27 March 2017

Developing scallop and geoduck aquaculture on British Columbia’s Central Coast: Recommendations from experts

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1. Introduction

Shellfish aquaculture is widely viewed as an important tool to economically and ecologically support the global demand for seafood. British Columbia (BC), Canada is well suited to the development of shellfish aquaculture and a successful industry already exists along much of the south coast and Vancouver Island. However, the Central Coast of British Columbia is a largely untapped aquaculture resource (Figure 1). Developing a successful shellfish aquaculture industry on the Central Coast could provide an important source of income to local residents and Coastal First Nations, potentially with low impact on local wildlife and ecosystems.

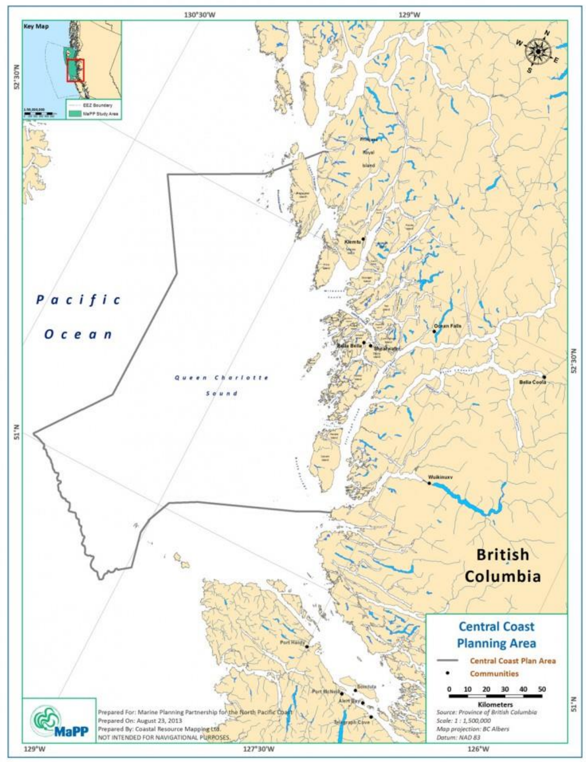

Figure 1 - Central Coast of British Columbia, Canada

Despite the growing popularity of shellfish aquaculture as an alternative to the wild harvest of fish and invertebrates, little is known about the optimal and tolerable habitat parameters necessary for ocean-based shellfish aquaculture. Although wild scallop and geoduck readily grow in the cold, productive BC waters, successful aquaculture farms must find ideal natural locations to optimize growth and minimize mass mortality events.

This project brings together the collective habitat knowledge of aquaculture experts from the Pacific coast of BC and Washington, USA to inform a GIS spatial model of suitable shellfish aquaculture sites throughout the Central Coast of BC.

2. Methods

Shellfish aquaculture experts were located via word of mouth, internet searches, and snowball sampling. We define experts as any individuals who work directly in the shellfish aquaculture industry (e.g., commercial shellfish harvesters, hatchery/farm operators, shellfish farm owners/managers) or actively conduct scientific research on shellfish aquaculture (e.g., university professors, federal scientists). Once an appropriate interview subject was located, they were informed of the project goals and sent an interview consent form to read and sign. Structured interview were conducted via telephone and took approximately 30-60 minutes to complete, depending upon expert knowledge of either scallops or geoducks.

We interviewed eight experts about geoduck aquaculture habitat parameters. Four of the eight geoduck experts were also qualified to respond to scallop aquaculture questions. One additional scallop specific expert was interviewed for a total of 8 geoduck interviews and 5 scallop interviews. To avoid confounding our results and to ensure the expertise of our interviewees, we did not interview experts who studied Atlantic shellfish species, operators who only worked in laboratory hatchery environments, or experts who focus only on wild commercial harvesting operations. We limited our interviews to eight geoduck experts and four scallop experts after snowball sampling began returning the same expert names, likely indicating expert saturation.

Care was taken to avoid forcing interviewees to answer questions on optimal and tolerable habitat parameters when they were unsure or had no information to support their response. We accepted educated guesses for optimal and tolerable growing conditions. Whenever possible we obtained numeric values for optimal and tolerable growing conditions; however, where numeric values were unavailable, we included additional expert information on habitat considerations in the descriptions below. Numeric responses to habitat parameter questions were averaged across respondents to develop optimal and tolerable range tables for various habitat parameters. We include additional information, recommendations, and considerations from shellfish experts regarding the development of aquaculture sites on the Central Coast.

3. Geoduck Aquaculture Recommendations

3.1. Substrate

Ideal geoduck aquaculture sites are heavily dependent upon adequate substrate for geoduck growth and harvesting (Table 1). Although geoduck can grow in many environments, including cobble ground, it is important to consider the marketability of geoduck grown in subprime substrate. For example, geoduck grown in cobble are often misshapen which makes them difficult to sell. Cobble also makes geoduck very difficult to harvest with the traditional method of high powered water jets controlled by divers. Geoduck in these substrates are often broken during harvest and are subsequently unmarketable. Additionally, geoduck grown in muddy, anoxic substrates have blackened shells and necks which makes them undesirable on the market.

Fine sand, especially ground shell, provides the ideal habitat for geoduck growth and harvesting for aquaculture purposes. In the absence of pure sand, fine gravel (1-2 cm) and sand mixed with pea-sized gravel also provide an acceptable habitat for geoduck aquaculture. Geoduck cannot grow on rocky substrates as they are unable to dig into these environments.

Before selecting a geoduck aquaculture site, it is recommended that the site is sampled with test holes to a depth of 1 m to assess substrate suitability beyond the surface layer. These tests assess the substrate composition for elements like rubble and inorganic debris which could compromise the ability of aquaculturists to harvest or produce a marketable product.

Table 1. Substrate suitability for geoduck aquaculture, ranked in order of preference from high to low.

Substrate	Suitability	Considerations
Fine sand (e.g., ground shell)	Optimal	Ideal for harvest and growth
Fine gravel (e.g., pebbles the size commonly found in fish tanks)	Adequate	Adequate for harvest and growth

Gravel (pea-sized)	Tolerable	May become more difficult to harvest
Mud/silt	Less tolerable	Easy to harvest but shells and necks become blackened and undesirable
Cobble (golf ball sized)	Least tolerable	Difficult to harvest and prone to breakage; geoduck become misshapen and unmarketable.
Rock	Intolerable	Geoduck cannot dig in to hard substrate

3.2. Depth

In the wild, geoduck have been found at depths of over 400 feet (122 m) and can likely grow even deeper (Table 2). However, for aquaculture harvesting purposes it is important to seed juvenile geoduck at or above diveable depths. Juvenile geoducks within this report refer to geoducks that have not yet been seeded into the grow out phase and are still in their nursery system. Geoducks generally stay in their nursery until they reach about 2 cm in size or approximately 8-10 months of age. Commercial divers can operate at extreme depths (>200 ft or 61 m), however, to maximize harvesting efficiency and minimize harvest costs geoduck should not be seeded below approximately 50 ft (15 m). At 50 ft (15 m) and above, divers can stay underwater longer and take shorter breaks between dives which facilitates efficient and affordable harvesting. Furthermore, geoduck grow faster with greater food availability. Phytoplankton is more abundant in shallower water. Thus, seeding geoduck between 40 ft and the intertidal is the most advantageous from a growth and harvesting perspective. However, one expert stated that aquaculturists often harvest their brood stock from the 45-60 ft (14-18 m) range. Anecdotally, these geoduck grow slower but are heartier and provide better nursery stock. Additionally, it is often easier to obtain permits for deeper geoduck farms because they are less visible to local residents who often dislike the sight of aquaculture equipment and the sediment produced during harvesting.

Table 2. Optimal and tolerable depth ranges for mature and juvenile geoduck (<2 cm or 8-10 months). Depths are rounded to the nearest foot and meter. Numeric values were averaged across expert responses.

DEPTH	**Mature**		**Juvenile**	
	Feet	**Meters**	**Feet**	**Meters**
Optimal maximum	42	13	38	12
Optimal minimum	9	3	8	2
Diver tolerable maximum	53	16	55	17
Tolerable maximum	365	111	367	112
Tolerable minimum	0	0	3	1

3.3. Temperature

Mature geoduck generally prefer a temperature range from 8.5 °C to 17.3 °C, however, they can survive a temperature range from 0 °C to 28 °C (Table 3). Juvenile geoduck prefer a temperature range from 7.5 °C to 19.3 °C and can survive in a range from 0 °C to 25.2 °C. When seeding geoduck it is important to consider temperature and avoid seeding below 10 °C, since the ability of geoduck to dig into sediment in cold water is greatly reduced. In 10 °C water and above geoduck typically take ~45 minutes to dig into sediment but below 10 °C they can take up to nine hours to dig in due to a slowed metabolic rate. Slow dig in during seeding can greatly increase predation and cause mass mortalities in valuable juvenile seed stock.

Additionally, in water 17 °C or warmer geoduck metabolic rates are greatly increased and they will rapidly siphon water in search of phytoplankton. If phytoplankton is readily available this increase metabolic rate promotes rapid growth. However, if there is a food shortage geoduck can waste valuable energy siphoning low nutrient water. Thus, it is important to look for aquaculture locations where water temperature and food availability increase in tandem.

Geoduck can also survive short bouts of freezing temperatures in the intertidal zone as long as freezing temperatures do not persist long enough to freeze the deep ground where geoduck are buried. Geoduck cannot readily survive the freezing of any part of their anatomy, and as soon as geoduck flesh freezes there is a very high probability of mortality. Experts also state that geoduck can survive > 30 °C temperatures and regularly do so in Mexican waters. However, this is not a major concern in BC where ocean waters rarely reach these temperature highs.

Typically, geoduck nursery systems are located in shallower water (10-15 ft or 3-5m) and juveniles prefer waters cooler than 15-20 °C. In water above 20 °C juvenile geoduck should not be handled to avoid undue stress. It is important to monitor these shallow nursery areas in the summer, especially in shallow bays which may see surface temperatures rise enough to threaten nursery stock.

Table 3. Optimal and tolerable temperature ranges for mature and juvenile geoduck (<2 cm or 8-10 months). Temperatures are given in degrees Celsius. Numeric values were averaged across expert responses.

TEMPERATURE	**Mature (°C)**	**Juvenile (°C)**
Optimal maximum	17.3	19.3
Optimal minimum	8.5	7.5
Tolerable maximum	28.5	25.2
Tolerable minimum	-0.5	0

3.4. Salinity

Mature geoduck prefer salinities from 31 ppt-28.3 ppt and can survive 36-17.7 ppt. Juveniles prefer from 31-25.3 ppt and can survive 36-16.5 ppt (Table 4). Geoduck juveniles are very susceptible to salinity changes. For example, in 2014 juveniles located in shallow water in Baynes Sound, Vancouver Island died after heavy rainfall altered the salinity near the surface. Thus, juvenile geoduck should not be placed in nursery areas too close to the surface or near estuaries where heavy rainfall or snowmelt can lower salinities to lethal levels.

Table 4. Optimal and tolerable salinity ranges for mature and juvenile geoduck (<2 cm or 8-10 months). Salinities are given in parts per thousand (ppt). Numeric values were averaged across expert responses.

SALINITY	**Mature (ppt)**	**Juvenile (ppt)**
Optimal maximum	31	31
Optimal minimum	28.3	25.3
Tolerable maximum	36	36
Tolerable minimum	17.7	16.5

3.5. Tidal Speed

Little is known about optimal and tolerable tidal speeds for geoduck aquaculture. Experts suggest that geoduck prefer areas of moderate to high current due to higher food availability. However, geoduck are also known to grow well in calm bays with limited tidal exchange. For aquaculture purposes experts suggest a minimum of 0.5 knots to keep nutrients flowing and a maximum of 4-5 knots with good slack tides to allow divers to harvest geoduck (Table 5). It is likely that geoduck can grow in extremely high current provided the flow rate does not strip away the sandy soft sediment necessary for geoduck habitat.

Table 5. Optimal tidal speed range for geoduck. Speeds are given in knots. Numeric values were averaged across expert responses.

TIDAL SPEED	**Knots**
Optimal maximum	4.3
Optimal minimum	0.5

3.6. Productivity

There is no known minimum or maximum level of primary productivity (cells per litre) necessary for wild geoduck aquaculture. Chlorophyll A satellite imaging could be a useful tool for habitat modelling to pinpoint possible productivity “hot spots”. Experts suggest ideal geoduck aquaculture sites should exhibit frequent plankton blooms throughout the year to ensure food availability. However, sites with perpetual plankton blooms should be assessed with test holes for anoxic conditions which will be muddy and produce subprime, oxygen-starved geoduck.

Furthermore, although red tides are not problematic for geoduck health, geoduck which ingest plankton from red tides are often unmarketable due to their negative health impact on humans. Water sampling of plankton species and abundance should be conducted to ensure low levels of dinoflagellates associated with red tides. Additionally, geoduck will eat most phytoplankton, however, some species are very large and can get caught in geoduck gills and cause damage or mortality. Again, water sampling is a good way to avoid areas with an overabundance of large phytoplankton species. Several studies have examined juvenile geoduck phytoplankton feeding preferences in a hatchery environment (Arney et al. 2015, Marshall et al. 2014a, Marshall et al. 2014b, Liu et al, 2016, Ren et al. 2015). However, these preferred species are not found in wild BC waters. Further studies on preferred, naturally occurring BC phytoplankton species should be considered.

3.7. Additional Geoduck Aquaculture Considerations

Predation should be considered when modelling potential aquaculture habitat. Many experts are concerned about sea otter predation in the Central Coast region of BC. Thus, site selection should prioritize areas with low abundance of sea otters. Other top predators such crabs and moon snails are typically abundant in most habitats and thus very difficult to avoid. New aquaculture farms need to prepare for crab and moon snail predation with nets and other anti-predator protection.

It is also important to avoid injuring geoduck when harvesting since injured geoduck release an amino acid that attracts predators like crabs, potentially causing mass mortality during harvest. Additionally, it is important to consider weather and wave action when selecting aquaculture sites as high swell and wave action can pull out geoduck predator protection nets.

Geoduck aquaculture sites should also avoid placement near sewage outfalls and other contaminants like cadmium that could contaminate geoduck and make them unmarketable. Population centers should also be avoided as much as possible, since local residents are typically resistant to the appearance of industrialized aquaculture along undeveloped shorelines.

It is also important to consider any possible genetic contamination imported geoduck seed stock could have on local wild geoduck populations. Similar to the concerns around farmed Atlantic salmon in Pacific waters, cross-breeding and possible diseases should be considered when developing geoduck farms.

Site selection should also consider logistics and their associated costs. For example, aquaculture sites will need a minimum of float plane access to allow for export of mature geoduck to the market and importation of juvenile seed stock. Additionally, staffing availability and travel costs should be factored into site selection.

Finally, most aquaculture tenure agreements stipulate that geoduck farms must maintain a minimum 30 ft distance from eelgrass beds to avoid sedimentation and destroying eelgrass habitat. A study by Liu et al. (2015) found no significant increase in sedimentation after geoduck harvesting, especially compared to stormy days in the same areas. The majority of sediment disturbed by high powered water streams used to remove geoducks settled within 3-7 ft (1-2 m) of the harvest point. Thus, a 30 ft (9 m) buffer zone between geoduck harvesting areas and eel grass beds should sufficiently protect eelgrass habitat.

4. Scallop Aquaculture Recommendations

4.1. Depth

Wild scallops can frequently live and grow in deep waters (>100 ft or 30 m) but for aquaculture they grow faster at shallower depths based on food availability. Optimal scallop aquaculture depth is between 15-35 ft (5-11 m) and tolerable depth for aquaculture is 0-70 ft (0-21 m) for juveniles, and 0-400 ft (0-122 m) for adults (Table 6). Juvenile scallops within this report refer to scallops approximately 1-2 cm in size or approximately 8-12 months of age. Although scallops can tolerate shallow depths in calm seas, wave action near the surface frequently causes "sea sickness" as scallops become agitated and begin swimming within their baskets. Agitated scallops waste valuable energy swimming and frequently bite on to other scallops and cause internal damage to one another. Scallop "sea sickness" can cause massive mortality on aquaculture farms so it is important to keep scallop nets deep enough to avoid swell and surface chop. Experts recommend keeping scallops above 60 ft (18 m) to maximize diver harvesting time and minimize costs, and below 10-15 ft (3-5 m) to avoid wave agitation.

Table 6. Optimal and tolerable depth ranges for mature and juvenile (<8-12 months or 1-2 cm) scallop. Depths are rounded to the nearest foot and meter. Numeric values were averaged across expert responses.

DEPTH	**Mature**		**Juvenile**	
	Feet	**Meters**	**Feet**	**Meters**
Optimal maximum	35	11	35	11
Optimal minimum	15	5	15	5
Diver tolerable maximum	70	21	70	21
Tolerable maximum	400	122	70	21
Tolerable minimum	5	2	0	0

4.2. Temperature

Mature scallops prefer a temperature range from 9.75 C to 18 C and juveniles prefer 9.75 C to 17.5 C (Table 7). Juvenile scallops can tolerate 0.5 C to 27.5 C and mature scallops can tolerate 0.5 C to 30 C. The summer is also a season of concern in warm shallow waters, especially for juvenile scallops which can become stressed if handled in waters warmer than 24 C. In shallow bay nursery systems, aquaculturists should monitor temperatures and avoid handling juvenile stock when temperatures pass the 24 C threshold.

Table 7. *Optimal and tolerable temperature ranges for mature and juvenile (<8-12 months or 1-2cm) scallops. Temperatures are given in degrees Celsius. Numeric values were averaged across expert responses.*

TEMPERATURE	**Mature (°C)**	**Juvenile (°C)**
Optimal maximum	18	17.5
Optimal minimum	9.75	9.75
Tolerable maximum	30	27.5
Tolerable minimum	0.5	0.5

4.3. Salinity

Scallops prefer a salinity range from 27.5-30 ppt and can tolerate 24-36 ppt (Table 8). It is important to monitor salinity levels in the spring and fall when snow melt or heavy rains lower salinity near the surface. Scallops are very sensitive to salinity changes and should be kept deep enough that heavy rains cannot lower the salinity below 24 ppt. Aquaculture site selection should consider local snowmelt patterns, estuary locations, and rainfall runoff routes.

Table 8. Optimal and tolerable salinity ranges for scallops. Salinities are given in parts per thousand (ppt). Numeric values were averaged across expert responses.

SALINITY	**(ppt)**
Optimal maximum	30.3
Optimal minimum	27.5
Tolerable maximum	36
Tolerable minimum	24

4.4. Tidal Speed

Similar to geoduck aquaculture, little is known about optimal and tolerable tidal speeds for scallop aquaculture. Experts suggest that scallops prefer areas of moderate to high current due to higher food availability. However, scallops species that do not anchor to rocks, such as the popular Weathervane Japanese Scallop hybrid used in most BC aquaculture, cannot survive long in areas where strong current will continually tumble them in their baskets. Experts suggest an optimal minimum of 0.5 knots and a maximum of 3.5 knots to accommodate food availability requirements and diver harvesting need (Table 9). Scallops can likely tolerate up to 10 knots of current provided they are not dislodged from their resting places.

Table 9. Optimal and tolerable tidal speed ranges for scallops. Speeds are given in knots. Numeric values were averaged across expert responses.

TIDAL SPEED	Knots
Optimal maximum	3.5
Optimal minimum	0.5
Tolerable maximum	10
Tolerable minimum	0.5

4.5. Wave Height

There is limited information on optimal and tolerable wave height for scallop aquaculture, however, experts suggest an optimal range from 0-3 ft (0-1 m) of wave height at the surface (Table 10). There should be no more than 0.5 ft (0.2 m) of movement at scallop depth within the water column. Scallop baskets should be kept deep in the water (>10 ft or 3 m) to minimize agitation from storm systems. Aquaculture site selection should consider frequency and intensity of waves in potential farm locations and avoid areas that experience waves and storm surges on a regular basis. Scallop "sea sickness", as mentioned in the depth description above, can cause mass mortality of scallop stock during prolonged agitation. Ideal aquaculture sites should be located in calm bays with limited storm action even during winter months.

Table 10. Optimal wave height range for scallops. Heights are rounded to the nearest foot and meter. Numeric values were averaged across expert responses.

WAVE HEIGHT	Feet	Meters
Optimal maximum	3	1
Optimal minimum	0	0

4.6. Additional Scallop Aquaculture Consideration

Scallop aquaculture sites should avoid avoid high traffic areas with barges or log booms that can rip out scallop suspension systems. Attention to sewage outflows and contamination are also important when selecting farming sites. One aquaculture expert described an ideal scallop aquaculture site, "*Baynes Sound on Vancouver Island would be ideal since it's nice and protected from wave action and has heavy tidal flow and massive phytoplankton blooms*". The interviewee suggested placing scallop rafts at a depth of 10 ft (3 m) and no deeper than 20 ft (6 m).

As with geoduck aquaculture, protection from predators is essential. Scallop baskets should be inspected regularly and emptied of predatory flatworms and crab larvae that settle in baskets and mature and begin predating on scallops.

High sediment areas are also bad for scallops as they are filter feeders. High concentrations of sediment in the water can clog up scallops and prevent them from getting enough phytoplankton. Water tests should be done at regular intervals before sites are selected to test for high particulate concentrations.

It is also important to consider public perception when selecting aquaculture sites. Although some people enjoy the look of scallop farms, some residents may find scallop farms unattractive from shore so consultations with local residents and avoidance of pristine or highly populated locations are recommended.

5. Additional Considerations for Developing Shellfish Aquaculture on the Central Coast

Geoduck may be harder to grow quickly on the Central Coast because the water temperatures are lower which may decrease food availability and geoduck metabolic rate. This may make grow out times impractical for aquaculturists. It's best to grow out a geoduck in 7-10 years but it is possible that it may take as long as 15-20 years on the central coast depending on water temperature and food availability. However, the majority of experts still believe the creation of shellfish aquaculture on the central coast is viable. However, due to higher sea otter populations on the central coast more care to avoid prime otter habitat and set up advanced predator protection systems may be necessary.

Finally, it is important to consider health of marine ecosystems when developing shellfish aquaculture sites. Many other species depend upon the wild ecosystems necessary to support geoduck and scallop farms. Full environmental impact assessments are necessary to avoid damaging delicate ecosystems and species. Additionally, people value pristine landscapes in the Central Coast and Coastal First Nations want and deserve a stake in the development of their traditional territories. Shellfish aquaculture development should ensure local resources remain in the hands of area residents and adhere to the social, environmental, and economic goals of First Nations and resident groups.

6. Acknowledgements

We thank the experts who provided detailed information for this report: Tom Broadley from Manatee Holdings; Grant Dovey from the Underwater Harvesters Association; Sarah Dudas from Vancouver Island University; Erik Jakobson with Fan Seafoods; Erin Latham from the University of Victoria; Chris Pearce with Fisheries and Oceans Canada; Todd Russell of Island Scallops; Sean Smyrichinsky from UB Diving; and Brent Vadopalas of the University of Washington. This work was funded by a Mitacs Elevate fellowship to Aerin Jacob and a MEOPAR Reponse Core grant to Aerin Jacob and Natalie Ban. Permission to conduct the interviews was granted by the UVic Human Research Ethics Board (16-245).

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