiatives promoting the economics of shellfish farming have been in conflict with existing environmental protections (Ward 2014).

The Washington Department of Fish and Wildlife has permitting requirements for shellfish farms and maintains an enforcement division. No public records of enforcement activities were identified for this report. The Department of Health, pursuant to the National Shellfish Sanitation Program, has strict tagging requirements for the harvest and shipment of shellfish, which, although related to consumer health, allow for traceability of harvested geoduck.

Some stakeholders, such as conservation organizations, have challenged geoduck farm permitting and management, and ostensibly serve as watchdogs for the Puget Sound marine environment in some instances. There are two formal public processes, which anyone can use to report habitat concerns, that are outlined in the State Environmental Policy Act (SEPA) and the National Environmental Policy Act (NEPA). A number of cases concerning shellfish aquaculture (including geoduck aquaculture) have gone to court or hearings boards with outcomes that have included the affirmation of counties’ abilities to manage shellfish harvest, forcing compliance with industry-developed Environmental Codes of Practice, removal of aquaculture gear, fines, and denial of permits (WDOE 2017). Hearings boards have previously determined that PCSGA Environmental Codes of Practice are sufficient to manage ecological impacts (Hall et al. 2015). The SMP for aquaculture directs counties to consider the best available science and expert consultation in the ongoing development of their management of shellfish aquaculture in Shoreline Management Programs.

Farms report having authorities from both ACOE and WDOE visit their operations occasionally and working to accommodate these visits with either boat access or landowner approval to reach the farm plots (pers. comm., E. Ewald, Taylor Shellfish 2023). More broadly, any regulatory staff from any agency may reach out to geoduck growers if a formal complaint is filed, and enforcement staff may request to visit sites if they feel the complaint is warranted (pers. comm., E. Ewald, Taylor Shellfish 2023). County staff may investigate farms if complaints are received that provide evidence that permit conditions have been intentionally or inadvertently violated (pers. comm., E. Ewald, Taylor Shellfish 2023).

The number of agencies involved can lead to complications and confusion (Ruddell 2012). In the past, unauthorized geoduck farming has occurred and violations have been documented by Kitsap Sun (2014) (WDOE 2023). Enforcement is specifically limited in its ability to monitor subtidal geoduck farming operations, although diving could be considered in special cases (pers. comm., R. Lee, ACOE 2023); however, this is considered to be a minor concern, given that most geoduck culture in Washington State is intertidal. County-level enforcement is authorized under the Washington DOE's Shoreline Master Program, and all county plans are transparently available on the DOE website (WDOE, 2023). There is clear evidence of some enforcement actions taking place, with evidence of penalties and accountability (WDOE 2023)(WDOE 2017).

<u>British Columbia</u>
The regulatory and permitting system for geoduck aquaculture is transparent, and regulatory agencies are easily identified. A list of all shellfish aquaculture license holders, including the general location of aquaculture sites, species permitted, and other basic information, is publicly available online (DFO 2023a)(DFO 2023b). A list of pending aquaculture applications and decisions is publicly available on the DFO website (DFO 2023c). Government reports and permitting documents are readily available on agency websites and publicly available via the Access to Information Act. The Fisheries Act clearly outlines the authority of DFO and the province to regulate shellfish aquaculture and enforce rules. The Fisheries Act outlines fines, seizures, and punishments for contravening regulations.

Compliance of the geoduck industry in meeting harvest notification timelines is published in aggregate with sea cucumber and sea urchin facilities, which have the same regulation (DFO 2020). Over the years 2017–20, an average of 75% of harvest notifications were received on time, with the remaining fraction submitted late (DFO 2020).

In British Columbia, DFO Conservation and Protection (C&P) Fishery Officers enforce relevant regulations, monitor aquaculture operations, and perform investigations in response to complaints from monitors and the public. The Fishery Officers that enforce aquaculture are located in both Campbell River and Nanaimo, BC (DFO 2017a). The DFO also maintains teams of specialists, such as biologists and resource managers, that verify compliance with regulations and conditions of license by conducting site visits (according to a comprehensive annual schedule) and environmental compliance audits (DFO 2017a). Surveillance is robust, with Fishery Officers regularly patroling by land, water, and air, and conducting inspections to validate license reporting and compliance (DFO 2017a).

The industry reports that DFO planes fly over their farm plots, boats are boarded and inspected one or two times per year, nursery farm rafts are inspected one or two times per year, and DFO is equipped with remote submarine crafts to inspect the seafloor at subtidal farms (pers. comm., Anonymous Industry 2023). The industry also points out that, because their harvest plans are submitted 72 hrs before work and clearly state the area where they will be working, DFO has all the information to inspect the process at will at any time.

Penalties are in place, with the Fishery Act allowing a maximum penalty of "$100,000 and/or 2 years in jail for an indictable conviction" (DFO 2020). There are publicly available data to describe the content and extent of recent enforcement actions relating to shellfish aquaculture, though this is not specific to geoduck aquaculture. For all shellfish aquaculture, the DFO enforcement effort has been targeting debris management and product traceability. Fishery Officer investigations of shellfish operations in 2020 were associated with "(1) poor tagging practices and record keeping, (2) unlawful transfers, harvests and wet storage, (3) annual reporting requirements, and (4) habitat related violations. Approximately half of investigations resulted in warnings, and one conviction was achieved. Several significant investigations were complex and will remain ongoing past 2020" (DFO 2020). Noncompliance rates were estimated to be about 15% in 2020 for all shellfish industry, not only geoduck (DFO 2020). The enforcement actions and outcomes are also published in public reports, with convictions planned to be published in future versions (DFO 2020).

The Integrated Geoduck Management Framework emphasizes the importance of the traceability of cultured geoduck product to ensure that all product entering the market has been produced according to regulations aimed at sustainability, and the DFO has developed a monitoring program to support this (DFO 2017b). BC shellfish enforcement infrastructure has been well thought-out and appears to function effectively to the current scale of the industry.

Factor 3.2b: Summary

Enforcement organizations are identifiable and contactable in both Washington and British Columbia. Some evidence of past noncompliance has occurred in Washington, but so has enforcement, and details of enforcement actions are reported by both DOE and ACOE. Washington has recently updated its shellfish aquaculture management to include county-level regulatory authority in addition to the existing state and federal regulations. Washington has a transparent and evolving approach to geoduck aquaculture management, with multiple layers of oversight, a concern for cumulative impacts, and a commitment to the best available science.

Canada's industry is comparably small; however, government-sponsored study of the geoduck industry over previous decades has recently led to the opening of geoduck aquaculture beyond the Strait of Georgia—a change that comes after a highly precautionary approach to growth and reflects the DFO's knowledge that the industry can expand in an environmentally sustainable way. Canada has made information on its enforcement transparent and accessible, with summary reports readily available online. Regulatory details are available for all aspects of geoduck culture in BC, which reflects a commitment to cumulative impacts, ecosystem-based management, and the use of the best available science. The management and enforcement infrastructure for BC is described in detail in public documents, including the Integrated Management of Shellfish Aquaculture Plan (2017a), the Integrated Geoduck Management Framework (2017b), and the shellfish license regulatory language (DFO 2021). BC regulations are echoed in a representative industry association that encourages best management practices to its membership (representing 85% of the shellfish industry by value) that are in alignment or go above and beyond regulatory requirements (i.e., net negative marine debris). Importantly, some habitat impacts can be effectively managed by regulation, such as those to eelgrass, for which both British Columbia and Washington have clear protections.

The only limitation to the score is the uncertainty in the adequacy of enforcement to the entire scale of the industry and its ability to adequately ensure sustainable growth without degrading habitat functionality. The score for Factor 3.2b—Enforcement of habitat management measures is 4 out of 5 for being effective, with some limitations.

Overall, management and enforcement are considered robust, with minor limitations to the estimated enforcement capacity to ensure sustainable growth. The score for Factor 3.2b is 4 out of 5. When combined with the Factor 3.2a score of 5 out of 5, the final Factor 3.2 score is 8 out of 10.

Conclusions and Final Score

The impacts of geoduck aquaculture on marine habitat appear to be minor to moderate, with impacts largely ephemeral, and limited to the farm site. Habitat on geoduck farms appears to be maintaining functionality, but uncertainty remains, as noted by nearly all the authors cited in this section. The combination of the nature of apparent effects and remaining uncertainty (such as in the cumulative effects of repeated farm cycles and the impacts of scales larger than in existing studies) factor into the score of 7 of 10 for moderate habitat impacts for Factor 3.1.

There are limitations in management and enforcement in both British Columbia and Washington, but both jurisdictions have worked to strengthen their infrastructure, have supported scientific understanding, and have shown evidence of enforcement. The permitting process is extensive and transparent, and it reflects robust management of both regions. Overall, management and enforcement are considered robust, with minor limitations to enforcement. Factor 3.2 receives a score of 8 out of 10. Factors 3.1 and 3.2 combine to give a final Criterion 3—Habitat score of 7.3 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)	**10**	
Critical?	NO	**GREEN**

Brief Summary

Chemicals of high concern such as antimicrobials, herbicides, or pesticides are not used at any point during the farming of geoduck (hatchery or grow-out). For a small fraction of the production cycle, government-approved cleaning chemicals are used in the hatchery setting and may be discharged in diluted and/or degraded or neutralized form to the marine environment. There is no evidence of significant environmental impacts from this type of chemical use. Overall, with no evidence of significant chemical use, and a demonstrably low need for chemical use, the final numerical score for Criterion 4—Chemical Use is 10 out of 10.

Justification of Rating

Pesticide Use

Both intertidal and subtidal geoduck farms have never and currently do not utilize any chemicals for pest control (Dewey et al. 2011)(pers. comm., Anonymous industry representative 2013)(pers. comm., PCSGA 2023)(pers. comm., E. Ewald, Taylor Shellfish 2023)(pers. comm., Jim Parsons, Jamestown Seafood, A Jamestown S'Klallam Tribal Enterprise 2023)(pers. comm., Anonymous Industry 2023). Predator exclusion devices and manual labor are used to prevent and remove predators and fouling from gear as necessary, obviating the need for pesticides.

Antimicrobials

Antimicrobials are not used in the hatchery or during grow-out phases of geoduck clam farming (pers. comm., E. Ewald, Taylor Shellfish 2023)(BCSGA 2023)(pers. comm., Jim Parsons, Jamestown Seafood, A Jamestown S'Klallam Tribal Enterprise 2023)(pers. comm., Anonymous industry representative 2013)(pers. comm., Anonymous industry 2015)(pers. comm., Anonymous Industry 2023).

Cleaning chemicals in the hatchery

Chemicals are used to clean hatchery equipment and surfaces. Some of the cleaning substances that may be used are dilute hypochlorite (bleach) and other chlorine-based solutions, as well as Vortexx (a common peroxide-based sanitizer) and acetic acid (pers. comm., E. Ewald, Taylor Shellfish 2023). Sodium hypochlorite is approved for use in food processing and disinfection of agriculture produce surfaces (NIH PubChem 2023a); Vortexx is a common sanitizer for food processing and disinfectant in agriculture applications as well as hospitals (US EPA 2001); and acetic acid is used as a food additive for human consumption and a disinfectant (NIH PubChem 2023b).

Such cleaning solutions are used in dilution and diluted further through subsequent rinsing. Water used in combination with these solutions typically goes into floor drains where it is captured and contained, then neutralized before being discharged to the nearby marine environment (pers. comm., B. Blake 2013)(pers. comm., Anonymous industry 2013)(pers. comm., Anonymous industry 2015). This water is likely further diluted by additional water outflowing from the hatchery, which may be as high as 27.3 liters/second or nearly 2.4 million liters/day in one large Washington hatchery (Rensel 2013). Alternately, chlorine-based cleaning solutions may be left to dry on tanks and equipment (a common practice in aquaculture settings), which provides beneficial desiccation (another element of disinfection) and allows the chlorine to degrade, thereby limiting (via desiccation) any potential discharge. Hatcheries are typically co-located at or near farm sites, and there is clear incentive to maintain water quality of the receiving waters.

Similar chemicals may also be used to sterilize and then neutralize seawater that is used for batch cultures of microalgae, though there are effective bag culture methods that are preferrable to some hatcheries that do not require this (pers. comm., Anonymous Industry 2023). Any use of chlorine to sterilize seawater for batch microalgae cultures absolutely must be fully neutralized with sodium thiosulfate, otherwise the water would not allow microalgae to grow. Thus, hatcheries are exceptionally careful about neutralizing chlorine in batch cultures. Water used in geoduck seed culture tanks is not chemically treated in any way, with mechanical and UV filtration being the primary water sterilization methods in this case (pers. comm., Anonymous Industry 2023).

The U.S. Environmental Protection Agency regulates point-source water discharge for pollution under its National Pollutant Discharge Elimination System (NPDES) Program, pursuant to the Clean Water Act (CWA), including effluents related to concentrated aquatic animal production (CAAP) facilities, such as fish hatcheries. After review in 2003–04, the EPA determined that molluscan shellfish hatchery and nursery systems produce a relatively low total animal biomass and minimal pollutant discharges and exempted these facilities from NPDES regulation (US EPA 2004). As a result of this exemption, no monitoring data of hatchery outflows are available because data were not required by federal permitting (pers. comm., E. Ewald, Taylor Shellfish

2023). Although there is grey literature that reports measurements of the outflow composition from one large Washington shellfish hatchery (Rensel Associates 2013), which found no significant changes in parameters related to nutrient composition or pH, the study did not test for chemical effluents and was limited in duration. A recent court case claimed that there was chlorine discharge from a shellfish hatchery in Washington that caused an NPDES permit to be required, despite WDOE providing confirmation that it did not deem an NPDES permit necessary for the facility (US Court of Appeals Ninth Circuit No. 16-35957)(CaseText 2022). Permit applications are currently being developed and reviewed by WA DOE. Site-specific monitoring and reporting requirements will be outlined as part of these permitted facilities, and will be available for public review once finalized. There are currently no environmental monitoring datasets published during, or since, the case that could be considered here (Olympic Forest Coalition v. Coast Seafoods 2016), so this does not affect scoring.

The shellfish aquaculture industry is a major proponent for monitoring and water quality improvement, and geoduck seed are particularly sensitive to water quality (pers. comm., C. Eardley, WDFW 2023), further demonstrating the imperative for best practices to maintain water quality. Shellfish hatcheries are generally located in areas of fairly pristine water quality, with shellfish grow-out commonly occurring on beaches in proximity to hatcheries. The Washington Department of Fish and Wildlife reports no known significant environmental effects of hatchery discharge in WA (pers. comm., C. Eardley, WDFW 2023).

In British Columbia, DFO licenses hatcheries, and waste discharge authorizations are the responsibility of the BC Ministry of Environment and Climate Change Strategy (BCME) through the comprehensive Environmental Management Act (EMA) (Environmental Management Act [SBC 2003] Chapter 53), which outlines permitting, enforcement, and penalties for waste discharge. BCME is the relevant authority to apply for discharge permits from land-based and marine aquaculture facilities. In research for the prior report, it was found that shellfish hatcheries generally had not required discharge permits because of the perceived minimal levels of pollutant discharge (VIU 2008)(pers. comm., B. Kingzett 2015)(pers. comm., C. Pearce, DFO 2016). But when inquiring with the BC Ministry of Agriculture and Food about what discharge permits are required for a shellfish hatchery in BC in 2023, the agency provided direction to its waste discharge authorization application and suggested that it would follow the complex process framework, which involves multiple meetings with provincial ministry staff and the sharing of various technical information to inform the permit decision-making (pers. comm., BCMA 2023)(BCMA 2023b). Thus, it appears that discharge permitting is required for shellfish hatcheries in BC. Two hatcheries in BC were contacted for this assessment, but neither was able to provide information. DFO records of access licenses, which are issued for geoduck broodstock or Pacific oyster spat collection, only numbered an average of approximately nine licenses annually over 2016–20 for both species in aggregate (DFO 2020), which is a relatively small number of licenses that reflect a likely small number of hatcheries spawning geoduck in BC; DFO noted that many facilities are using natural set on marine facilities, as approved in the shellfish conditions of license, and thus do not require access licenses (pers. comm., DFO 2023).

In general, shellfish hatcheries produce a small total biomass of shellfish (juvenile "seed"), have an exceptionally low use of chemicals (including zero use of antibiotics, meaning no concern of antibiotic resistance whatsoever), and their discharges are considered minor by regulators, which have exempted hatcheries from discharge permits. Geoduck is typically one of many species produced in a given shellfish hatchery, of which there are a total of 7 licensed hatcheries in Washington (5 current and 2 in process of annual renewal) and 13 licensed (though not all active) in British Columbia (pers. comm., C. Eardley, WDFW 2023)(DFO 2023b), demonstrating a quite low number of facilities to which this discussion pertains.

Conclusions and Final Score

Chemicals of high concern such as antimicrobials, herbicides, or pesticides are not used at any point during the farming of geoduck (hatchery or grow-out). For a small fraction of the production cycle, government-approved cleaning chemicals are used in the hatchery setting and may be discharged in diluted and/or degraded or neutralized form to the marine environment. There is no evidence of significant environmental impacts from this type of chemical use. Overall, with no evidence of significant chemical use, and a demonstrably low need for chemical use, the final numerical score for Criterion 4—Chemical Use is 10 out of 10.

Criterion 5: Feed

Impact, unit of sustainability and principle

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

Criterion 5 Summary

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

Brief Summary

Geoduck is a filter feeder and is not provided any external feed. Therefore, the final score for Criterion 5—Feed is 10 out of 10.

Justification of Rating

Only small volumes of cultivated microalgae are required for the hatchery phase of geoduck culture, and no external feed is provided during grow-out. No fishmeal, fish oil, or terrestrial animal or plant products are consumed by the industry.

Conclusions and Final Score

Geoduck is a filter feeder and is not provided any external feed. Therefore, the final score for Criterion 5—Feed is 10 out of 10.

Criterion 6: Escapes

Impact, unit of sustainability and principle

- Impact: competition, genetic loss, predation, habitat damage, spawning disruption, and other impacts on wild fish and ecosystems resulting from the escape of native, non-native and/or genetically distinct fish or other unintended species from aquaculture operations
- Sustainability unit: affected ecosystems and/or associated wild populations.
- Principle: preventing population-level impacts to wild species or other ecosystem-level impacts from farm escapes.

Criterion 6 Summary

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

Brief Summary

Geoduck is a sessile animal, so it cannot escape directly; however, farmed geoduck reaches reproductive age and has been observed spawning in the natural environment during grow-out. There is no technology in place (e.g., sterilization techniques) to prevent escaped gametes or larvae from entering the environment and interacting with wild conspecifics. As a highly fecund species, this is considered a high escape risk, so Factor 6.1 Escape Risk scores 0 out of 10. Geoduck populations are largely panmictic at the waterbody scale, and there is a general acceptance that there is a homogenous population of Pacific geoduck across its native range. But there is a phenomenon of microgeographical (patchy) genetic variation among wild populations and there is uncertainty of the potential impacts that farmed geoduck genetics may have at this scale. Only wild broodstock are used (i.e., all farmed offspring are first generation), and regulatory measures and best management practices are in place to maximize the genetic diversity of farmed geoduck seed and to maintain wild-type genetics as closely as possible. There is inherent modification of normal selective pressures during the capture and conditioning of broodstock and the hatchery-rearing environment that cannot be removed from the production cycle—the potential impacts of which are not well understood on geoduck seed genetics, though they likely result in increased genetic variability retained in the hatchery seed cohort, relative to wild seed, given the more relaxed selective pressures in a hatchery environment. As a native species with high genetic similarity to wild conspecifics (e.g., one generation domesticated), the score for Factor 6.2 is 8 out of 10 for a low to moderate risk. Factors 6.1 and 6.2 combine to give a final numerical score of 4 out of 10 for Criterion 6—Escapes.

Justification of Rating

Factor 6.1: Escape Risk

Because geoduck is a sessile animal, there is no direct risk of escape from geoduck farms, but geoduck is cultured in the natural environment without the use of sterility measures that would safeguard against reproductive (egg/fry/juvenile) escapes from planted stock. Geoduck reaches sexual maturity within the timespan of an average 5-year farm cycle [a cycle ranges between 4 and 7 years (pers. comm., E. Ewald, Taylor Shellfish April 2023)]. It is noted by the industry that spawning events of planted geoduck are uncommon (pers. comm., E. Ewald, Taylor Shellfish April 2023). Similarly, in BC, geoduck has been observed spawning before harvest at ages 8–10 (note that no spawn settling has been observed; just gamete release) (pers. comm., Anonymous Industry 2023). In the literature, Vadopalas et al. (2015) and Hand and Marcus (2004) conclude that spawning of farmed geoduck has been shown, given gonad histological section analysis.

Geoduck is a broadcast spawner, releasing sperm and eggs synchronously to fertilize in the water column. Spawning occurs from about January to July (Goodwin and Pease 1989), and a female may release up to 40 million eggs over several spawning sessions each season (Beattie 1992). Fertilized eggs develop and graduate to a pelagic larval period that lasts 16 to 47 days. During this time, geoduck larvae move according to a combination of both passive (drift) and active strategies and may disperse great distances from their natal locations. Geoduck larvae then settle to the substrate, where they begin burial and growth after an extended period of pedal-palp feeding on the benthos.

Geoduck reaches 50% maturation by year 2 and widespread maturation by year 3 (Campbell and Ming 2003)(Vadopalas et al. 2015). Males mature sooner and at a smaller size than females, and male-biased sex ratios of cultured geoduck ages 2–5 years suggest that geoduck has protandric dioecy (first develops as male and later transitions to female), because sex ratios in wild populations are found to be 1:1 (Vadopalas et al. 2015). This maturation time potentially provides years of spawning opportunity for farmed geoduck before harvest. Geoduck farming often occurs near wild aggregations, and reproduction by wild and farmed geoducks has also been shown to be synchronous (Vadopalas et al. 2015). Further, the high stocking density of farmed geoduck suggests a higher likelihood of reproductive success compared to wild populations (Vadopalas 2015).

Importantly, Vadopalas (2015) points out that farmed geoduck has a significantly shorter reproductive lifespan, because it is harvested after about 5 years (in Washington), compared to the average 30-year reproductive lifetime of a wild geoduck. Although there may be some geoduck unharvested because of difficulty locating the animals when their siphons are retracted, growers keep internal planting and harvest records to manage recapture, and they expect that if an animal is not harvested or lost to mortality or predation, it would likely be harvested in a subsequent season (pers. comm., E. Ewald, Taylor Shellfish 2023). Also, the average fecundity of 3- to 5-year-old farmed geoducks was estimated to be only 25% of that of their wild mixed-age counterparts, using gonadal weight as a proxy, which suggests their reduced reproductive success in comparison (Vadopalas et al. 2015). Farmed geoduck grown in BC potentially has a longer reproductive lifespan because it may take up to 10 years to reach market size. Despite the reduced fecundity and shortened breeding period of farmed geoduck (because it is harvested relatively early in its life span), which likely limits its reproductive success compared to wild counterparts, there is still a risk for farmed genetics to enter wild populations.

Although best management practices are in place, and regulation in both British Columbia and Washington is generally guided by the best available science, geoduck aquaculture occurs in an open system, and there is evidence of geoduck spawning before harvest. Thus, the risk of escapes is considered moderate to high. The score for Factor 6.1 is 0 out of 10 for the high risk of escape.

Factor 6.2: Competitive and Genetic Interactions

Location of farms

Farm plots co-occur in proximity to wild geoduck populations. Thus, there is concern that genetic introgression from farmed geoducks to wild conspecifics may be occurring (Straus et al. 2015), and that such introgression may threaten adaptations of the wild populations or reduce genetic variation, which could reduce the resilience of wild populations to perturbations such as disease or environmental stressors (as reviewed in Straus et al. 2013 and Straus et al. 2015).

Characteristics of farmed stock

Native, wild broodstock are collected annually and used to spawn first-generation progeny in onshore hatcheries, which are then planted in the wild environment for grow-out. Broodstock are not permitted to be selectively bred by the regulations of both WDFW in Washington and the DFO in British Columbia.

Ecological risk of escapes

As established in Factor 6.1, escapees in the form of either gametes or larvae are quite likely entering the environment (even if spawning events are uncommonly observed). Vadopalas et al. (2015) summarize two potential pathways for genetic interaction of farmed geoduck with wild geoduck: 1) synchronous spawning between farmed populations in close proximity to wild conspecifics that results in intermixing; and 2) successfully settled planktonic larvae from farmed geoduck populations settling, maturing, and potentially propagating with wild geoduck. Geoduck eggs are suggested to be viable for an estimated 6 hours, and there is a high likelihood of fertilization if there is synchronous spawning in high-density groups like that of farmed geoduck plots (Feldman et al., 2004 and unpublished data from Vadopalas and Davis cited within).

The primary genetic concern is that cultured geoduck may contribute gametes/larvae to the environment that are significantly different (e.g., more related, containing less genetic diversity) than wild geoduck. If so, this has the potential to decrease the diversity within or between wild populations in a manner that may reduce the fitness of wild geoduck. This is a concern because sustaining high genetic diversity is important for wild geoduck to maintain resilience against selective forces (Straus et al. 2013).

Because Pacific geoduck aquaculture co-occurs with wild conspecifics, the fate of their gametes/larvae are expected to be the same as that of wild geoduck, which is a widespread mixing process across its native range. As reviewed by Straus et al. (2013), research generally points to regional-scale (50–300 km) and large-scale (hundreds to thousands of km) panmixia, or homogenous population structure throughout Puget Sound and the Straits of Juan de Fuca and Georgia, for example. Vadopalas et al. (2004) observed general panmixia among Puget Sound geoducks and between Puget Sound and Alaska geoducks, and Miller et al. (2006) noted panmixia at geographical scales of 50–300 km. The panmixia hypothesis is also supported by Suárez-Moo et al. (2016), which concluded large-scale population connectivity (thousands of km and a large portion of the species' range) between Canada, the United States, and Mexico. This type of panmixia is often explained by the geoduck having a relatively long larval phase of 47 days at 14 °C before settling (Goodwin et al. 1979), which would allow long transport distances, as well as its high fecundity, long life span, overlapping generations, and quite high genetic diversity within geoduck populations that may facilitate widespread genetic mixing (Feldman et al. 2004)(pers. comm., B. Vadopalas, UW 2023).

There is another characteristic of geoduck population structure that is potentially highly complex and consequential to the discussion of genetic risk. Geoduck dispersal can result in a phenomenon described in the literature as a patchy settlement of genetically related individuals (Vadopalas et al. 2012). Essentially two things that seemingly contradict each other are true: there is evidence of widespread homogeneity across the northeast Pacific, and there is evidence of patchy settlements of more closely related individuals.

Vadopalas et al. (2004) tested microsatellites and allozymes among geoduck individuals (n = 1,645) collected from 17 sites covering the 5 subbasins of Puget Sound, the Strait of Juan de Fuca, and the Georgia Strait, and found that only 1 site had genetic differentiation from the others (Freshwater Bay in the Strait of Juan de Fuca). Among the other 16 sites, there was no evidence of geographically distinct population structure.

The discovery of highly related (likely full sibling) wild geoducks in close proximity at 35 m depth supports the theory that geoduck larvae may codisperse (Vadopalas et al. 2012). Geoduck are also known to form larval clusters via their byssal threads and mucus of about 100 individuals, which has been observed in static flow conditions (unpublished data by Vadopalas and Davis within Vadopalas et al. 2012). Limited genetic exchange between areas with less connectivity may demonstrate genetic variation, such as the findings of Miller et al. (2006), which note a pattern of significant genetic isolation by distance on the east vs. west coasts of Vancouver Island. Microgeographic variation among geoduck populations has been found in Washington State (Vadopalas et al. 2004)(Vadopalas et al. 2012) and Baja California, Mexico (Suárez-Moo et al. 2013), and geographic variation in morphometry and life history traits on the scale between Washington to Mexico has also been documented (Wood et al. 2018). Although genetic variation has been found on microgeographical scales, this heterogeneous settlement is poorly understood, and it is generally accepted that there is broad enough larval dispersal to support genetic homogeneity of geoduck genetics over larger distances (Vadopalas et al. 2012).

Straus et al. (2013) summarizes the state of knowledge on Pacific geoduck population structure as needing further understanding into the adaptive differentiation (response to natural selection at smaller geographical scales) among wild geoduck aggregations, which the author states is important for determining the consequences of introgression from farmed geoduck stocks to wild stocks. Further, Vadopalas et al. (2004) and Vadopalas et al. (2012) indicate that some uncertainty remains in understanding population dynamics of the species—including in explaining observed microgeographical genetic heterogeneity (differentiation at small geographical scales).

Genetic testing has been done on farmed geoduck to better understand genetic risk. Straus et al. (2015) found that farmed geoduck exhibited lower genetic diversity than its wild counterparts. Similar results were in a Straus (2010) Ph.D. dissertation. In Straus et al. (2015), farmed geoduck year-class samples were found to originate from an average of 57 effective breeders (i.e., the size of the broodstock spawning group that parented them) compared with an estimated 120 effective breeders for wild geoduck genetic samples. Reductions in allelic richness and the effective number of breeders, as well as in greater relatedness of farmed vs. wild geoduck populations, pointed to the potential genetic consequences of limited numbers of broodstock being used in hatchery production at that time in the farms that were sampled. The authors conclude with the suggestion for geoduck hatcheries to adopt partial factorial mating schemes to increase genetic diversity, or adopt sterilization techniques (Straus et al. 2015). The study also notes that, although farmed individuals were more related than wild individuals, the mean relatedness of geoduck year-class individuals was lower than the averages generally reported for cultured shellfish, and that the geoduck hatchery successfully husbanded seed from a greater variety of families than is typical of other shellfish culture methods (Straus et al. 2015), demonstrating the effort of the industry to use precautionary spawning protocols before required by regulation. The industry has responded to this research by adopting partial factorial mating schemes, as described. The potential genetic differences between cultured geoduck seed and wild conspecifics are related to capture and conditioning, as well as selection pressures of the hatchery environment (Vadopalas and Davis 2004)(Straus et al. 2008).

To minimize the risk to wild populations, it is critical that the genetic composition of farm seed be as close to wild-type genetics as possible. Although wild-captured broodstock are required in both Washington and British Columbia, additional husbandry practices are necessary to maximize the genetic diversity of seed, and government regulations or industry codes of practice are in place to further minimize genetic risk. A series of recommendations made by Straus et al. (2015) and Vadopalas et al. (2015) provide geoduck spawning practices to minimize genetic risk to wild geoducks, including:

1. Use of wild broodstock only.
2. Maximize the effective number of breeders used in hatchery seed production.

3. Avoid recycling broodstock from year to year and rotate broodstock as much as possible.
4. Utilize broodstock of local provenance.
5. Utilize maturation control (triploidy and tetraploidy).

In Washington, wild-sourced geoduck broodstock regulations are in place to ensure that only first-generation progeny are seeded on farm plots. Washington geoduck operators must apply for a shellfish transfer permit that indicates the source of the animals being moved into and out of the hatchery, as well as destinations for animals moved out of the hatchery (pers. comm., C. Eardley, WDFW 2023). Imported geoduck seed (BC is the only allowable import origin) must be produced from wild, WA-sourced geoduck broodstock, and proof (fish tickets, import records, local regulatory attestation of facility conditions) must be provided as part of the import permitting process. The WDFW compliance team (a total of four people) is quite active inspecting shellfish aquaculture facilities statewide, and has adequate resources to visit every hatchery in the state during 2023 to conduct updated inspections, as well as to visit nurseries and other related aquaculture facilities (pers. comm., C. Eardley, WDFW 2023).

Beyond the requirement for broodstock to be collected from within the state, Washington does not currently have government regulations to guide broodstock spawning protocols to maximize genetic diversity. But WDFW has conducted workshops, research projects, and retained advisors in order to prepare requirements for the hatchery production of all native species, to protect genetic resources as a precautionary approach (pers. comm., C. Eardley, WDFW 2023). There is a voluntary “local provenance” guideline between North Puget Sound and South Puget Sound growers; WDFW requires imported seed to be from broodstock collected near where most geoduck seed will be out-planted within WA; and the agency operates under the assumptions of high genetic connectivity of geoducks within Puget Sound (pers. comm., C. Eardley, WDFW 2023).

The industry in WA does demonstrate the use of best management practices to minimize the genetic risk to wild geoduck. For example, PCSGA (representing 13 geoduck growers in Washington State) recommends that their members keep broodstock from different growing areas separated in the hatchery when working with genetically isolated stocks, and to stay aware of and implement the best available science for maintaining the genetic integrity of the natural populations of shellfish in farmed areas (PCSGA 2019). Geoduck operators in Washington have also actively participated in published research to evaluate their hatchery stock genetics and generate recommendations for minimizing genetic risk (Straus et al. 2015)(pers. comm., E. Ewald, Taylor Shellfish April 2023), demonstrating proactive commitment to science-based management of genetic risk.

A large geoduck operator in Washington reports using only local wild broodstock collected from Puget Sound, maximizing the number of breeders in hatchery production, and rotating broodstock annually (pers. comm., E. Ewald, Taylor Shellfish April 2023). To maximize the genetic diversity of geoduck seed, they report adopting a partial factorial spawn design (a direct response to a finding of the Straus et al. 2015 study), which eliminates the potential for sperm competition (i.e., where one male can fertilize a majority of eggs produced in a spawning event). To do this, they report the following methods:

During a commercial spawn, the males and females are spawned separately with gametes from each individual kept separate. Once all individuals have finished spawning, the eggs from each female are counted separately then pooled in equal number if possible (to ensure an equal contribution for each female used). This pool of eggs is then divided into groups, one for each male collected, and fertilized by the sperm collected from one individual male. This design eliminates the potential for sperm competition (i.e., each male gets the opportunity to contribute and fertilize an equal amount of eggs). After about 30 minutes (to ensure that all the eggs from each pool are fertilized), the pools of eggs are combined and raised in the hatchery larvae tanks (pers. comm., E. Ewald, Taylor Shellfish April 2023).

Also, the company reports using the following broodstock collection practices to further maximize genetic diversity:

Only wild individuals are collected, and all geoduck harvested are used as broodstock, reducing the impact [that] size and or shape selection could have on genetic diversity. The total number of broodstock used varies, but in general 4 to 5 groups of broodstock are delivered to the hatchery from December to July, for a total of about 500 to 600 individuals. In addition, broodstock are collected from the different geographical regions where our geoducks are grown. Taylor's three main growing regions are South Puget Sound, Hood Canal, and North Puget Sound (Discovery Bay). The broodstock collected from each region are kept and conditioned in separate tanks. Individual batches of larvae and seed are labeled according to broodstock region and grown separately (often at different times of the year). These groups are then planted in the same geographical regions where their broodstock originated. Although this self-imposed regulation is followed most of the time, there are occasional isolated cases where seed from one region needs to be planted in another, but this is rare (pers. comm., E. Ewald, Taylor Shellfish April 2023).

Smaller hatcheries also report abiding by the recommendations to use only wild, local broodstock that are rotated annually, and using 2 to 6 groups of breeders each year, ranging between 20 and 100 animals per spawning group, depending on the operation (pers. comm., Anonymous Industry 2023).

WDFW requires that geoduck seed produced out-of-state be produced from Washington-sourced broodstock, as stipulated in the Washington Shellfish Import requirements: "Production of species native to Washington (such as geoduck) must utilize 100% Washington-sourced wild broodstock which have been previously approved by WDFW. Documentation (such as purchase receipts, fish receiving tickets, or customs documentation) will be required" (WDFW 2021).

Although there is no regulated genetic testing program for geoduck seed (pers. comm., C. Eardley, WDFW 2023), research in cooperation with industry demonstrates that BMPs are being used. Straus et al. (2015) noted that the geoducks used in their study “must have been the result of large number of broodstock used in the hatchery, contrasting with the common practices found in other cultured molluscan shellfish.” But there was variation among year-classes—indicating encouraging, if inconsistent, signs that recommendations were effective.

Overall, Washington appears to be largely operating according to the best available science, and abiding by four of the five recommendations for minimizing risk according to Straus et al. (2015) and Vadopalas et al. (2015). Sterilization practices (i.e., triploidy) would be a significant improvement beyond the practices currently in place to minimize genetic risk. WDFW has supported and continues to be supportive of sterility research (pers. comm., C. Eardley, WDFW 2023).

In British Columbia, geoduck broodstock collection happens under strict Geoduck Brood Stock and Hatchery Protocol and Hatchery Licence conditions defined in the Integrated Management Framework that are designed to limit impacts on the “health and diversity of wild geoduck populations” (DFO, 2017b). This guidance is also echoed in the government documentation of the Harmonized Application Guidebooks for Shellfish Aquaculture. Licenses for geoduck broodstock collection are issued by DFO under Section 4 of The Fisheries Act, and the DFO states that the “transfer of broodstock to the aquaculture facility will also be reviewed for potential disease, genetic and ecological risks” (DFO 2017b). For example, DFO will not issue a license for geoduck broodstock collection from a tenure that has been previously seeded by farmed geoduck (DFO 2017b). The movement of collected geoduck broodstock to a hatchery facility is covered by another regulatory layer of an Introductions and Transfers License issued by DFO under their authority to implement the Fishery General Regulations (Section 56) (DFO 2017b).

Other specific DFO regulations to maximize the genetic diversity of geoduck seed in BC are:

- **Shellfish transfer zones:** Geoduck transfer can only happen within and not between Shellfish transfer Zones (Figure 7) under the conditions of the DFO license (DFO 2021)(DFO 2017b).
- **Number of broodstock:** “A minimum of 100 geoducks (1:1 sex ratio) shall be collected for brood stock for each hatchery lot to be spawned from a single transfer zone” (DFO, 2017b).
- **Broodstock replacement rate:** “All brood stock in each hatchery shall be collected from wild geoduck populations and replaced yearly with fresh brood stock, when hatchery is active, in order to maximize genetic diversity of hatchery produced seed and minimize possible genetic impacts of cultured geoducks on the wild populations. Brood stock geoduck may not be sold and must be destroyed when they are replaced by fresh brood stock” (DFO, 2017b).
- **Prohibition on captive geoduck broodstock programs:** “Use of hatchery-produced geoducks as brood stock is prohibited due to the increased risks of genetic drift in the hatchery production. The requirement for an Introductions and Transfers licence issued under Section 56 of the *Fishery General Regulations* for all geoduck movements will ensure that geoduck brood stock in hatcheries comes from a wild stock source” (DFO, 2017b).
- **Breeding group size minimum:** “A minimum of 30 males and 30 females shall be used when conducting a hatchery spawning event. These geoducks must be from a wild stock source,

refreshed annually and from the same Transfer Zone. Although the sex ratio of the brood stock collection will be unknown until the first spawning, it is currently believed that the minimum brood stock collection of 100 animals will provide a suitable buffer of 40 animals to enable hatcheries to meet this requirement" (DFO, 2017b).

- **Prohibition on seed import:** "Seed imports from Washington are not permitted due to genetic differences observed between Strait of Georgia and Washington State geoducks (Miller et al. 2006) Since the degree of genetic differentiation between BC and Alaska populations of geoducks is unknown, import of geoduck seed from Alaska is prohibited" (DFO, 2017b).

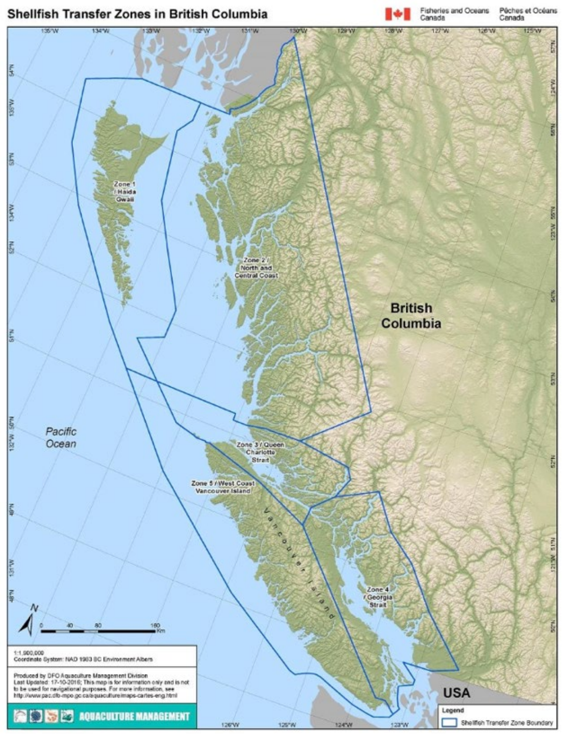


Figure 7: Shellfish transfer zones in British Columbia, as defined by the conditions for Shellfish Aquaculture Licensing of the federal Department of Fisheries and Oceans (DFO, 2021).

The BMPs of the BC shellfish industry are outlined by the BCSGA, which represents a significant proportion of BC shellfish growers (135 members and 85% of the BC shellfish industry by value). Their Environmental Codes of Practice reflect an understanding of the Shellfish Transfer Zone restrictions (BCSGA 2023).

Overall in BC, the genetic risk of farmed geoduck appears to be highly regulated and managed according to the best available science, abiding by four of the five recommendations for minimizing risk according to Straus et al. (2015) and Vadopalas et al. (2015). There are no requirements for sterilization (i.e., polyploidy) of farmed seed.

Maturation control is considered a key tool for minimizing the genetic risk to wild geoduck populations from cultured animals. Polyploidy occurs naturally in both plants and animals, and techniques for inducing it artificially are used in agriculture and aquaculture. Polyploidy (triploidy), a technique that results in cultured shellfish producing nonviable gametes, is commonly used in the culture of oysters, finfish, and produce. Induction of triploidy in farmed geoduck is possible (Vadopalas and Davis 2004), but triploidy has not been implemented commercially for geoduck aquaculture.

Overall, geoduck broodstock are native, wild-collected within their region, and replaced completely on an annual basis, which would allow for no more than a single generation of domestication pressures (i.e., related to the capture and conditioning of broodstock and the hatchery rearing environment). Regulations and industry codes of practice guide protocols that are designed to maximize genetic diversity, and the industry has responded to science-based recommendations to adapt methods such as partial factorial breeding schemes by adopting these new practices to improve genetic diversity. Geoduck seed are anticipated to have a high genetic similarity to wild conspecifics (consistent with a score of 8). There is still uncertainty about the potential adaptive differentiation of wild geoduck populations at microgeographic scales that may be vulnerable to homogenization, and the potential impact of repeated introductions of hatchery-reared seed from wild broodstock overall. The score for Factor 6.2 is 7 out of 10.

Conclusions and Final Score

Geoduck is a sessile animal, so it cannot escape directly; however, farmed geoduck reaches reproductive age and has been observed spawning in the natural environment during grow-out. There is no technology in place (e.g., sterilization techniques) to prevent escaped gametes or larvae from entering the environment and interacting with wild conspecifics. As a highly fecund species, this is considered a high escape risk, and Factor 6.1: Escape Risk scores 0 out of 10. Geoduck populations are largely panmictic at the waterbody scale, and there is a general acceptance that there is a homogenous population of Pacific geoduck across their native range. There is a phenomenon of microgeographical genetic variation among wild populations, and there is uncertainty of the potential impacts that farmed geoduck genetics may have at this scale. Only wild broodstock are used (i.e., all farmed offspring are first generation), and regulatory measures and best management practices are in place to maximize the genetic diversity of farmed geoduck seed and to maintain wild-type genetics as closely as possible. There is inherent modification of normal selective pressures during the capture and conditioning of broodstock and the hatchery rearing environment that cannot be removed from the production cycle, the potential impacts of which are not well understood on geoduck seed genetics. As a native species with high genetic similarity to wild conspecifics (e.g., one generation domesticated),the score for Factor 6.2 is 8 out of 10 for a low to moderate risk. Factors 6.1 and 6.2 combine to give 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

Disease Risk-based assessment

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

Brief Summary

The geoduck industry has not had major disease issues to date, and risk management infrastructure is in place in both Washington and British Columbia in the form of best management practices used by growers, government regulations, and industry-sponsored risk reduction programs. It is of note that the understanding of geoduck disease is relatively nascent; however, the regulatory mechanisms for monitoring seed health before allowing transfer would seem adequate to detect and manage any pathogens that may emerge in the future, as is the significant global infrastructure for notification and containment of reportable pathogens. Most major companies involved in geoduck production in Washington appear to be involved in the strongest industry disease risk-management program available, and BC also has a strong risk-management regulatory framework. Various agencies in Washington and BC have additional requirements and the leeway to manage risk conservatively, and the industry has a vested interest in preventing disease issues. There is no currently known disease risk to wild organisms from geoduck farms, but because farms may operate at higher densities than wild geoduck populations and are open to the environment in proximity to wild geoduck populations, a precautionary approach is taken. The final numerical score for Criterion 7—Disease, Pathogen and Parasite Interaction is 7 out of 10.

Justification of Rating

Because the disease data quality and availability is moderate/low (i.e., a Criterion 1 score of 5 or lower for the Disease category), the Seafood Watch Risk-Based Assessment was utilized.

No infectious disease or pathogenic organisms have been found in the limited studies of cultured geoduck in the assessment region. The disease and pathogen ecology of geoduck is still developing (Dorfmeier et al. 2015)(Cáceres-Martínez et al. 2015)(Straus et al. 2013). The most recent research in the assessment region is two decades old (Bower and Blackbourn

2003). As outlined by Bower and Blackbourn (2003), geoduck suffers from physical abnormalities such as fungal infections, warts, lesions, and pustules, but these have not been found to be contagious in lab conditions. On the coast of Baja California, Mexico, Cáceres-Martínez et al. (2015) found an apparent darkening of the geoduck siphon of harvested geoduck (also observed in Bower and Blackbourn 2003), which was a deformation of the periostracum that would likely lead to greater health issues for the clams because this is their first barrier against disease. But no infectious diseases were found—only parasites and symbionts.

The industry confirms that there have been no known disease outbreaks on geoduck farm sites or hatcheries, including from operators in practice for over 20 years (pers. comm., Jim Parsons, Jamestown Seafood, A Jamestown S'Klallam Tribal Enterprise 2023)(pers. comm., Anonymous Industry 2023), and there are no common local parasites or pathogens of geoduck in Puget Sound (pers. comm., E. Ewald, Taylor Shellfish 2023). Further, the industry reports that weather-related mortalities are the most common type of mortality on the farm sites (heavy rains that lower salinity, and super heat events)(pers. comm., Anonymous Industry 2023).

Viral Pathogens

Elsewhere, nonhost-specific viruses have been observed in Alaskan geoduck, but with no apparent signs of pathogenicity [as reviewed in Straus (2013)]. There are no records in the literature of geoduck viral pathogens in the assessment area.

Bacterial Pathogens

Bacterial pathogens are an important consideration for disease management in the hatchery for most aquaculture species. Even with careful use of mechanical and UV filtration, bacteria can still enter microalgal or larval systems. Hatcheries can be affected by the bay water conditions that they source water from, and this has been the cause of hatchery mortalities in the past (pers. comm., Anonymous Industry 2023). *Vibrio* spp., which are often a bacterial concern for some aquaculture species, are of low concern in geoduck hatcheries because they run at relatively low water temperatures (pers. comm., Anonymous Industry 2023). There is a historical record in 2006 and 2007 of *V. tubiashii* causing losses of larval and juvenile shellfish (including geoduck) on the West Coast of North America as a result of blooms of *V. tubiashii* in coastal waters caused by unusually warm surface seawater (Elston et al. 2015), but this is not an ongoing concern for geoduck growers.

Parasites

Dorfmeier et al. (2015) conducted the first study of Pacific geoduck to look at parasite identification, prevalence, intensity, and geographic distribution in Washington. The study identified five distinct parasites in various parts of wild adult geoduck anatomy. These included *Rickettsia*-like organisms [such organisms were also observed by Cáceres-Martínez et al. (2015) in Mexico]. *Rickettsia* spp. have been an issue for wild and cultured shellfish (abalone) elsewhere (Friedman et al. 2000), but those observed by Dorfmeier (2015), Bower and Blackbourn (2003), and Cáceres-Martínez (2015) did not appear to evoke a host response, and no association with damage or mortality was identified. An unidentified metazoan, and the first report of microsporidia-like parasites (one of which has the potential to affect reproduction) in geoduck was observed. The authors state a need for continued exploration of geoduck parasites to better understand disease risk and distribution.

Cáceres-Martínez et al. (2015) investigated geoduck symbionts, parasites, and diseases in *Panopea generosa* in Mexico. The study identified the presence of protozoans and fungi in some clams and suggested a possible (though inconclusive) link between protozoan and fungal infection and dark, leathery siphon and mantle surfaces [dubbed LSGC or leathery surface of geoduck clams by Bower and Blackbourn (2003)], a pathology that is believed to be a cause of mortality in cultured geoduck in Mexico. Two species of copepods occupying various regions of some geoducks were also observed, including a parasitic species (*Pseudomyicola spinosus*) with a wide international distribution that is known to be a pest to cultured and wild bivalves. A trematode was also found in some clams in low numbers. The study found no infectious agents in association with siphon and mantle blisters and swellings [symptoms also documented in Bower and Blackbourn (2003)], but did note a small sample size.

<u>Control Measures</u>

On-Farm Protocols

In Washington, best management practices are used by the industry to manage pathogens in shellfish hatcheries. The biosecurity plan shared by one large hatchery for this assessment includes a risk analysis and a discussion of disease transmission routes and disease hazards that reflect an understanding of the reportable pathogens specified by the World Organisation for Animal Health (WOAH, formerly OIE), which are required by law to be reported if detected (pers. comm., E. Ewald, Taylor Shellfish 2023). Recordkeeping to manage biosecurity within facilities includes logs on all movements of animals, water quality, and health logs and pathology reports that are made available to APHIS or WDFW upon request (pers. comm., E. Ewald, Taylor Shellfish 2023). Robust disinfection and monitoring protocols are used to prevent pathogens, such as limiting visitors, screening and treating intake water, nets and covers for exterior tanks, regular cleaning and sanitizing of hatchery infrastructure, and pathogen testing of broodstock and larvae or seed (pers. comm., E. Ewald, Taylor Shellfish 2023). The hatchery's largest facility in Quilcene, WA has a dedicated water intake source and in-line filtration (pers. comm., E. Ewald, Taylor Shellfish 2023). Growth and mortality monitoring occurs in the hatchery several times per week, and records are maintained on a cloud database. To diagnose disease, the hatchery uses either pathology (Histology or PCR) or investigation into water conditions (i.e., biotoxins and/or blooms that affect shellfish health). Note that, because there are no apparent significant pathogens of geoduck, there are currently no WOAH-reportable pathogens of the species. There are no reported treatments for disease of geoduck by the industry, and procedures are in place to not transfer any affected batches and to not accept any shellfish on-site that are showing signs of disease (pers. comm., E. Ewald, Taylor Shellfish 2023).

Smaller hatcheries also have adequate biosecurity capabilities for disease risk management. One small hatchery producing approximately 750,000 seed annually (relatively small in comparison to major geoduck hatchery facilities in Washington that may produce >10 million seed annually) describes filtering incoming water first mechanically (to 1 um) and then with UV light before it enters the facilities (pers. comm., Anonymous Industry 2023). This series of mechanical and UV filtration is a practical method to greatly reduce the risk of pathogen entry in incoming water, and indicates that smaller hatcheries have similar capabilities as larger hatcheries in managing the pathogen risk of incoming water .

The industry-promoted High-Health Shellfish Program provides a protocol if there were to be an outbreak of a certifiable infectious disease (which there are currently none listed by WOAH for geoduck). The protocol includes reasonable measures to notify regulatory authorities; to contain, disinfect, and destroy infected stock; to determine the source of infection; and to develop an ongoing response plan with the relevant regulatory agency (pers. comm., E. Ewald, Taylor Shellfish 2023).

In BC, if geoduck seed must be produced outside their Shellfish Transfer Zone, a quarantine protocol is required to minimize risk , as stated in the Geoduck Hatchery Protocol of the DFO's Integrated Geoduck Framework:

Where a hatchery operator wishes to bring geoduck from a different transfer zone for spawning inside a hatchery, treatment of both influent and effluent water in and out of the hatchery is required to minimize risks of disease transfer between Zones. Isolation of hatchery lots (brood stock and/progeny) from different zones is also required. Hatchery operators shall provide the details of such isolation and quarantine systems to the Introductions and Transfers Committee for review and approval prior to the issuance of an Introductions and Transfers license. Progeny may only be introduced into the marine environment within the Transfer Zone from which their brood stock was sourced (DFO, 2017b).

The largest BC geoduck farm operator reports ensuring that all equipment that comes into contact with hatchery seed is kept well-cleaned to protect the animals at this vulnerable life stage (pers. comm., Anonymous Industry 2023). The seed is separated from the sand only once between the nursery and planting into the subtidal benthos, and they are inspected at that time for any sign of disease (pers. comm., Anonymous Industry 2023). Farmworkers are constantly watching for signs of disease or mortality, and though no specific records are taken, mortality is estimated to be <10% (pers. comm., Anonymous Industry,2023).

Legislation/Government

As members of the WOAH, both the United States and Canada are held to agreed-to international standards on aquatic animal health (Aquatic Animal Health Code as well as the Manual of Diagnostic Tests for Aquatic Animals) (OIE 2022). Requirements include information sharing and cooperation to minimize the risk related to some diseases, biosecurity and quarantine requirements, restrictions on transferring of shellfish, and the use of zoning (Elston and Ford 2011)(OIE 2022).

Canada’s National Aquatic Animal Health Program (NAAHP) aims to prevent the introduction and spread of serious pathogens associated with live animals, and Canada also has protocols in the Shellfish License Conditions (DFO 2021) and Integrated Geoduck Management Framework (DFO 2017b) specific to disease risk management in geoduck culture. These include the ability to restrict the movement of shellfish between management zones if deemed necessary from a risk management perspective, and implementing an Introductions & Transfers (I&T) License requirement that is reviewed by committee to assess the disease risk of proposed transfers (e.g., broodstock to hatcheries, seed to farm plots, seed between hatcheries) (DFO 2017b). An I&T license may also be required for within-zone transfer, such as the movement of broodstock to the hatchery or of seed from the hatchery to the farm, and the isolation and quarantine protocols are reviewed by committee (DFO 2017b). The laws behind the license [Section 56 of Fishery (General) Regulations, GOC, 2023] require that the animals do not have any disease harmful to the conservation and protection of wild species. Risk mitigation measures may be prescribed by the committee through licensing.

The NAAHP is a regulatory program codelivered by DFO and the Canadian Food Inspection Agency, which is mandated “to protect Canada’s aquatic resources by preventing the introduction or spread of infectious diseases in wild or farmed aquatic animals” (CAAHRC 2023). Geoduck broodstock are not permitted to be collected from areas under biotoxin closure, related to food safety management (unless by special approval under the Management of Contaminated Fisheries Regulations) (DFO 2023/2024). The U.S. has a similar plan, called the National Aquaculture Health Plan & Standards (NAHP&S), administered by USDA-APHIS, that requires disease inspection protocols for any international shellfish transfers (USDA-APHIS 2021).

Washington restricts all movements of shellfish and aquaculture gear via the use of transfer permits and disease testing. WDFW maintains independent approval processes and standards from USDA-APHIS, including a restriction on the eligible geography for source locations (West Coast states only), further restrictions within state (only certain embayments qualify), a long-term demonstrated health history of an eligible embayment/facility, and annual health screens of both broodstock and seed for all imports (pers. comm., C. Eardley, WDFW 2023). WDFW also requires WDFW-approved biosecurity plans from source facilities (pers. comm., C. Eardley, WDFW 2023). Geoduck hatcheries also confirm that their standard practices include providing samples of seed for pathogen and basic histology testing in order to obtain WDFW certification to move seed, which is essential to transport seed from the hatchery to a farm plot for grow-out (pers. comm., Jim Parsons, Jamestown Seafood, A Jamestown S'Klallam Tribal Enterprise 2023)(pers. comm., Anonymous Industry 2023).

These requirements apply to both large and small producers. Even if facilities are not shipping internationally, all in-state producers must have a Shellfish Transport Permit from WDFW, which comes with requirements intended to manage shellfish health risks (e.g., disease) (pers. comm., C. Eardley, WDFW 2023). WDFW inspects all in-state hatcheries, and reports good compliance with hatchery permitting requirements and active involvement in working with, consulting, and inspecting all facilities in Washington State (and has toured a number out-of-state as well) (pers. comm., C. Eardley, WDFW 2023).

Transport of shellfish and aquaculture gear between Canada and Washington is also restricted, with WDFW testing requirements to minimize the risk of disease transfer (WDFW 2021). Import and transfer permits are required by Washington (WAC 220-340-150) and are evaluated based on the pest and disease transfer risk. Permits must accompany all transfer shipments. WDFW only approves imports from British Columbia that originate from verifiable, fully closed systems that are also subject to the same requirements described for Washington State facilities, and seed must be washed clean before transport (saltwater rinse only; because of the sensitivity of geoduck seed, WDFW cannot require a chlorine rinse like it does with oyster and clam seed) (pers. comm., C. Eardley, WDFW 2023).

The importation of geoduck seed from Washington or Alaska into British Columbia is strictly prohibited (DOE 2017b). One grower reports having routine disease inspections at its onshore hatchery and floating upweller system (FLUPSY) facilities by USDA-APHIS as part of its RAEF (Registered Aquatic Export Facility) inspection program for international animal export (pers. comm., E. Ewald, Taylor Shellfish 2023).

Shellfish growers have a vested interest in preventing the spread and outbreak of disease because their business, and potentially livelihood, depends upon the health and survival of their stock. Industry best management practices in Washington and British Columbia both advocate for abiding by all regulations and permitting, with specific language aimed at preventing the spread of exotic species and disease, such as through gear inspections, appropriately cleaning and storing gear, and not transferring materials from sites that are known to contain pests/disease to other areas (BCSGA 2023)(PCSGA 2019).

Industry codifications of hygiene management for shellfish export or transfer—such as the industry-promoted Shellfish High Health Program—are in place for preventing and spreading shellfish disease. This plan requires a customized animal health management plan for shellfish seed producers (hatcheries, nurseries, and broodstock), which reduces the risks associated with infectious disease outbreaks from hatchery-produced shellfish (Elston 2004)(Elston and Ford 2011). Examples of High Health Program procedures are described previously in the On-Farm Protocols section of this criterion.

PCSGA encourages members to keep source and pathology records for broodstock, and to ensure that seed stock is sourced from facilities with health-monitoring programs that consider enzootic pathogens, notifiable organisms, and OIE-listed pathogens (PCSGA 2019). The USDA Animal and Plant Health Inspection Service (APHIS), which issues certifications necessary for interstate (and international) export of live shellfish, has in the past endorsed the High Health Program for meeting national and international standards for bivalve health (PCSGA 2011).

In 2021, the USDA released its National Aquaculture Health Plan & Standards (NAHP&S), which outline new standards for testing, surveillance, inspections, risk mitigation, and response

(USDA-APHIS 2021). Within this document are the Comprehensive Aquaculture Health Program Standards (CAHPS), which outline five pillars of pathogen planning for all aquatic facilities and appear to be a codification of the High Health Program within federal regulations (USDA-APHIS 2021).

The industry-supported Pacific Shellfish Institute has also identified research and management priorities to maintain and strengthen disease risk management (PSI 2023). The U.S. geoduck industry is also dependent upon the import requirements of market countries, which may have additional disease risk management requirements for import/export certificates.

<u>Impacts on wild geoduck/other wild species</u>
Currently, there are no known infectious diseases of Pacific geoduck, and thus no known impacts to wild species. Although a lack of basic knowledge of disease and inadequate testing and monitoring has previously been responsible for the spread of disease by the shellfish aquaculture industry (Galliardi 2014), the geoduck industry presently appears to be adequately testing and monitoring shellfish in a manner that would detect and potentially contain any pathogens that may emerge.

Conclusions and Final Score
The geoduck industry has not had major disease issues to date, and risk management infrastructure is in place in both Washington and British Columbia in the form of best management practices used by growers, government regulations, and industry-sponsored risk reduction programs. It is of note that the understanding of geoduck disease is relatively nascent; however, the regulatory mechanisms for monitoring seed health before allowing transfer would seem adequate to detect and manage any pathogens that may emerge in the future, as is the significant global infrastructure for notification and containment of reportable pathogens. Most major companies involved in geoduck production in Washington appear to be involved in the strongest industry disease risk-management program available, and BC also has a strong risk-management regulatory framework. Various agencies in Washington and BC have additional requirements and the leeway to manage risk conservatively, and the industry has a vested interest in preventing disease issues. There is no currently known disease risk to wild organisms from geoduck farms, but because farms may operate at higher densities than wild geoduck populations and are open to the environment in proximity to wild geoduck populations, a precautionary approach is taken. The final numerical score for Criterion 7—Disease, Pathogen and Parasite Interaction is 7 out of 10.

Criterion 8X: Source of Stock—Independence from Wild Fisheries

Impact, unit of sustainability and principle

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

This is an "exceptional" criterion that may not apply in many circumstances. It generates a negative score that is deducted from the overall final score. A score of zero means there is no impact.

Criterion 8X Summary

Source of stock parameters	Score	
C8X Independence from unsustainable wild fisheries (0–10)	**0**	
Critical?	NO	**GREEN**

Brief Summary

Geoduck is highly fecund. One animal can produce tens of millions of gametes annually and can spawn multiple times each year (Goodwin and Pease 1989). Thus, small numbers of broodstock are required to produce vast quantities of seed. Though wild-caught broodstock is used for hatchery production of farm animals, this practice promotes genetic diversity of the farm stock, and the taking of small numbers from robust wild populations is not anticipated to have a significant impact. The final numerical score for Criterion 8X—Source of Stock is 0 out of 10, meaning that no reductions have been made for this criterion.

Justification of Rating

The use of wild-sourced geoduck broodstock is part of the best practices recommended by science and required by agencies to reduce the genetic risks of growing hatchery-produced, limited parentage animals in the same environment as their wild congeners.

In British Columbia, shellfish companies are permitted to harvest a limited number of wild BC geoducks to be used in the hatchery as broodstock. BC geoduck broodstock collection permits between 2006 and 2012 ranged from 100 to 250 animals each, and it was estimated that up to 1,500 kg (3,306 lb) of geoduck (or 0.1% of the commercial total allowable catch) was to be collected as broodstock (DFO 2014). Over the 2023–24 period, DFO estimates that approximately 1,400 kg (2,805 lb, up to 0.1% of the commercial total allowable catch) of geoduck broodstock may be collected in BC. Only licensed hatcheries are eligible to apply for broodstock collection licenses from the government (DFO 2023/2024). Harvesters must apply for a collection permit and an Introductions & Transfers (I&T) License from the DFO (even if the collection is within the farm's permitted shellfish transfer zone), their collection must be verified by a DFO-approved observer, and the collection event must comply with a number of other regulations outlined in a set of guidelines put forth by the agency (DFO 2023/2024).

In Washington, broodstock is harvested from wild populations that are carefully managed and considered stable (Fisher et al. 2008)(Shamshak and King 2015). Although Washington has no broodstock collection permit (explained by WDFW as a decision to not permit the collection of public resources for private commercial use), geoduck broodstock is generally purchased from wildstock harvesters or harvested from private tidelands where the shellfish is considered private property (pers. comm., C. Eardley, WDFW 2023). Puget Sound's wild geoduck population was estimated at 29,000 mt (674 million pounds) in 2007 (Washington Sea Grant 2007). The WDFW keeps a list of priority habitats and species for conservation, which are those that require "protective measures for their survival due to their population status, sensitivity to habitat alteration, and/or recreational, commercial, or Tribal importance." Currently, Pacific geoduck is listed as a priority species only because of its vulnerability to habitat alteration and its recreational, commercial, and Tribal importance —not its population status (WDFW 2022b). A large operator in Washington states that their broodstock collection process is done by contracting "with local Tribes to source wildstock animals during their harvest of tracts throughout Puget Sound region," and that all broodstock is sourced from wild resource areas, as required by the WA Dept. of Fish and Wildlife (pers. comm., E. Ewald, Taylor Shellfish 2023).

Conclusions and Final Score

Geoduck is highly fecund. One animal can produce tens of millions of gametes annually and can spawn multiple times each year (Goodwin and Pease 1989). Thus, small numbers of broodstock are required to produce vast quantities of seed. Though wild-caught broodstock is used for hatchery production of farm animals, this practice promotes genetic diversity of the farm stock, and the taking of small numbers from robust wild populations is not anticipated to have a significant impact. The final numerical score for Criterion 8X—Source of Stock is 0 out of 10, meaning that no deductions have been made for this criterion.

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

Species of conservation concern have legal protections in both the United States and Canada and are not expected to be significantly affected by geoduck aquaculture. Both countries have requirements for nonharmful exclusion methods by shellfish operators, and best management practices are being used in the industry. Predator exclusion is done passively using HDPE mesh and PVC tubes. At times during the culture cycle, predators or competitors may be removed by hand and relocated in a nonlethal manner. The potential for wildlife to become entangled in the predator exclusion mesh is considered exceptionally rare at most. The species commonly found on geoduck plots by operators are considered to have healthy population statuses, with many supporting commercial fisheries. Thus, impacts on wildlife populations resulting from geoduck aquaculture are considered to be low. The final numerical score for Criterion 9X—Wildlife and Predator Mortalities is –2 out of –10.

Justification of Rating

A risk-based approach is used for scoring because there are no specific data available on the wildlife mortality numbers or impacts to their populations, as a result of the size, scale, and geographic spread of the industry.

<u>Wildlife Protections/Control</u>

Governance

Threatened and endangered species are protected federally by the Endangered Species Act in the United States and the Species at Risk Act in Canada, which prohibit the unpermitted take of protected species in order to provide safeguards against extinction or extirpation—

including considerations of important habitat in siting geoduck aquaculture. Geoduck farm sites are within federally designated Critical Habitat for some species in Washington, but there is significant regulation within the permitting consultation process for the Endangered Species Act, which finds that shellfish aquaculture does not jeopardize the existence of ESA-listed species (NOAA 2022). The Marine Mammal Protection Act, the Bald and Golden Eagle Protection Act, and the Migratory Bird Treaty Act in the U.S. offer additional protections. These protections are reflected in management, and permit holders are responsible for complying.

The U.S. has effective regulations for the nonharmful exclusion of wildlife, to minimize interactions or potential impact. Approved work windows are required to protect spawning habitat for sand lance and surf smelt (Conservation Measure #6 from the Programmatic Biological Opinions for Shellfish Activities in Washington State Inland Marine Waters [U.S. Fish and Wildlife Service {USFWS} Reference Number 01EWFW00-2016-F-0121, National Marine Fisheries Service {NMFS} Reference Number WCR-2014-1502]). In addition, Conservation Measure #23 provides specific requirements for reporting any entrapment or entanglement of wildlife in aquaculture gear, including inspecting for any wildlife entanglements, attempting to release them without harm, providing notice to the relevant authorities (USFWS/NMFS) within 24 hours, and filing photographic records and written logs.

"Take" of certain species is outlined in a farm's Army Corps permit and the Programmatic Consultation with USFW, NOAA, and NMFS. Any take that results from farm operations would require reporting of entrapment or entanglement to the appropriate authority and cooperation with any change identified to BMPs (pers. comm., E. Ewald, Taylor Shellfish 2023). Maximum take limits are set on an industry-wide basis and not an individual farm level, and all records are kept and audited by the relevant agencies (i.e., USFW, NOAA, NMFS) (pers. comm., E. Ewald, Taylor Shellfish 2023). Reports of entrapments are not readily available on any of the agency websites but would be accessible to the public through an FOIA request. Given that the extensive Biological Opinion of NOAA NMFS did not reveal significant risk that would jeopardize the population of ESA-listed species, such an entrapment is considered exceptionally rare at most.

At the county level in Washington State, WDOE mandates that all County Shoreline Master Plans require a County Use permit for all new geoduck aquaculture [WAC 173-26-241(2)(b)(ii)(D) and (3)(b)(iv)], and wildlife-specific concerns for each county as it relates to the permitting of geoduck aquaculture appear on an individual basis in each county plan.

DFO also has enforcement practices for the nonharmful exclusion or control of wildlife by the shellfish industry. The DFO requires that shellfish aquaculture license holders construct and maintain predator exclusion in a manner that prevents "entrapment, injury, or death to fish or marine mammals" and that any incidental catch of wildlife at a shellfish aquaculture facility must immediately be returned to the water in a manner that causes the least harm (DFO 2021). Similar to the reporting requirements in Washington, the DFO Shellfish License requires immediate notice and a written report within 7 days in the case of entrapment or death of a marine mammal (DFO 2021). DFO publishes statistics online on the aquaculture-associated mortalities of marine mammals related to the finfish industry, though there are no shellfish-specific statistics; DFO has confirmed that there have been no mortalities of marine mammals reported to date (pers. comm., DFO 2023). The DFO does appear to have significant enforcement and compliance resources for shellfish aquaculture in BC to inspect and levy penalties for any noncompliance with antipredator netting regulations (DFO 2023).

Deliberate lethal wildlife control of sea lions is not permitted under shellfish licenses in the United States or Canada, and the DFO further requires that no acoustic deterrents are allowed to deter sea lions (DFO 2021).

Regulations are placed on farms during times when there may be protected species present. For example, one operator is required to control sedimentation and disturbance to summer-run chum in Hood Canal between February 1 and April 30 (although they currently do not have geoduck planted in the Hood Canal growing area with summer-run chum habitat) (pers. comm., E. Ewald, Taylor Shellfish 2023). Federal protections are in place for sand lance and surf smelt spawn (see the following section), which prevent disturbing their fertilized eggs, though these species will not interact with all farms, depending on their tidal depth.

Farm Practices

Geoduck aquaculture uses a passive, exclusionary approach to predator management for the majority of the farm cycle, and no lethal control is used. Predator exclusion devices used on geoduck farms are usually in the form of HDPE netting (mesh) or PVC and mesh tubing. Gear is usually in place for the first 1–2 years of intertidal cultivation, or 4–6 years for subtidal cultivation in BC, before being removed.

In preparation for seeding juvenile geoduck, farmers may relocate sand dollars out of the planting area to prevent them from being damaged, which is done only by hand (either through the use of divers in subtidal areas, or by placing them in 5-gallon buckets filled with water) and relocating them outside the farm perimeter (pers. comm., Anonymous Industry 2023). Not all bays have sand dollars (pers. comm., Jim Parsons, Jamestown Seafood, A Jamestown S'Klallam Tribal Enterprise 2023). Crabs may be relocated if they happen to be present in the tubes at the time of planting, when they could potentially eat the seed before it has a chance to burrow (pers. comm., Jim Parsons, Jamestown Seafood, A Jamestown S'Klallam Tribal Enterprise 2023). Subtidal farmers may hand-relocate sea stars before casting seed over their plots (pers. comm., Anonymous Industry 2023).

After seed are planted, the primary predators are sea stars, crabs, moon snail, and flounder (pers. comm., Anonymous Industry 2023). Mussels and barnacles that colonize on PVC nursery tubes are left alone, and the growers do not find that they affect the growth or survival of the geoduck (pers. comm., Jim Parsons, Jamestown Seafood, A Jamestown S'Klallam Tribal Enterprise 2023). Cockles may be removed to a minor degree (pers. comm., Anonymous

Industry 2023), though once the tubes are removed, the cockles are not an issue (pers. comm., E. Ewald, Taylor Shellfish 2023).

The amount of predation varies from site to site and year to year, and the removal of predators and/or competitive species is not necessary at all farm sites (pers. comm., E. Ewald, Taylor Shellfish 2023). No noise devices or traps are used on farms, and only nonlethal predator exclusion is currently permitted (pers. comm., E. Ewald, Taylor Shellfish 2023).

During geoduck harvest, horse clams are harvested as incidental catch (pers. comm., E. Ewald, Taylor Shellfish 2023)(pers. comm., Jim Parsons, Jamestown Seafood, A Jamestown S'Klallam Tribal Enterprise 2023)(pers. comm., Anonymous Industry 2023). The two species of horse clam in the assessment region both have authorized fisheries (WDFW 2023b).

Farms are monitored regularly for species interactions by their crews, and farms (some with many decades of geoduck farming experience) report not observing any concerning negative interactions with birds or fish (pers. comm., E. Ewald, Taylor Shellfish 2023)(pers. comm., Jim Parsons, Jamestown Seafood, A Jamestown S'Klallam Tribal Enterprise 2023)(pers. comm., Anonymous Industry 2023). One farm reports regularly having eagles around and near the farm site with no interactions in 23 years of operations (pers. comm., Anonymous Industry 2023).

Subtidal farms in BC report seeing sea urchins (green and red), sea cucumbers, starfish, crabs, cockles, tube worms, horse clams, sea lions, and seals (pers. comm., Anonymous Industry 2023). Culverts are used on floating rafts to passively exclude sea lions (pers. comm., Anonymous Industry 2023). Also, divers will hand-remove crabs, sea stars, or octopus if they are underneath the antipredator nets (pers. comm., Anonymous Industry 2023).

There are industry codes of practice in both Washington and BC that reflect best management practices for wildlife interactions. The PCSGA's Industry Environmental Codes of Practice (ECOP) in Washington direct farmers to conduct pest and predator control measures in nonlethal and low-impact ways, echoing regulatory requirements (PCSGA 2019). The PCSGA directs farmers to leave sand dollars in place when possible as the first option, or to relocate them to other sections of the sand dollar bed, or to move them to similar and viable habitat (PCSGA 2019). Although significantly more brief, the British Columbia Shellfish Growers' Association (BCSGA) ECOP mirrors many of the recommendations found in the PCSGA ECOP, as well as Canadian regulatory requirements, such as directing farmers to check farm gear for entanglements regularly and to ensure that it is well secured so it cannot harm animals or become debris, and to maintain complete and accurate records of predator exclusion nets including their locations, installation, inspection, and maintenance (BCSGA 2023).

Wildlife Species Population Status

The number of interactions is not known. Of the species that came up as regularly interacting with geoduck farms through data requests for this assessment, their population statuses are:

- Cockles (*Clinocardium nuttallii*)—common on Puget Sound beaches, geographic range from Alaska to California; common enough for ongoing public shellfish harvest (WDFW 2023a).
- Horse clams (*Tresus capax* and *Tresus nuttallii*)—both have stable enough populations for there to be permitted shellfish harvests with a valid license (WDFW 2023b).
- Red sea urchin (*Strongylocentrotus franciscanus*)—there is an open fishery for this species in Canada (DFO 2023d).
- Green sea urchin (*Strongylocentrotus droebachiensis*)—a commercial fishery for their roe is in current operations (DFO 2023e).
- Flounder (unspecified species)—the two species in the farm area, arrowtooth flounder (*Atheresthes stomias*) and starry flounder (*Platichthys stellatus*) both support commercial/recreational fisheries (WDFW 2023c).
- Sea cucumbers (unspecified species)—sea cucumbers support a commercial fishery in BC.
- Sea stars (unspecified species), crabs (unspecified species), tube worms (unspecified species)

Invertebrate wildlife rapidly colonizes structures placed in the marine environment. Many of the species found to colonize or otherwise use geoduck farm sites have robust populations within the Pacific Northwest region covered in this assessment (Stokesbury et al., 2011). In addition, these species are capable of rapidly recolonizing disturbed seafloor habitats (Stokesbury et al. 2011), and the resilience of community structure after disturbance related to geoduck culture activities has been observed in several studies (see Criterion 3—Habitat).

A modeling study of species interactions in South Puget Sound between 2012 and 2054 concluded that shellfish aquaculture would be "benign or beneficial to most species" (Preikshot et al., 2015). Although it is important to consider the limitations of modeling, based on our present understanding of species interactions, this study did use approximately 40 years of historical ecosystems models (1970—2012) to base the prediction.

Wildlife interactions may also occur during harvest, though these are likely limited to animals within the sediment that are disturbed when the sediment is made fluid, and resilience has been demonstrated in some of these populations. Horse clam that is harvested as incidental catch while harvesting geoduck has a population status that supports a fishery, so impacts are considered negligible. The total impacts of harvest are discussed in detail in Criterion 3—Habitat.

An ACOE Aquaculture Lead in Seattle confirmed that they were unaware of any entanglements specific to geoduck aquaculture (pers. comm., R. Lee 2023), which is significant given that the ACOE is the agency that receives reports of entanglements. This confirms that there are no known negative interactions with wildlife (including marine mammals) at geoduck farm sites.

In BC, there are regulations for commercial harvest priority, which govern a portion of geoduck culture areas, that allow for the harvesting of wild geoduck (or any other “valuable species”) at the site before the DFO license is issued to an operation for commercial geoduck cultivation, with the intent to “allow a significant portion of the economic value of the wild species to be accrued to the public fishery” (DFO 2017b). In this way, there would be commercial fishery removal of species, potentially including making the sediment fluid, before the aquaculture license is issued.

Conclusions and Final Score

Species of conservation concern have legal protections in both the United States and Canada and are not expected to be significantly affected by geoduck aquaculture. Both countries have requirements for nonharmful exclusion methods by shellfish operators, and best management practices are being used in the industry. Predator exclusion is done passively using HDPE mesh and PVC tubes. At times during the culture cycle, predators or competitors may be removed by hand and relocated in a nonlethal manner. The potential for wildlife to become entangled in the predator exclusion mesh is considered exceptionally rare at most. The species commonly found on geoduck plots by operators are considered to have healthy population statuses, with many supporting commercial fisheries. Thus, impacts on wildlife populations resulting from geoduck aquaculture are considered to be low. The final numerical score for Criterion 9X—Wildlife Mortalities is –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

Washington

Escape of secondary species parameters		Score	
F10Xa International or trans-waterbody live animal shipments (%)		10	
F10Xb Biosecurity of source/destination		6	
C10X Escape of secondary species Final Score		**–0.8**	**GREEN**

British Columbia

Escape of secondary species parameters		Score	
F10Xa International or trans-waterbody live animal shipments (%)		5	
F10Xb Biosecurity of source/destination		6	
C10X Escape of secondary species Final Score		**–0.4**	**GREEN**

Brief Summary

Both Washington and British Columbia have regulations and permitting requirements in place that aim to prevent the spread of nonnative species within the state/province and across international boundaries. The use of transfer permits and management zones is intended to reduce the risk of spreading nonnative species. Movement of live geoduck is largely limited to the movement of juvenile "seed" from the hatchery to the farm setting. Some movement of aquaculture gear and vessels occurs, and this presents a risk vector to the spread of nonnative species. But industry protocols are in place to dry gear upland to remove biofouling, and it is redeployed in the same water body from which it was removed. Washington and British Columbia are estimated to have 10% and <10% of total seed transported trans-waterbody, respectively. The source hatcheries are the most biosecure segment of geoduck aquaculture, and shellfish hatcheries are classified as moderate risk systems that use active best management practices for design, construction, and biosecurity management. For Washington, the final numerical score for Criterion 10X—Escape of Secondary Species is a minor deduction of –0.8 out of –10. For British Columbia, the final numerical score for Criterion 10X—Escape of Secondary Species is a minor deduction of –0.4 out of –10.

Justification of Rating

Factor 10Xa—International or trans-waterbody live animal shipments
All movement of seed is strictly controlled in the assessment area, and the mass transfer of animals without inspection, quarantine, or other appropriate management procedures does not occur in Washington or British Columbia. Geoduck seed in the assessment area generally travels a relatively short distance relative to other types of bivalve culture. So, although the movement of other species of shellfish has led to numerous species introductions in the Pacific Northwest, including the introduction of nonnative predatory pest species, diseases, bacteria, parasites, and nonnative toxic phytoplankton (McKinsdey et al. 2007)(Straus et al. 2013)(Galliardi 2014), there has been no association of geoduck culture with the spread of these organisms. The concern evaluated here is that the movement of seed from hatchery and nursery to farm areas, as well as the movement of gear and vessels, presents some risk of introducing or spreading alien species (other than diseases and pathogens, which are assessed in Criterion 7).

There are three primary movements of geoduck in the assessment scope:

1) Within the Puget Sound region;
2) Within BC's shellfish transfer zones;
3) Limited international broodstock and seed transfer between Washington and British Columbia (whereby broodstock from Washington are shipped to closed hatcheries in British Columbia and their seed is shipped back to Washington).

Criterion 10X considers a trans-waterbody movement to occur when the source waterbody is ecologically distinct from the destination (farming) waterbody, such that the live animal movements represent a risk of introducing species (pathogens, parasites, other secondary species) not present in the destination waterbody. Managers and scientists consider Puget Sound, together with the Strait of Georgia, to be a single ecoregion—the Puget Sound/Georgia Basin system (WDFW 2005)(Fraser et al. 2006). Thus, no "trans-waterbody" movement of live animals occurs under this definition, but some movement of live animals in the form of seed and broodstock does occur across international boundaries. Also, Seafood Watch typically considers risk at the waterbody scale, but spreading existing invasive species from one region within a waterbody to another region of the same waterbody (e.g., southern Hood Canal to northern Hood Canal or Northern Baynes Sound to Southern Baynes Sound) is also potentially harmful and has occurred in conjunction with other species farmed in the Northwest shellfish industry. Note that Washington and British Columbia differ slightly in their management of risk and are accordingly assessed separately in Criterion 10X.

<u>Washington</u>
Broodstock are sourced from South Sound, North Sound, and Hood Canal growing areas, and typically the distance between sourcing areas and farms is approximately 60 miles (pers.

comm., E. Ewald, Taylor Shellfish 2023). Geoduck seed is produced both within the state and imported from closed hatchery facilities in BC about 200 mi from South Puget Sound (though the seed is progeny from wild Washington-sourced geoduck broodstock only). Some importation of geoduck seed from BC takes place, estimated at about 10% of the seed needs of the industry (pers. comm., C. Eardley, WDFW 2023).

For the slight risk of transfer of nonnative species with geoduck aquaculture corresponding with the movement of some seed from British Columbia to Washington, as well as the potential movement of gear between farm sites, the score for Factor 10Xa is 8 out of 10 for Washington.

British Columbia

Now that BC has opened geoduck culture beyond the Strait of Georgia (DFO 2017b), it is relevant to consider the potential risk across the entire potential production region in BC. DFO maintains boundary regions for five distinct Shellfish Transfer Zones (Figure 8), and states that "[t]hese zones are generally delineated based on definable oceanographic and ecographic discrete areas (e.g., oceanic vs. inside waters). Consideration is also given to historical movements of shellfish in the aquaculture and commercial fisheries sectors for trade and commerce" (DFO 2021). Canada does not permit the importation of geoduck seed from non-BC waters, and geoduck seed must be produced from wild BC broodstock that are sourced from within the Shellfish Transfer Zone they will be planted in—without exception (DFO 2017b)(DFO 2021). DFO also oversees the transfer of geoduck broodstock to aquaculture facilities through their Introductions & Transfers licensing process, which is an application reviewed individually by committee, including considerations "for potential disease, genetic and ecological risks" of the proposed transfer (DFO 2017b). Shellfish license holders are allowed to move stock only within zones, not between zones (DFO 2021).

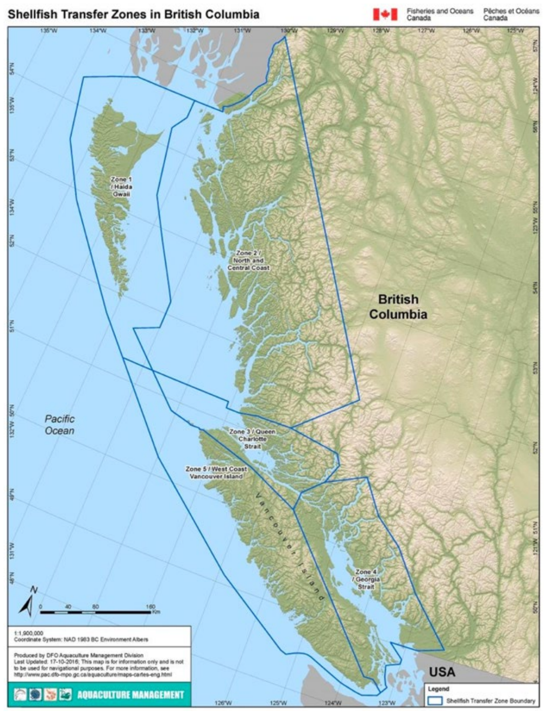


Figure 8: Shellfish Transfer Zones in British Columbia that are regulated by the Department of Fisheries and Oceans (map from DFO 2021).

The industry reports that its seed stock are sourced from the same shellfish transfer zone in which they are planted, and that gear is occasionally transported <100 mi, with pressure washing and air drying before transport (pers. comm., Anonymous Industry 2023). The distance from hatchery to grow-out site is approximately 35 nm for one grower (pers. comm., Anonymous Industry 2023).

There are cases where geoduck broodstock must be spawned in a hatchery located in a different zone than the zone where broodstock were collected from—though all resulting seed will only be permitted to be planted within the zone where the broodstock originated. The stipulations for the broodstock origin zone are based on genetic concerns, but the transfer of broodstock between zones also presents a possible avenue for the transfer of secondary species. Within the Integrated Geoduck Framework, the DFO describes their process to manage this:

Where a hatchery operator wishes to bring geoduck from a different transfer zone for spawning inside a hatchery, treatment of both influent and effluent water in and out of the hatchery is required to minimize risks of disease transfer between Zones. Isolation of hatchery lots (brood stock and/progeny) from different zones is also required. Hatchery operators shall provide the details of such isolation and quarantine systems to the Introductions and Transfers Committee for review and approval prior to the issuance of an Introductions and Transfers licence. Progeny may only be introduced into the marine environment within the Transfer Zone from which their brood stock was sourced" (DFO 2017b).

Canada does produce some seed for Washington farmers and is required to use Washington-sourced broodstock to do so (WDFW 2021), meaning that a limited number of live animals are imported for such production. In terms of scoring, the movement of these broodstock is considered a low level of reliance on animal movements in the scale of the industry (greater than 0%, but less than 10% of production).

Although there is minimal movement of live geoduck broodstock into British Columbia from Washington, this does present some risk, as does the potential movement of gear and vessels between sites. Because an estimated <10% of production is reliant on international/trans-waterbody animal movements, the score for Factor 10Xa is 9 out of 10 for BC.

Factor 10Xb—Biosecurity of source/destination

<u>Biosecurity of Source (Hatcheries) and Destination (Intertidal/Subtidal)</u>

<u>Washington</u>
Broodstock are collected from the wild and moved into hatcheries to produce seed before planting juveniles in the intertidal and subtidal environment. Hatchery biosecurity is thus a critical component of the culture cycle. One large hatchery operator in Washington provided its high-health plan (described in more detail in Criterion 7) as well as its Biosecurity Plan, which include strict biosecurity protocols for admitting wild broodstock to spawning programs and maintaining broodstock in good health by preventing the introduction of exotic infectious diseases. Protocols include keeping dedicated spaces only for broodstock, limiting entry into broodstock holding areas, conducting ongoing health surveillance, and logging health records (pers. comm., E. Ewald, Taylor Shellfish 2023). Onshore hatchery facilities have locked gates and restrict access to unauthorized personnel. The seawater used is transported from a nearby bay, and through a series of filters and heat exchangers before being used in the hatchery. Water is changed in larval tanks every few days. Smaller hatcheries are also well equipped to manage biosecurity, with both mechanical and UV sterilization of flow-through seawater to larval tanks, and either sterile seawater batch culture or bag culture of microalgae (pers. comm., Anonymous Industry 2023).

Large shellfish hatcheries often culture multiple species, so the overall approach to biosecurity is important. Hatcheries may import shellfish broodstock (not geoduck, but other species) from outside Washington that are subject to disease and parasite testing by WDFW, and an individual quarantine system is used to test and approve each animal for entry into the facility if it originates from areas where disease is present or from undesignated areas. Any shellfish that test positive for a certifiable disease are destroyed (pers. comm., E. Ewald, Taylor Shellfish 2023).

WDFW regulations are in place to prevent the spread of nonnative species, including transfer permits for movement of live shellfish around the state and analyzing the risk of spreading nonnative species from one area to another when making permitting decisions (WAC 220-340-150) (WDFW 2023d). Spatial restrictions are used for the movement of shellfish and gear; for example, transfer is prohibited from “Oyster Drill Restricted Areas,” and there is restricted movement among other similarly designated or heavily conditioned areas to reduce the risk of spreading pest species (pers. comm., C. Eardley, WDFW 2023). WDFW actively inspects shellfish aquaculture facilities to promote compliance and to educate stakeholders on the risks and risk management related to the transfer of secondary species (pers. comm., C. Eardley, WDFW 2023). Import protocols from out of state are also in place, which include permits and proof (fish tickets, import records, local regulatory attestation of facility conditions) to be provided to WDFW authorities (pers. comm., C. Eardley, WDFW 2023). Geoduck seed in British Columbia that is intended for Washington farms is required to be produced under quarantine to prevent unintentional species (and genetic and disease) introductions, using Washington-sourced broodstock (WDFW 2021). British Columbia also has its own requirements for broodstock coming into its facilities from Washington, including documentation on the source and verification of quarantine requirements for those animals entering BC hatcheries (pers. comm., C. Eardley, WDFW 2023).

Transport of shellfish and aquaculture gear between Canada and the United States requires import and transfer permits by Washington (WAC 220-340-150). The state also requires disease inspection and consultation with experts (RCW 77.115.030), but sanitation requirements for other shellfish species—such as dilute chlorine dips to sanitize shellfish and gear being moved into Washington from British Columbia—do not apply to geoduck (pers. comm., C. Eardley, WDFW 2023). Maps and information about Washington regulations are readily available online (WDFW, 2023d). WDFW also notes that a lot of harvested shellfish also go through processing facilities to reduce the risk of transferring pest species such as European green crab (pers. comm., C. Eardley 2023).

The WDFW transfer regulations apply to the movement of aquaculture gear before it is redeployed into the marine environment. Though there are no specific requirements for geoduck gear, the agency operates with the knowledge that this gear is pulled ashore to dry and/or used on the same farm site (pers. comm., C. Eardley, WDFW 2023). In practice, any gear (such as PVC tubes) that is not needed for redeployment within the same growing area (often at the same farm as part of the rotational cycle) is collected and returned to an upland site for cleaning or storage, though in some cases it may be immediately redeployed (pers. comm., E. Ewald, Taylor Shellfish 2023). It is common practice to air-dry biofouled nets, and nursery tubes may be dried as well if heavily fouled, through this is rarely necessary. Gear may be staged on nearby uplands or on anchored boats before redeployment, which is generally in the same growing area (approximately 2 mi) (pers. comm., E. Ewald, Taylor Shellfish 2023).

The destination for geoduck leaving the hatchery is the open environment. Geoduck is planted in the sand within PVC nursery tube structures and covered with antipredator netting. When used, nursery gear and antipredator netting are maintained with best management practices to reduce biofouling and provide adequate water flow to maintain the health of the cultured animals.

The shellfish industry's general BMPs for the culture of all species to reduce the risk of introducing secondary species, as presented by PCSGA (2019), are:

- Obtain proper permits for transferring shellstock from one body of water to another.
- Ensure seed stock is sourced from facilities with health-monitoring programs that take into consideration enzootic pathogens, notifiable organisms, and OIE-listed pathogens.
- Conduct periodic pathology screens.
- Out-plant only stock and species approved for the growing area and keep records that identify the source of shellstock planted.
- Support the development of practical and scientifically responsible regulations regarding transporting shellstock.
- Comply with all applicable wildlife transfer regulations.

The scoring for Factor 10Xb is:

<u>Source:</u> flow-through hatcheries with active best management practices for design, construction, and management of escape and entry prevention (biosecurity). Considered low to moderate risk. Score: 6 out of 10.

<u>Destination:</u> open system with effective best management practices for design, construction, and management of entry prevention (biosecurity). Considered moderate to high risk. Score: 1 out of 10.

Because of active BMPs for design, construction, and management of escape and entry prevention (biosecurity), the source of transported animals scores 6 out of 10. For being an open system with BMPs, the destination of the transported animals scores 1 out of 10. Therefore, the score for Factor 10Xb is 6 out of 10 (the higher of the two scores).

<u>British Columbia</u>
Hatcheries in BC contacted for the assessment were unable to participate. In general, British Columbia hatchery practices for geoduck are modeled after those in Washington, and are expected to score at least the same for source and destination as Washington hatcheries.

BC has established management zones (Shellfish Transfer Zones; Figure 8) that apply to the minimization of risk associated with invasive species, genetic concerns, and disease. Maps and information about these restrictions are readily available online. Aquatic Invasive Species regulations and authority are outlined in the Fisheries Act. DFO has developed an Integrated Management of Shellfish Aquaculture Plan and an Integrated Geoduck Framework according to the best available science to address concerns that are associated with geoduck aquaculture, including the spread of invasive species, and has now allowed industry expansion outside the Strait of Georgia with confidence from its research that this management framework will adequately protect natural habitats and wild populations of geoduck (DFO 2017a) (DFO 2017b).

Transfer of live shellfish and aquaculture gear between the United States and Canada is strictly controlled. Canada does not permit the importation of geoduck seed from non-BC waters, and all seed must be produced from wild BC broodstock appropriate to the management zone (DFO 2017b)(DFO 2021). An Introductions and Transfers Committee reviews all license applications and may mandate mitigation measures as a Condition of License (DFO 2017b).

The destination for geoduck leaving the hatchery is the open environment. Seed must be planted within the same Shellfish Transfer Zone that the broodstock originated from, without exception (DFO 2017b). There are stipulations that, if broodstock must be transferred to a hatchery in a different zone to produce seed, the hatchery facility must treat both influent and effluent water and isolate the hatchery lots from those of different zones to minimize the disease transfer risk. Any such transfer would be subject to the Introductions and Transfers Committee process for consideration on an individual basis, including the potential disease, genetic, and ecological risks of the movement (DFO 2017b).

Industry best management practices in BC advocate for abiding by all regulations and permitting, with specific language aimed at preventing the spread of exotic species, including inspecting and cleaning gear and not allowing invasive species to be introduced to new areas (BCSGA 2023).

Source: flow-through hatcheries with active BMPs for design, construction, and management of escape and entry prevention (biosecurity). Considered low to moderate risk. Score: 6 out of 10.

Destination: open system with effective BMPs for design, construction, and management of entry prevention (biosecurity). Considered moderate to high risk. Score: 1 out of 10.

As a result of the assumption of practices similar to Washington hatcheries, the source of transported animals scores 6 out of 10. Because of being an open system with BMPs, the destination of the transported animals scores 1 out of 10. Therefore, the score for Factor 10Xb is 6 out of 10 (the higher of the two scores).

Conclusions and Final Score

Both Washington and British Columbia have regulations and permitting requirements in place that aim to prevent the spread of nonnative species within the state/province and across international boundaries. The use of transfer permits and management zones is intended to reduce the risk of spreading nonnative species. Movement of live geoduck is largely limited to the movement of juvenile “seed” from the hatchery to the farm setting. Some movement of aquaculture gear and vessels occurs, and this presents a risk vector to the spread of nonnative species. But industry protocols are in place to dry gear upland to remove biofouling, and it is redeployed in the same water body from which it was removed. Washington and British Columbia are estimated to have 10% and <10% of the total seed transported trans-waterbody, respectively. The source hatcheries are the most biosecure segment of geoduck aquaculture, and shellfish hatcheries are classified as moderate-risk systems that use active best management practices for design, construction, and biosecurity management. For Washington, the final numerical score for Criterion 10X—Escape of Secondary Species is a minor deduction of –0.8 out of –10. For BC, the final numerical score for Criterion 10X—Escape of Secondary Species is a minor deduction of –0.4 out of –10.

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

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Appendix 1: Data Points and all Scoring Calculations

Washington State and British Columbia

Criterion 1: Data	
Data Category	**Data Quality**
Production	7.5
Management	10.0
Effluent	10.0
Habitat	5.0
Chemical Use	7.5
Feed	10.0
Escapes	7.5
Disease	5.0
Source of stock	10.0
Wildlife mortalities	7.5
Escape of secondary species	7.5
C1 Data Final Score (0–10)	**7.955**
	Green

Washington State and British Columbia

Criterion 2: Effluent	
Effluent Evidence-Based Assessment	**Data and Scores**
C2 Effluent Final Score (0–10)	**10**
Critical?	NO

Washington State and British Columbia

Criterion 3: Habitat	
F3.1. Habitat conversion and function	**Data and Scores**
F3.1 Score (0–10)	7
F3.2 Management of farm-level and cumulative habitat impacts	
3.2a Content of habitat management measure	5
3.2b Enforcement of habitat management measures	4
3.2 Habitat management effectiveness	8.000
C3 Habitat Final Score (0–10)	**7.333**
Critical?	No

Washington State and British Columbia

Criterion 4: Chemical Use	
Single species assessment	Data and Scores
Chemical use initial score (0-10)	10.0
Trend adjustment	0.0
C4 Chemical Use Final Score (0-10)	**10.0**
Critical?	No

Washington State and British Columbia

Criterion 5: Feed	
5.1 Wild Fish Use	
5.1a Forage Fish Efficiency Ratio (FFER)	**Data and Scores**
Fishmeal from whole fish, weighted inclusion level %	0.000
Fishmeal from by-products, weighted inclusion %	0.000
By-product fishmeal inclusion (@ 5%)	0.000
Fishmeal yield value, weighted %	22.500
Fish oil from whole fish, weighted inclusion level %	0.000
Fish oil from by-products, weighted inclusion %	0.000
By-product fish oil inclusion (@ 5%)	0.000
Fish oil yield value, weighted %	5.000
eFCR	1.000
FFER Fishmeal value	**Unfed**
FFER Fish oil value	**Unfed**
Critical (FFER >4)?	No

5.1b Sustainability of Source fisheries	Data and Scores
Source fishery sustainability score	Unfed
Critical Source fisheries?	No
SFW "Red" Source fisheries?	No
FFER for red-rated fisheries	n/a
Critical (SFW Red and FFER >=1)?	No
Final Factor 5.1 Score	**10.000**

5.2 Net Protein Gain or Loss (%)	Data and Scores
Weighted total feed protein content	17.900
Protein INPUT kg/100kg harvest	17.900
Whole body harvested fish protein content	18.000
Net protein gain or loss	Unfed
Species-specific Factor 5.2 score	**10**
Critical (Score = 0)?	No
Critical (FFER >3 and 5.2 score <2)?	No

5.3 Feed Footprint	Data and Scores
GWP (kg CO2-eq kg^{-1} farmed seafood protein)	n/a
Contribution (%) from fishmeal from whole fish	n/a
Contribution (%) from fish oil from whole fish	n/a
Contribution (%) from fishmeal from by-products	n/a
Contribution (%) from fish oil from by-products	n/a
Contribution (%) from crop ingredients	n/a
Contribution (%) from land animal ingredients	n/a
Contribution (%) from other ingredients	n/a
Factor 5.3 score	**10**
C5 Final Feed Criterion Score	**10.0**
Critical?	**No**

Washington State and British Columbia

Criterion 6: Escapes	Data and Scores
F6.1 System escape risk	0
Percent of escapees recaptured (%)	0.000
F6.1 Recapture adjustment	0.000
F6.1 Final escape risk score	0.000
F6.2 Invasiveness score	8
C6 Escape Final Score (0–10)	**4.0**
Critical?	No

Washington State and British Columbia

Criterion 7: Disease	Data and Scores
Evidence-based or Risk-based assessment	Risk
Final C7 Disease Criterion score (0–10)	**7**
Critical?	No

Washington State and British Columbia

Criterion 8X Source of Stock	Data and Scores
Percent of production dependent on wild sources (%)	0.0
Initial Source of Stock score (0–10)	0.0
Use of ETP or SFW "Red" fishery sources	No
Lowest score if multiple species farmed (0–10)	n/a
C8X Source of stock Final Score (0–10)	**0**
Critical?	No

Washington State and British Columbia

Criterion 9X Wildlife Mortality parameters	Data and Scores
Single species wildlife mortality score	–2
System score if multiple species assessed together	n/a
C9X Wildlife Mortality Final Score	**–2**
Critical?	No

Washington State

Criterion 10X: Introduction of Secondary Species	Data and Scores
Production reliant on trans-waterbody movements (%)	10
Factor 10Xa score	8
Biosecurity of the source of movements (0–10)	6
Biosecurity of the farm destination of movements (0–10)	1
Species-specific score 10X score	–0.800
Multispecies assessment score if applicable	n/a
C10X Introduction of Secondary Species Final Score	**–0.800**
Critical?	n/a

British Columbia

Criterion 10X: Introduction of Secondary Species	Data and Scores
Production reliant on trans-waterbody movements (%)	5
Factor 10Xa score	9
Biosecurity of the source of movements (0–10)	6
Biosecurity of the farm destination of movements (0–10)	1
Species-specific score 10X score	–0.400
Multispecies assessment score if applicable	n/a
C10X Introduction of Secondary Species Final Score	**–0.400**
Critical?	n/a