Monterey Bay Aquarium
Seafood Watch®

Farmed Pacific Geoduck

Panopea generosa (formerly *Panopea abrupta*)

Washington State, USA and British Columbia, Canada

On Bottom Culture

January 24, 2014

Brian Albaum, Seafood Watch staff

Disclaimer

Seafood Watch and Seafood Reports are made possible through a grant from the David and Lucile Packard Foundation.

Final Seafood Recommendation

Criterion	Score (0-10)	Rank	Critical?
C1 Data	7.92	GREEN	
C2 Effluent	10.00	GREEN	NO
C3 Habitat	7.22	GREEN	NO
C4 Chemicals	10.00	GREEN	NO
C5 Feed	10.00	GREEN	NO
C6 Escapes	10.00	GREEN	NO
C7 Disease	8.00	GREEN	NO
C8 Source	9.00	GREEN	
3.3X Wildlife mortalities	-2.00	GREEN	NO
6.2X Introduced species escape	0.00	GREEN	
Total	**69.36**		
Final score	**8.67**		

Final Score	8.67
Initial rank	GREEN
Red criteria	0
Interim rank	GREEN
Critical Criteria?	NO
Final Rank	BEST CHOICE

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

Summary

Pacific geoduck aquaculture operations in Washington State, USA and British Columbia, Canada are shown to have a minor impact on surrounding environments. Geoduck culture does not require the use of chemicals or external feeds, indicating that there are no significant effluents emanating from geoduck farms. Additionally, geoduck aquaculture scores highly in all the assessed criteria, resulting in a final numerical score of 8.93 and a final recommendation of "Green – Best Choice".

Executive Summary

Pacific geoduck clams (*Panopea generosa)* are the world's largest species of burrowing clam: for aquaculture operations juvenile geoduck are buried in the sediment where they remain for the duration of the production cycle. The aquaculture industry for Pacific geoduck is centered in Washington State, USA and British Columbia, Canada. Overall, geoduck aquaculture is shown to have minimal environmental impacts:

- Data availability and robustness was generally good for the purposes of this assessment;
- As bivalves naturally filter-feed the water to obtain nutrition, no external feeds are provided to cultured geoduck clams and therefore geoduck farming does not result in significant effluents;
- While habitat modification occurs during the course of geoduck culture, the disturbances are infrequent during the 6-7 year production cycle, and the effects are shown to be minor and rapidly reversible;
- No chemicals are used in the farmed geoduck industry;
- Geoducks are sedentary organisms that burrow into the sediment during the juvenile stage and remain buried their entire lives; the risk of escape is therefore negligible. Any animals that did remove themselves from the sediment would quickly fall prey to intertidal predators. In addition, as geoduck broodstock are collected from the wild, potential escapes from natural broadcast spawning would be genetically similar to wild populations;
- Clams in general are not highly susceptible to disease and there is no evidence of disease transmission between cultured and wild geoduck;
- Geoduck broodstock are collected from the wild, but the small number of individuals required is not considered to have a significant impact on the status of wild populations;
- Overall, geoduck aquaculture has minimal environmental impacts and scores highly in all assessed criteria, resulting in a "Green – Best Choice" Seafood Watch recommendation.

Table of Contents

Introduction

Scope of the analysis and ensuing recommendation

Species
Farmed geoduck clam (*Panopea generosa*)

Geographic Coverage
Washington State, USA and British Columbia, Canada. While it is recognized that there are nascent geoduck aquaculture industries in Alaska and Mexico, these production volumes are minor and as such these regions are not included in the scope of this assessment.

Production Methods
On-bottom culture utilizing intertidal and subtidal benthic plots. Harvested using "stingers"/ low-pressure water guns.

Species Overview
Pacific geoducks (*Panopea generosa* Gould, 1850) are the largest species of burrowing clam in the world (ADFG 2013). They are found in soft intertidal and subtidal substrates from approximately the zero tide line down to 100 meters along the Pacific coast of North America, ranging from Alaska to California (Anderson 1971). They are extremely long-lived organisms, with many examples of animals over 100 years old (Goodwin 1976, Shaul and Goodwin 1982, Sloan and Robinson 1984, Campbell and Ming 2003).

Geoducks are broadcast spawners that commonly spawn in the spring and summer (Sloan and Robinson 1984, Campbell and Ming 2003) and produce veliger larvae that remain planktonic for 16 to 47 days (Goodwin *et al.* 1979). Postlarvae settle onto the substrate and develop into juveniles that burrow into the sediment. Following metamorphosis from veliger to juvenile stage, adult geoducks remain in the general substrate area of settlement (ADFG 2013). Muscular, extendable siphons can reach lengths of up to 1 meter and are pushed up through the sediment and used to filter-feed for phytoplankton, the principal food item of the species (ADFG 2013).

Lucrative commercial wild fisheries exist in the states of Washington and Alaska, and in British Columbia, Canada (Hoffmann *et al.* 2000). Aquaculture operations are centered in Washington state and British Columbia. While intertidal husbandry of geoduck is a relatively new aquaculture technology, given the extractive nature of bivalve farming and the fact that no feed inputs are required, it is generally accepted that the environmental impacts are minimal (Brown and Thuesen 2011).

Common/ Market Names

Scientific Name	*Panopea generosa*
Common Name	Pacific geoduck/ King clam/ Elephant-trunk clam
United States	Geoduck clam/ Giant clam
Germany	Geoduck-Muschel
Spain	Almeja
France	Panope
Japan	Mirugai

Production Statistics

The following tables illustrate the wild-capture and aquaculture production of geoduck in 2010. More recent production figures were unavailable at the time of this report.

Table 1. 2010 wild-capture geoduck production (tonnes) (Source: GSGislason 2012)

British Columbia	Alaska	Washington	Mexico	**Subtotal (Wild)**
1610	382	1963	1241	**5196**

Table 2. 2010 aquaculture geoduck production (tonnes) (Source: GSGislason 2012)

British Columbia	Washington State	**Subtotal (Farmed)**
45	613	**658**

The Washington Department of Natural Resources is currently trialing a program to license geoduck farmers to operate on state-owned tidelands; however, to date commercial geoduck aquaculture occurs principally on privately-owned lands that are either leased by commercial shellfish growers or farmed by landowners themselves in small-scale operations (Brown and Thuesen 2011). This differs from the wild-stock commercial fishery that occurs in subtidal, state- or provincially-managed aquatic lands throughout Puget Sound, Washington and British Columbia (Brown and Thuesen 2011).

Import/ Export Statistics

Major sources of geoduck imports to the United States (both farmed and wild) in 2012 included Canada (192.5 mt) and Mexico (0.7 mt) (NOAA 2013). In 2012 the United States exported a total of 3964.6 mt of geoduck, with primary destinations including China (3414 mt) and Canada (531.5 mt) (NOAA 2013).

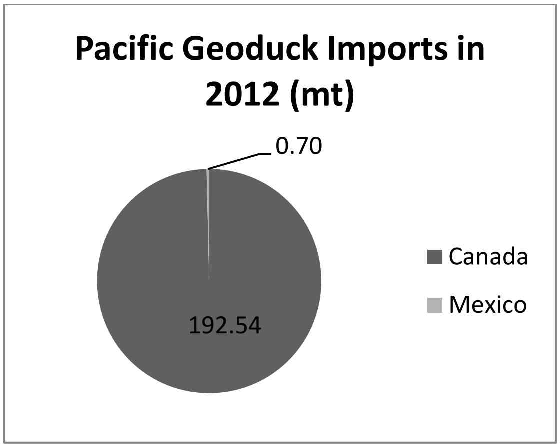

Figure 1. Volume of Pacific geoduck imported to the United States in 2012.

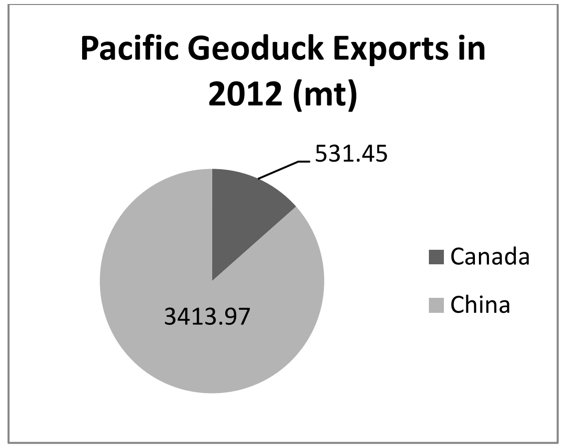

Figure 2. Volume of Pacific geoduck exported from the United States in 2012.

Product Forms

The vast majority of geoduck farmed in the Pacific Northwest (Washington State and British Columbia) is sold as live product. Relatively minor volumes are frozen or canned.

Analysis

Scoring guide

- With the exception of the exceptional factors (3.3x and 6.2X), all scores result in a zero to ten final score for the criterion and the overall final rank. A zero score indicates poor performance, while a score of ten indicates high performance. In contrast, the two exceptional factors result in negative scores from zero to minus ten, and in these cases zero indicates no negative impact.
- The full Seafood Watch Aquaculture Criteria that the following scores relate to are available here http://www.montereybayaquarium.org/cr/cr_seafoodwatch/content/media/MBA_SeafoodWatch_AquacultureCriteraMethodology.pdf
- The full data values and scoring calculations are available in Appendix 1

Criterion 1: Data quality and availability

Impact, unit of sustainability and principle

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

Criterion 1 Summary

Data Category	Relevance (Y/N)	Data Quality	Score (0-10)
Industry or production statistics	Yes	7.5	7.5
Effluent	No	n/a	n/a
Locations/habitats	Yes	10	10
Predators and wildlife	Yes	7.5	7.5
Chemical use	No	n/a	n/a
Feed	No	n/a	n/a
Escapes, animal movements	Yes	5	5
Disease	Yes	7.5	7.5
Source of stock	Yes	10	10
Other – (e.g. GHG emissions)	No	n/a	n/a
Total			**47.5**

C1 Data Final Score	**7.92**	**GREEN**

Justification of Ranking

Information availability and robustness is generally good with respect to geoduck aquaculture. Industry and production statistics are available through the Food and Agricultural Organization (FAO) of the United Nations, the Washington State Department of Fish and Wildlife, and the British Columbia Ministry of Agriculture. Geoduck are filter-feeders and therefore remove phytoplankton and organic material from the water column- as no external feed is provided, effluent was deemed to be not applicable to this assessment and data availability for this criterion was not scored. As no chemicals are used in geoduck aquaculture, this criterion is also not relevant to this assessment and was not scored in this data criterion. There is some information on geoduck escapes and diseases, however like chemical use these issues do not present major challenges to the industry and as such small amounts of information on these subjects is to be expected. The impacts of geoduck aquaculture on locations and habitats surrounding farms have been extensively studied and therefore a great deal of information is available for this criterion. Additionally, the source of farmed stock is well documented and studies conclusively show that the removal of wild individuals for use as broodstock has no impact on wild populations.

Overall the data availability score is 7.92 out of 10.

Criterion 2: Effluents

Impact, unit of sustainability and principle

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

Criterion 2 Summary

Rapid assessment – used when good quality data clearly defines an appropriate score

C2 Effluent Final Score	**10.00**	**GREEN**

Justification of Ranking

Bivalve mollusks are filter-feeders, meaning that they filter water to gather phytoplankton and other organic materials on which to feed: in this way, bivalve shellfish culture is known as "extractive" whereas the presence of the farming operation contributes to an overall decrease of nutrients in the surrounding system. As such, these operations do not require any inputs of external feeds, relying completely on natural plankton populations to provide nutrition to the growing animals.

All bivalve shellfish produce two main types of wastes: the first is typical metabolic solid waste in the form of feces. The second is a waste unique to bivalves: as the animal filter-feeds, some particles in the water that are deemed unfit for digestion (due to size, density, or other factors) are encased in mucus and discharged from the animal. These wastes are known as pseudofeces due to the fact that they resemble typical metabolic feces. The accumulation of both feces and pseudofeces has the potential to cause negative environmental impacts. This is generally only a concern with suspended three dimensional shellfish culture systems such as mussel rafts where greater densities of animals are cultured and accumulation of feces/pseudofeces can occur. Geoduck are cultured in a single layer in the sediment and therefore these impacts are considered minimal.

Another potential effluent to consider is associated with geoduck harvest methods. Harvesting occurs on the beach at low tide or by diving when tides are not low. In either case, harvesters use high-volume, low-pressure water pipes (known as "stingers") to liquefy the sediment and remove market-sized geoducks (Straus *et al.* 2009). While water gun harvest causes increased turbidity, suspension of sediments, and the release of nutrients contained within the benthos (Fisher *et al.* 2008), geoduck farming takes place in shallow coastal areas which experience a high frequency of disturbances (e.g. storms, currents, boat wakes) and have been shown to recover from these disturbances within a few weeks or months (Coen 1995). Additionally, species in these areas tend to be opportunists that tolerate highly turbid conditions and are capable of rapidly recolonizing disturbed seafloor habitats (Stokesbury *et al.* 2011). Therefore, the environmental footprint associated with geoduck harvest appears to be minimal (Kaiser *et al.* 1996).

As geoduck farming does not require any external feed inputs and the animals themselves contribute to an overall reduction in nutrients, a score of 10 out of 10 is assigned to the effluent criterion.

Criterion 3: Habitat

Impact, unit of sustainability and principle

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

Criterion 3 Summary

Habitat parameters	Value	Score	
F3.1 Habitat conversion and function		7.00	
F3.2a Content of habitat regulations	4.25		
F3.2b Enforcement of habitat regulations	4.50		
F3.2 Regulatory or management effectiveness score		7.65	
C3 Habitat Final Score		**7.22**	**GREEN**
Critical?	NO		

Justification of Ranking

Factor 3.1. Habitat conversion and function

Geoducks are farmed in soft sediments in the intertidal and subtidal benthic zones. In the Seafood Watch Aquaculture Criteria, habitat conversion is assessed by the effect of aquaculture activities on ecosystem services. Geoduck farming (and bivalve farming in general) has been associated with few negative impacts (Giles *et al.* 2009), however the habitat impacts that do occur are discussed below.

The Washington Department of Fish and Wildlife (WDFW) actively cultivated geoducks beginning in the 1970s through 2000 and developed many of the culture practices in use today (Feldman *et al.* 2004). In an effort to reduce predation on juvenile geoducks, WDFW experimented with growing outplanted geoduck seed in mesh-covered polyvinylchloride (PVC) tubes placed in intertidal beds as well as in tree planting cones placed in subtidal beds (Feldman *et al.* 2004); while both these practices were deemed initially successful in reducing predation on cultured geoduck (Feldman *et al.* 2004), current operations do not use tree planting cones because they discolor the geoducks (reducing their market value) and dissolve too quickly, resulting in increased predation late in the production cycle. As such PVC tubes are the principal method used to prevent predation.

The placement of anti-predation equipment into the benthos of the growing area may have inherent visual impacts; however the habitat impacts appear minimal (Fisher *et al.* 2008).

Additionally, these predator exclusion tubes are only in place for the first 1-2 years of what is typically a 6-7 year production cycle, indicating that any visual impacts are temporary.

Pacific herring (*Clupea pallasii*) spawn on three-dimensional substrate in the intertidal zone, including macroalgae and ironically geoduck tubes (Fisher et al. 2008). If a geoduck aquaculture site is located in a documented herring spawning area, industry Best Management Practices dictate that farmers avoid disruptive activities during the herring spawning and incubation periods (Fisher et al. 2008). Additionally, tubes or netting are purposefully not removed if found to contain herring eggs (Fisher et al. 2008). Finally, the removal of anti-predation equipment is conducted during seasons in which daylight and tides correspond to crews being able to work on the beach (i.e. late April through September) – these time periods inherently miss the spawning season (i.e. February/ March) for herring in the Pacific Northwest (Lassuy 1989). Therefore, while geoduck aquaculture has the potential to impact herring spawning, all indications are that this is not occurring.

Once out-growing is complete, geoducks are harvested using “stingers”, a device that utilizes high volume/low-pressure water to quickly soften the sediment around the geoduck so they can be pulled from the benthos (Straus *et al.* 2009). This practice may alter the abiotic condition of the sediment (grain size, oxygen, nutrient levels, etc.) as well as alter the community of organisms in the benthos (Straus et al 2009). However, geoduck farming takes place in shallow coastal areas which have been shown to recover from major disturbances within a few weeks or months (Coen 1995), a timeframe that represents a very minor portion of the 6-7 year production cycle. Species in these areas tend to be opportunists that tolerate highly turbid conditions and are capable of rapidly recolonizing disturbed seafloor habitats (Stokesbury *et al.* 2011). Several additional studies demonstrate that although there are localized short-term effects involved in bivalve aquaculture, no evidence of sustained habitat loss or water-quality decline can be detected (Kaiser *et al.* 1996; Dumbauld *et al.* 2009, Sauchyn *et al.* 2013).

While habitat impacts associated with geoduck aquaculture exist, they appear to be minimal and short-lived. Therefore, a score of 7 out of 10 has been assigned for the maintenance of habitat functionality score, indicating that while habitat impacts occur, overall habitat functionality is maintained.

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

Factor 3.2 considers both the content of national/ regional legislation regulating habitats (F3.2a) as well as that legislation’s enforcement (F3.2b). See Appendix 1 for specific scores relating to the outcome of Factor 3.2.

Geoduck aquaculture occurs in both the United States of America and Canada, creating two different regulatory environments within the region under assessment.

Washington State

In the United States, the U.S. Army Corps of Engineers issues aquaculture permits before a farm can be established; this requires consultation with the National Marine Fisheries Service and the U.S. Fish and Wildlife Service, as well as State-level approval that the operation is consistent with relevant coastal zone management (CZM) programs. In Washington State, approval is required from the Washington Department of Ecology for consistency with the Clean Water Act and relevant coastal zone managements programs (Washington State Department of Ecology 2008). Additionally, 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 (Washington State Department of Ecology 2008). Prior to harvesting, farm operators must be licensed by the state Department of Health and each farm site must be certified as meeting water quality standards.

Washington State Department of Natural Resources (WDNR) has created a set of Best Management Practices (BMPs) for geoduck aquaculture on public tidelands. Site-selection BMPs are directed at avoiding and minimizing potential impacts of aquaculture operations on aquatic (or terrestrial) resources and interactions with other users of marine resources (Dewey *et al.* 2011, Getchis and Rose 2011). In addition, the Pacific Coast Shellfish Growers Association (PCSGA) has developed an Environmental Code of Practice for shellfish aquaculture. It should be noted that relatively small volumes of geoduck are cultivated on WDNR tidelands with the majority of production occurring on private tidelands where the BMPs are at the discretion of the tideland owner.

British Columbia

British Columbia is the main producer of farmed geoducks in Canada. Historically, all individual Canadian Provinces were responsible for aquaculture planning, site leasing, licenses and approvals for sites, aquaculture training and education, collection of statistics, and the management of the industry's day-to-day operations. However, as a result of a ruling by the British Columbia Supreme Court in February 2009, marine aquaculture in B.C. was classified as a fishery and therefore placed under the exclusive jurisdiction of the federal government. As such, in December 2010, regulatory authority of the finfish and shellfish aquaculture industries in B.C. was transferred from the Province of British Columbia to the federal department of Fisheries and Oceans Canada (DFO).

The primary federal legislations for the regulation of aquaculture are the Fisheries Act Regulations (1995, as amended 2012), the Pacific Aquaculture Regulations (2010), the Canadian Environmental Assessment ACT (1992) and the Navigable Waters Protection Act (1985) while the applicable provincial regulations include the Fisheries Act (1996), the Aquaculture Regulation (2002), and the Environmental Management Act (SCBC 2003 C.53). Additionally, the B.C. Shellfish Growers Association employs the Environmental Management System Code of Practice that fosters commitment to working with growers to protect marine resources (Dewey *et al.* 2011).

In British Columbia, Conservation and Protection (C&P) fishery officers enforce relevant regulations, monitor aquaculture operations, and perform investigations in response to complaints (Fisheries and Oceans Canada 2013). The results of site inspections and technical audits are made available online to provide public transparency and validate publically-available data reported by the industry (Fisheries and Oceans Canada 2013).

Overall Factor 3.2 receives a score of 7.65 out of 10.

Factors 3.1 and 3.2 combine to result in an overall score of 7.22 for Criterion 3 – Habitat.

Factor 3.3X: Wildlife and predator mortalities

A measure of the effects of deliberate or accidental mortality on the populations of affected species of predators or other wildlife.

This is an "exceptional" factor 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.

Factor 3.3X Summary

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

Justification of Ranking
Aquaculture operations can attract a variety of predators and result in direct or indirect mortality from trapping, entanglement, drowning, etc. Predator exclusion devices used on geoduck clam farms are usually in the form of netting or PVC tubing, both of which are forms of passive non-harmful barriers and result in minimal or no direct or accidental mortality of predators or other wildlife.

Based on dive surveys over planted geoduck beds and results of limited laboratory studies, epibenthic predators of juvenile geoducks in Puget Sound include crabs (*Cancer productus* and *Cancer gracilis*), sea stars (*Pisaster brevispinus* and *Pycnopodia helianthoides*), gastropods (*Polinices lewisii*, *Natica* sp. and *Nassarius mendicus*), and flatfishes (*Platichthys stellatus*, *Parophyrs vetulus*, *Lepidopsetta bilineata*, and *Psettichthys melanostictus*) (Feldman *et al.* 2004). Black scoters (*Melanitta nigra americana*) are suspected but unconfirmed predators of juvenile geoduck seed (Feldman *et al.* 2004).

In preparation for seeding juvenile geoduck, farmers occasionally engage in the removal and relocation of predatory snails and sea stars from the culture beds. The removal of these predator species has not been shown to have any long-term or population-level impacts and the shallow coastal areas where geoduck farming occurs has been shown to recover from major disturbances in relatively short timespans (Coen 1995). Species in these areas, including all the predatory species listed above, have robust populations within the Pacific Northwest region covered in this assessment (Stokesbury *et al.* 2011), and no endangered or threatened species are known to prey on cultured geoducks. Additionally, these species are capable of rapidly recolonizing disturbed seafloor habitats (Stokesbury *et al.* 2011). One potential source of mortalities associated with geoduck farms are birds and other air-breathing organisms that become trapped or entangled in the nets placed over the culture area, however no widespread evidence of these types of mortalities exists.

While minor numbers of predator mortalities may occur, there is no evidence to suggest wide-scale mortalities and therefore measurable impacts on surrounding wildlife populations. A score of -2 out of -10 is therefore assigned to this factor.

Criterion 4: Evidence or Risk of Chemical Use

Impact, unit of sustainability and principle

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

Criterion 4 Summary

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

Justification of Ranking

Historically, the purpose of chemical treatment in bivalve aquaculture has been to prevent predators, fouling, and infection by disease-causing bacteria, viruses, and protozoans. The use of chemical substances (i.e. copper sulfate, calcium oxide, sand coated with trichloroethylene, and insecticides) to control predators of molluscs was pioneered in the United States in the 1930s (Loosanoff 1960, Jory *et al.* 1984). While such chemicals proved effective at predator control, the environmental and public health risks far outweighed the benefits. As such, chemicals are no longer used to control predators on shellfish farms and have never been used on geoduck clam farms.

Best management practices for geoduck farming designate manual labor to prevent and remove predators and fouling from gear. As opposed to antibiotics, improved husbandry and cleaning methods are employed to prevent bacterial infections. No chemicals are used during the grow-out phase of geoduck culture. Cleaning solutions (bleach) and rinse water used during the hatchery phase go into floor drains that may outfall to the marine environment, however the volumes used are minimal and no impact of this discharge has been detected (Flimlin *et al.* 2010).

A review of predator controls in bivalve culture conducted by Jory *et al.* (1984) revealed that the installation of exclusionary devices (i.e. netting) was more successful than chemical treatment for control of bivalve predators. Some shellfish growers associations have adopted best management practices in which predator control is addressed by exclusionary devices and frequent inspection of sites followed by hand-removal and relocation of predators (Flimlin *et al.* 2010).

Antibiotics are not used in the grow-out phase of clam farming (British Columbia Shellfish Growers Association 2013). Bacteria that may cause disease in the larval phase often originate in algal cultures or from incoming water and pipes or other hatchery equipment; while it is possible to control these bacteria with antibiotics (Ford *et al.* 2001), this practice does not occur as hatchery operators are concerned with the development of antibiotic resistance. Instead hatchery operations rely on improved animal husbandry and regular cleaning of hatchery equipment (Ford *et al.* 2001, Flimlin *et al.* 2010). Dilute hypochlorite (bleach) solutions often are used for disinfection of equipment, but they are disposed of in the municipal sewer system instead of the marine environment (Flimlin *et al.* 2010).

Chemical use, other than sodium hypochlorite and sodium thiosulfate, in geoduck hatcheries does not occur, and although water is discharged to the marine environment, the relative volumes of these cleaning solutions used are minute and there is no demonstrable impact of chemical contamination as a result (Flimlin *et al.* 2010). Additionally, there is no use of chemicals during the grow-out phase of geoduck clam farming. The most effective methods of treatment for predator and fouling control is exclusion and manual removal, which does not entail discharge of active chemicals. Therefore, the chemical use score is 10 out of 10.

Criterion 5: Feed

Impact, unit of sustainability and principle

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

Criterion 5 Summary

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

Justification of Ranking

Bivalve shellfish farming does not utilize any fishmeal or fish oil as external feeds are not provided to the farm stock. Cultured geoduck clams are filter feeders and obtain nutrition by feeding on natural plankton populations. It is generally accepted that the avoidance of external feeds indicates that the environmental footprint regarding feed for geoduck is negligible for the purposes of this assessment. A score of 10 out of 10 is therefore assigned to Criterion 5 – Feed.

Criterion 6: Escapes

Impact, unit of sustainability and principle

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

Criterion 6 Summary

Escape parameters	Value	Score	
F6.1 Escape Risk		10.00	
F6.1a Recapture and mortality (%)	100		
F6.1b Invasiveness		9	
C6 Escape Final Score		**10.00**	**GREEN**
Critical?	NO		

Justification of Ranking

Factor 6.1a. Escape risk

Typical production systems for farmed bivalves include a hatchery phase and a grow-out phase. The grow-out phase for geoducks occurs in open systems (e.g. subtidal and intertidal flats in coastal and estuarine areas). However, while these systems are open to the environment (i.e. no separation between the culture area and the surrounding water column), juvenile geoduck seeded into the sediment for grow-out are not able to escape: as dictated by their physiology, geoducks are sedentary organisms and are not capable of escaping from the sediment into which they are seeded as juveniles.

Geoduck physiology dictates that the sediment itself is the main barrier between geoducks and their predators. If a juvenile or adult geoduck were to be removed from beneath the sediment, it would quickly fall prey to any number of the predatory organisms in the subtidal zone[1]: as such, the mortality rate of escaped geoduck is 100%. Harvesting of geoduck often results in a few individuals being left behind in the sediment, and it is also accepted that small numbers of juvenile geoduck are lost during outplanting (and thus are released into the environment).

[1] Most bivalves utilize their shells for defense against predators, drawing their entire body mass inside their shells and closing the shells tightly to avoid predation. Geoducks have small shells relative to their body mass and are not able to withdraw their large siphon and mantle completely inside their shells, meaning that they are unable to utilize their shells as predator defenses (WDFW 2013).

Despite the use of open systems for geoduck aquaculture, the risk of farm stock escaping is negligible. A score of 10 out of 10 is assigned to this factor.

Factor 6.1b. Invasiveness

Geoduck clams have a natural geographic range from Alaska to Baja California, however commercial wild harvests are centered in Alaska, British Columbia, and Washington state (WDFW 2013). This assessment evaluates geoduck aquaculture in the Pacific Northwest region, specifically Washington state and British Columbia. This indicates that geoduck aquaculture production, as assessed here, is occurring within the natural geographic range of the species.

Scientific studies in Puget Sound, Washington suggest that there is no reproductive isolation among populations of geoducks, indicating that all geoduck clams in the region belong to the same “metapopulation” and are capable of interbreeding (Valdopalas *et al.* 2004). Valdopalas *et al.* found extensive genetic diversity within the geoduck clam genome, and when coupled with the large endemic population size, concluded that the likelihood of cross-fertilization resulting in deleterious effects in the wild population is extremely remote (2004).

Furthermore, many (but not all) geoduck aquaculture operations have adopted best management practices aimed at reducing the potential for genetic interactions among hatchery and wild geoducks, as well as reducing the potential loss of genetic variation within the species over time (Fisher *et al.* 2008). As mature geoduck on farm sites are able to spawn before being harvested, there is potential for farmed gametes to enter the wild gene pool and as such the BMP’s are intended to avoid any domestication in the wild stocks. These BMPs include: a) no hatchery-produced geoducks are used as broodstock; b) local, wild individuals are collected for use as broodstock; c) different individuals are used for each spawn and broodstock are exchanged periodically for new wild geoduck; d) different aged organisms and multiple males and females are used for each spawn; e) thorough mixing of all gametes insures as diverse a genetic product as possible (Fisher *et al.* 2008).

There is no indication that escapees compete with wild populations for food, habitat, or breeding partners (Fisher *et al.* 2008). Additionally, geoducks that escape from farm sites would not modify habitats to the detriment of other species, nor would they have any significant impact on other organisms. The score for Factor 6.1b is 9 out of 10.

When the scores for Factor 6.1a and 6.1b are combined, the final numerical score for Criterion 6 – Escapes is 10 out of 10 indicating that there are no concerns relating to escapes from geoduck farming.

Factor 6.2X: Escape of unintentionally introduced species

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

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

Factor 6.2X Summary

Escape of unintentionally introduced species parameters	Score	
F6.2Xa International or trans-waterbody live animal shipments (%)	10.00	
C6 Escape of unintentionally introduced species Final Score	**0.00**	**GREEN**

Justification of Ranking

Trans-waterbody movement is defined as the source water body being ecologically distinct from the destination/ farming water body such that live animal movements represent a risk of introducing non-native species. While geoduck seed from Canada may be imported into the United States for grow-out in Washington state, this seed is required to be produced from Washington origin broodstocks and are spawned in quarantined systems in Canada, ensuring no introductions of other species. Appropriate testing and notification to Washington Department of Fish and Wildlife is required: Canada does not allow export of Canadian seed into the US and the US does not allow import of Canadian seed. Additionally, the Pacific Northwest is considered a homogenous ecological region for the purposes of this assessment. As such, no international or trans-waterbody shipment of live animals occurs in geoduck aquaculture. Therefore this exceptional score is not applied to this assessment (i.e. the deduction is zero).

Criterion 7. Disease; pathogen and parasite interactions

Impact, unit of sustainability and principle

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

Criterion 7 Summary

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

Justification of Ranking

Geoducks in general are not highly susceptible to disease and there are few reports of disease outbreaks affecting wild geoduck populations, thus there is little evidence to suggest that there is a major threat to wild geoduck stocks posed by aquaculture operations. In the case that disease affects geoduck culture, it is most likely to affect the hatchery stages of production as opposed to out-growing stages.

The high volumes and concentrations of juvenile shellfish in hatcheries represent an ideal environment for opportunistic disease agents to become established (Elston and Ford 2011). These agents may be introduced into shellfish hatcheries through a variety of vectors, including algal food sources, broodstock transfer, or incoming seawater (Elston and Ford 2011). Hatchery-produced geoduck larvae and seed have been shown to be extremely susceptible to large unexplained mortalities, however no peer-reviewed studies specific to geoduck were available at the time of this assessment. However, Paillard (2004) concluded that larvae of a related clam species (*Veneridae* spp.) are particularly vulnerable to bacterial and viral infections, including members of the genus Vibrio.

An *Isonema*-like amoeboflagellate was associated with disease and mortalities among cultured larval geoduck clams in the only geoduck clam experimental hatchery in operation in Washington State during the 1980s (Brown and Blackbourn 2003). There have been no other reports of invasive, pathogenic *Isonema* sp. and it was suggested that inclement conditions within the culture system may have predisposed the geoduck clam larvae to infection and the resulting mortalities (Brown and Blackbourn 2003). This flagellate is not known to infect juvenile or adult geoduck clams nor oyster larvae grown in the same hatchery facility as infected larval geoduck clams (Brown and Blackbourn 2003). In subsequent years, this parasite has not been encountered during the commercial hatchery production of geoduck seed in Washington nor in British Columbia (Brown and Blackbourn 2003).

There is no published research on disease specific to wild geoduck clams (*Straus et al.* 2008). Research is underway at Washington Sea Grant and the University of Washington to elucidate cultured and wild interactions with disease prevalence in wild geoduck populations (GARP 2009). Initial research indicates that the risk of farmed geoduck introducing disease (new or existing) to wild geoduck populations is low. However, geoducks are known to act as seasonal or temporary hosts to the algal species which cause paralytic shellfish poisoning (PSP) in humans (ADFG 2013).

There is no evidence of amplification or retransmission of disease from cultured to wild geoducks at this time. It is recognized that a risk of amplification of disease within the culture stock exists because the average biomass densities are higher on geoduck farms than in the wild; farms average 13.5 geoducks/ m^2. In the wild, geoduck distribution ranges from 0 – 22.5 geoducks/ m^2, with an average of 1.7 geoducks/ m^2 (Strauss *et al.* 2008).

In a preliminary study, cultured juvenile geoduck clams planted at four locations in the Strait of Georgia, British Columbia, were surveyed for infectious diseases: upon histological examination, none of the 795 cultured geoducks showed signs of infectious diseases or pathogenic organisms (Bower and Blackbourn 2003).

The U.S. Department of Agriculture requires compliance with the Shellfish High Health Plan for all shellfish farms applying for the Animal and Plant Health Inspection Service certifications necessary for interstate export of live shellfish. This Plan requires a customized animal health management plan for shellfish farms, which reduces the risks associated with infectious disease outbreaks (Elston and Ford 2011).

The World Organization for Animal Health has adopted the Aquatic Animal Health Code as well as the Manual of Diagnostic Tests for Aquatic Animals (OIE 2011, 2012). These documents provide a guide for authorities in member countries to develop and implement country-level standards related to aquatic products that carry the risk of disease.

Within state transfers of live bivalves for movement from one water body to another requires a transfer permit for the Washington Department of Fish and Wildlife. This provides further protection from the transfer of disease, parasites, or pests.

For the aquaculture industry in general, farm systems that are open to the environment represent a moderate to high risk of pathogen and parasite interaction between cultured and wild animals. However, adherence to existing laws and regulations, implementation of biosecurity measures and Best Management Practices, as well as a historical record of few disease outbreaks reduces this risk to low-moderate for geoduck aquaculture. As the scientific evidence suggests that the risk for amplification and/or retransmission of diseases from geoduck farming is low, a score of 8 out of 10 is assigned to the disease criterion.

Criterion 8. Source of Stock – independence from wild fisheries

Impact, unit of sustainability and principle

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

Criterion 8 Summary

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

Justification of Ranking

Geoduck clams are broadcast spawners with very high fecundity: tens of millions of gametes can be produced by a single animal in a single spawning session (ADFG 2013). As such, very low numbers of broodstock are needed to produce vast quantities of seed.

Geoduck aquaculture utilizes wild-caught broodstock for seed production (Fisher *et al.* 2008). Despite dependence on wild populations for broodstock, very low numbers of wild individuals are necessary to be collected as broodstock due to the high fecundity of geoducks. This removal of wild geoducks from the environment does not have demonstrable negative impacts on wild stocks and is beneficial in reducing the genetic risks associated with domestication selection across generations (Fisher *et al.* 2008).

Despite efforts directed at selective breeding of geoducks for commercial production, Hedgecock (2011) suggests that no shellfish can be considered domesticated and concludes that the risk of cumulative effects of domestication selection can be mitigated by continual replacement of hatchery broodstock with wild adults and exclusion of hatchery-bred adults from hatchery broodstock (as mandated by industry best Management Practices).

Though an independence from wild stocks is the goal of most aquaculture selective-breeding programs, in the case of commercial geoduck culture the maintenance of an outbred population through the use of wild-caught broodstock is important for genetic variability of an animal grown in its native range. Furthermore, this practice has no demonstrable environmental impact on wild populations. Therefore, a score of 9 out of 10 is applied to this criterion.

Overall Recommendation

The overall recommendation is as follows: **GREEN – BEST CHOICE**

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

– **Best Choice** = Final score ≥6.6 AND no individual criteria are Red (i.e. <3.3)

– **Good Alternative** = Final score ≥3.3 AND <6.6, OR Final score ≥ 6.6 and there is one individual "Red" criterion.

– **Red** = Final score <3.3, OR there is more than one individual Red criterion, OR there is one or more Critical score.

Criterion	Score (0-10)	Rank	Critical?
C1 Data	7.92	GREEN	
C2 Effluent	10.00	GREEN	NO
C3 Habitat	7.22	GREEN	NO
C4 Chemicals	10.00	GREEN	NO
C5 Feed	10.00	GREEN	NO
C6 Escapes	10.00	GREEN	NO
C7 Disease	8.00	GREEN	NO
C8 Source	9.00	GREEN	
3.3X Wildlife mortalities	-2.00	GREEN	NO
6.2X Introduced species escape	0.00	GREEN	
Total	**69.36**		
Final score	**8.67**		

Final Score	8.67
Initial rank	GREEN
Red criteria	0
Interim rank	GREEN
Critical Criteria?	NO
Final Rank	BEST CHOICE

Acknowledgements

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

Seafood Watch would like to thank the following individuals for providing their expert peer review:

- Brady Blake – Washington Department of Fish and Wildlife
- Perry Lund – Washington Department of Ecology
- Vicki Wilson – Arcadia Point Seafood
- Two additional Anonymous Reviewers

References

Alaska Department of Fish and Game (ADFG). 2013. Geoduck Clam (Panopea generosa) Species Profile. Available at http://www.adfg.alaska.gov/index.cfm?adfg=geoduck.main. Accessed 29 March 2013.

Anderson, A. M. J. 1971. Spawning, growth, and spatial distribution of the geoduck clam, *Panope generosa* (Gould) in Hood Canal, Washington. Ph. D. Dissertation, University of Washington, Seattle.

Beattie, H. and Blake, B. 1999. Development of culture methods for the geoduck clam in the USA (Washington state) and Canada (British Columbia). World Aquaculture 30(3): 50-53.

Blazer, V.S. and S.E. LaPatra. 2002. Pathogens of cultured fishes: potential risks to wild fish populations Pages 197-224 in. J. Tomasso, ed. Aquaculture and the Environment in the United States. U.S. Aquaculture Society, A Chapter of the World Aquaculture Society, Baton Rouge, LA.

Bower, S.M. and Blackbourn, J. 2003. Geoduck clam (Panopea abrupta): Anatomy, Histology, Development, Pathology, Parasites, and Symbionts. Department of Fisheries and Oceans Canada. Available at http://www.pac.dfo-mpo.gc.ca/science/species-especes/shellfish-coquillages/geopath/adlcc-eng.htm. Accessed 29 March 2013.

British Columbia Ministry of Agriculture. 2012. British Columbia Seafood Industry Year in Review- 2011. Victoria, BC.

British Columbia Shellfish Growers Association. 2012. http://bcsga.ca/about/frequently-asked-questions/. Accessed 27 March 2013.

Brown, R., and Thuesen, E. 2011. Biodiversity of mobile benthic fauna in geoduck (Panopea generosa) aquaculture beds in southern Puget Sound, Washington. Journal of Shellfish Research 30(3): 771-776.

Campbell, A., and M. D. Ming. 2003. Maturity and growth of the pacific geoduck clam, *Panopea abrupta,* in Southern British Columbia, Canada. *Journal of Shellfish Research* 22:85-90.

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

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

Dumbauld, B., Ruesink, J., & Rumrill, S. 2009. The ecological role of bivalve shellfish aquaculture in the estuarine environment: a review with application to oyster and clam culture in west coast (USA) estuaries. Aquaculture 290:196–223.

Elston, R. A. and Ford, S. E. 2011. Shellfish Diseases and Health Management, in Shellfish Aquaculture and the Environment (ed S. E. Shumway), Wiley-Blackwell, Oxford, UK.

Feldman, K., Vadopalas, B., Armstrong, D., Friedman, C., Hilborn, R., Naish, K., Orensanz, J., Valero, J., Ruesink, J., Suhrbier, A., Christy, A., Cheney, D., and Davis, J. 2004. Comprehensive literature review and synopsis of issues relating to geoduck (*Panopea abrupta*) ecology and aquaculture production. Washington State Department of Natural Resources.

Fisher, J.P., M. Meaders, S. Luchessa, and K. Meuller. 2008. A supplemental analysis of the environmental concerns associated with intertidal geoduck clam aquaculture: effects on wild geoduck genetics, potential for toxin resuspension, and effects on soft-sediment associated communities. Environ International Corporation. Seattle, WA.

Fisheries and Oceans Canada. 2013. Aquaculture Regulation and Enforcement Activities. Available at http://www.pac.dfo-mpo.gc.ca/aquaculture/enforcement-application-eng.html. Accessed on 06 December 2013.

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

Food and Agricultural Organization (FAO) of the United Nations. 2013. Canada. National Aquaculture Legislation Overview- Fisheries and Aquaculture Department. Accessed 26 March 2013. Available at http://www.fao.org/fishery/legalframework/nalo_canada/en.

Ford, S.E. 2001. Pests, parasites, diseases, and defense mechanisms. In: Krauter, J.N., M. Castagna (eds.). Biology of the hard clam. Elsevier: The Nethrlands.

GARP. 2009. Geoduck Aquaculture Research Program Interim Progress Report to the Washington State Legislature. Washington Sea Grant. Seattle, WA. 15pp.

Getchis, T.L., C.M. Rose. 2011. Balancing economic development and conservation of living marine resources and habitats: the role of resource managers. In: Shumway, S.E. (Ed.) Shellfish Aquaculture and the Environment. United Kingdom: Wiley-Blackwell. Pp: 425-446.

Giles, H., Broekhuizen, N., Bryan, K., and Pilditch, C. 2009. Modeling the dispersal of biodeposits from mussel farms: the importance of simulating biodeposit erosion and decay. Aquaculture. 291: 168-178.

Goodwin, C. L. 1976. Observations of spawnings and growth of subtidal geoducks (*Panope generosa,* Gould). *Proceedings of the National Shellfisheries Association* 65:49-58.

Goodwin, C. L., W. Shaul, and C. Budd. 1979. Larval development of the geoduck clam *(Panope generosa*, Gould). *Proceedings of the National Shellfisheries Association* 69:73-76.

GSGislason and Associates Ltd. 2012. The Market for Geoduck. Prepared for Canada Fisheries and Oceans. In Association with Archibald Bedard Consulting, Big Splash Seafoods Corp., and Edna Lam Consulting. Vancouver, Canada.

Hedgecock, D. 2011. Genetics of shellfish on a human-dominated planet. In: Shumway, S.E. (Ed.) Shellfish Aquaculture and the Environment. United Kingdom: Wiley-Blackwell. Pp: 339-357.

Hoffmann, A., A. Bradbury, and C. L. Goodwin. 2000. Modeling geoduck, *Panopea abrupta* (Conrad, 1849) population dynamics. I. Growth. *Journal of Shellfish Research* 19:57-62.

Jory, D.E., M.R. Carriker, E.S. Iversen. 1984. Preventing predation in molluscan mariculture: an overview. Journal of World Mariculture Society. 15: 421-432.

Kaiser, M., Edwards, D., and Spencer, B. 1996. Infaunal community changes as a result of commercial clam cultivation and harvesting. *Aquatic Living Resources* 9:57-63.

Lassuy, D.R.. 1989. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (Pacific Northwest)—Pacific herring. U.S. Fish and Wildlife Service Biological Report 82(11.126).

Loosanoff, V.L., C.L. MacKenzie, L.W. Shearer. 1960. Use of chemicals to control shellfish predators. Science. 131: 1522-1523.

National Oceanic and Atmospheric Administration (NOAA). 2013. Cumulative Trade Data by Product- Clam. National Marine Fisheries Service- Office of Science and Technology. Available at < http://www.st.nmfs.noaa.gov/commercial-fisheries/foreign-trade/applications/trade-by-product>. Accessed 4 April 2013.

OIE. 2011. Manual of diagnostic tests for aquatic animals. Available at http://www.oie.int/international-standard-setting/aquatic-manual/access-online/. Accessed 29 March 2013.

OIE. 2012. Aquatic animal health code. Available at http://www.oie.int/international-standard-setting/aquatic-code/access-online/ Accessed 29 March 2013.

Paillard, C. 2004. A short review of brown ring disease, a vibriosis affecting clams, Ruditapes philippinarum and Ruditapes dessicatus. Aquatic Living Resources. 17: 467-475.

Peterson, B. and Heck, K. 2001a. An experimental test of the mechanism by which suspension feeding bivalves elevate seagrass productivity. Marine Ecology Progress Series 218: 115-125.

Peterson, B. and Heck, K. 2001b. Positive interactions between suspension-feeding bivalves and seagrass - a facultative mutualism. Marine Ecology Progress Series 213: 143-155.

Reusch, T. and Williams, S. 1999. Macrophyte canopy structure and the success of an invasive marine bivalve. Oikos 84: 398-416.

Sauchyn, L., C.M. Pearce, J. Blackburn, L. Keddy, and S. Williams. 2013. Assessing potential benthic habitat impacts of small-scale, intertidal aquaculture of the geoduck clam (Panopea generosa). Canadian Science Advisory Secretariat Research Document 2013/001. Fisheries and Oceans Canada.

Shaul, W., and L. Goodwin. 1982. Geoduck (*Panope generosa*, Bivalvia) age as determined by internal growth lines in the shell. *Canadian Journal of Fisheries and Aquatic Sciences* 39:632-636.

Sloan, N. A., and S. M. C. Robinson. 1984. Age and gonad development in the geoduck clam *Panope abrupta* (Conrad) from southern British Columbia, Canada. *Journal of Shellfish Research* 4:131-137.

Stokesbury, K., Baker, E., Harris, B., and Rheault, R. 2011. Environmental impacts related to mechanical harvest of cultured shellfish. In: Shumway, S.E. (Ed.) Shellfish Aquaculture and the Environment. United Kingdom: Wiley-Blackwell. Pp: 319-338.

Straus, K.M., Crosson, L.M., and Vadopalas, B. 2009. Effects of geoduck aquaculture on the environment: a synthesis of current knowledge. Washington Sea Grant Technical Report WSG-TR 08-01.

Vadopalas, B., L. L. Leclair, and P. Bentzen. 2004. Microsatellite and allozyme analyses reveal few genetic differences among spatially distinct aggregations of geoduck clams (*Panopea abrupta*, Conrad 1849). Journal of Shellfish Research 23: 693-706.

Washington Department of Fish and Wildlife (WDFW). 2013. Geoduck clams. Available at http://wdfw.wa.gov/fishing/shellfish/geoduck/. Accessed 28 March 2013.

Washington State Department of Ecology. 2008. Final Progress Report- House Bill 2220 Shellfish Aquaculture Regulatory Committee. Report to the Washington State Legislature.

Washington State Department of Natural Resources (WSDNR). 2007. 2007 Best management Practices (BMP's) for geoduck aquaculture on state owned aquatic lands in Washington State.

Weise, A., Cromey, C., Callier, M., Archambault, P., Chamberlain, J., McKindsey, C. 2009. Shellfish-DEPOMOD: modeling the biodeposition from suspended shellfish aquaculture abs assessing benthic effects. Aquaculture. 288: 239-253.

About Seafood Watch®

Monterey Bay Aquarium's Seafood Watch® program evaluates the ecological sustainability of wild-caught (hyphen here but not in other places) and farmed seafood commonly found in the United States marketplace. Seafood Watch® defines sustainable seafood as originating from sources, whether wild-caught or farmed, which can maintain or increase production in the long-term without jeopardizing the structure or function of affected ecosystems. Seafood Watch® makes its science-based recommendations available to the public in the form of regional pocket guides that can be downloaded from www.seafoodwatch.org. The program's goals are to raise awareness of important ocean conservation issues and empower seafood consumers and businesses to make choices for healthy oceans.

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

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

Disclaimer

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

Seafood Watch® and Seafood Reports are made possible through a grant from the David and Lucile Packard Foundation.

Guiding Principles

Seafood Watch™ defines sustainable seafood as originating from sources, whether fished[2] or farmed, that can maintain or increase production in the long-term without jeopardizing the structure or function of affected ecosystems.

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

Seafood Watch will:

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

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

practices for some criteria may lead to more energy intensive production systems (e.g. promoting more energy-intensive closed recirculation systems).

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

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

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

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

Appendix 1 - Data points and all scoring calculations

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

Criterion 1: Data quality and availability

Data Category	Relevance (Y/N)	Data Quality	Score (0-10)
Industry or production statistics	*Yes*	7.5	7.5
Effluent	No	5	n/a
Locations/habitats	Yes	10	10
Predators and wildlife	Yes	7.5	7.5
Chemical use	No	n/a	n/a
Feed	No	n/a	n/a
Escapes, animal movements	Yes	5	5
Disease	Yes	7.5	7.5
Source of stock	Yes	10	10
Other – (e.g. GHG emissions)	No	n/a	n/a
Total			**47.5**

C1 Data Final Score	7.916666667	GREEN

Criterion 2: Effluent

C2 Effluent Final Score	**10.00**	**GREEN**

2.2 – Management of farm-level and cumulative impacts and appropriateness to the scale of the industry

Factor 2.2a - Regulatory or management effectiveness

Question	Scoring	Score
1 - Are effluent regulations or control measures present that are designed for, or are applicable to aquaculture?	Moderately	0.5
2 - Are the control measures applied according to site-specific conditions and/or do they lead to site-specific effluent, biomass or other discharge limits?	Moderately	0.5
3 - Do the control measures address or relate to the cumulative impacts of multiple farms?	Moderately	0.5
4 - Are the limits considered scientifically robust and set according to the ecological status of the receiving water body?	Moderately	0.5
5 - Do the control measures cover or prescribe including peak biomass, harvest, sludge disposal, cleaning etc?	Moderately	0.5
		2.5

Factor 2.2b - Enforcement level of effluent regulations or management

Question	Scoring	Score
1 - Are the enforcement organizations and/or resources identifiable and contactable, and appropriate to the scale of the industry?	Moderately	0.5
2 - Does monitoring data or other available information demonstrate active enforcement of the control measures?	Moderately	0.5
3 - Does enforcement cover the entire production cycle (i.e. are peak discharges such as peak biomass, harvest, sludge disposal, cleaning included)?	Moderately	0.5
4 - Does enforcement demonstrably result in compliance with set limits?	Moderately	0.5
5 - Is there evidence of robust penalties for infringements?	Moderately	0.5
		2.5

F2.2 Score (2.2a*2.2b/2.5)	**2.5**

C2 Effluent Final Score	**10.00**	**GREEN**
	Critical?	NO

Criterion 3: Habitat

3.1. Habitat conversion and function

F3.1 Score	**7**

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

Factor 3.2a - Regulatory or management effectiveness

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

Factor 3.2b - Siting regulatory or management enforcement

Question	Scoring	Score
1 - Are enforcement organizations or individuals identifiable and contactable, and are they appropriate to the scale of the industry?	Yes	1
2 - Does the farm siting or permitting process function according to the zoning or other ecosystem-based management plans articulated in the control measures?	Yes	1
3 - Does the farm siting or permitting process take account of other farms and their cumulative impacts?	Yes	1
4 - Is the enforcement process transparent - e.g. public availability of farm locations and sizes, EIA reports, zoning plans, etc?	Mostly	0.75
5 - Is there evidence that the restrictions or limits defined in the control measures are being achieved?	Mostly	0.75
		4.5

F3.2 Score (2.2a*2.2b/2.5)	**7.65**

C3 Habitat Final Score	**7.22**	**GREEN**
	Critical?	NO

Exceptional Factor 3.3X: Wildlife and predator mortalities

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

Criterion 4: Evidence or Risk of Chemical Use

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

Criterion 5: Feed

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

Criterion 6: Escapes

6.1a. Escape Risk

Escape Risk	**10**

Recapture & Mortality Score (RMS)	
Estimated % recapture rate or direct mortality at the escape site	100
Recapture & Mortality Score	1
Factor 6.1a Escape Risk Score	**10**

6.1b. Invasiveness

Part A – Native species

Score	4

Part B – Non-Native species

Score	**0**

Part C – Native and Non-native species

Question	Score
Do escapees compete with wild native populations for food or habitat?	No
Do escapees act as additional predation pressure on wild native populations?	No
Do escapees compete with wild native populations for breeding partners or disturb breeding behavior of the same or other species?	No
Do escapees modify habitats to the detriment of other species (e.g. by feeding, foraging, settlement or other)?	No
Do escapees have some other impact on other native species or habitats?	No
	5

F 6.1b Score	**9**

Final C6 Score	**10.00**	**GREEN**
	Critical?	**NO**

Exceptional Factor 6.2X: Escape of unintentionally introduced species

Escape of unintentionally introduced species parameters	Score	
F6.2Xa International or trans-waterbody live animal shipments (%)	10.00	
F6.2Xb Biosecurity of source/destination	10.00	
F6.2X Escape of unintentionally introduced species Final Score	**0.00**	**GREEN**

Criterion 7: Diseases

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

Criterion 8: Source of Stock

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