CONFLUENCE
ENVIRONMENTAL COMPANY

To: Mr. Jesse DeNike, Plauche & Carr
cc: Ms. Erin Ewald, Taylor Shellfish Farms

From: Kelly McDonald and Marlene Meaders

Kelly McDonald

Date: May 15, 2023

Re: Evaluation of Refined Geoduck Nursery Tubes

Enclosures: Attachment A – Photos

Taylor Shellfish Farms (Taylor Shellfish) is proposing to utilize a refined style of HDPE mesh geoduck (*Panopea generosa*) nursery tube for predator protection during the first 3 years of the culture cycle. The proposed tube is similar in design to the currently used rigid HDPE mesh tubes but is constructed in a way to allow greater flexibility of the material. The following technical memorandum provides a review of the ecological impacts of the currently used tubes and evaluates potential ecological impacts of the proposed tubes. The goal of this memorandum is to compare the types of geoduck nursery tubes and their relative impacts for permitting purposes.

1.0 DESCRIPTION OF ACTIVITIES

Cultivation of geoduck for commercial sale typically includes some form of predator protection during the most vulnerable life stage (i.e., first 2-3 years of growth). The methods and type of gear have evolved over time, but all methods are intended to limit predation on the cultivated shellfish. The following sections describe the current predator protection methods and the proposed refined method, including the gear, materials, installation methods, and removal methods.

1.1 Current Methods

Current predator protection methods use nursery tubes made of either polyvinyl chloride (PVC) pipe (see Attachment A, Photos 1 and 2) or a rigid high-density polyethylene (HDPE) mesh (see Attachment A, Photo 3). Prior to planting geoduck, these nursery tubes are inserted into the substrate. Installation may occur at low tide by farm crews on foot or at high tide by divers. Nursery tubes are typically 4 to 8 inches in diameter. Farm crews insert tubes up to 11 inches into the substrate and space them at 12 to 16 inches apart on center. This results in a density of approximately 1 tube per square foot. For installation at low tide, tubes are inserted by hand or by using a farm implement that disturbs substrate up to a depth of approximately 7 to 12 inches using a tool that removes a core of sediment. The tube is inserted into the hole, and the sediment is redeposited into the center of the tube. Low pressure water pumped through a hose may also be used for subtidal installation.

Once nursery tubes are in place, 3 or more geoduck seed are pushed into the ground up to 3 inches deep or placed on the surface to dig into the substrate on their own within the tubes. After planting, PVC nursery tubes may be covered with area nets. Rigid HDPE nursery tubes do not require additional nets. Area nets may be used after nursery tubes are removed to allow the juvenile geoduck to adjust to a reduced amount of predator protection. Nets are removed once predation pressures have reduced. Farm crews may access a geoduck culture plot for this phase of the work at low tide or during high tide with divers.

In most cases, area nets are secured to the substrate with J-shaped rebar stakes up to 30 inches deep along the perimeter of the net. The nets may also be secured using rope anchors with an end piece affixing the net to the substrate. The rope anchors are installed up to 5 feet deep. Area nets are installed in a square or rectangular configuration depending on the size of the geoduck culture plot. Multiple area nets may be joined with appropriate materials (e.g., bar locks).

Nursery tubes may be used for up to 2 years of the total 4- to 7-year culture cycle. Tubes are removed by hand, or by disturbing the substrate with low-pressure water pumped through a hose to a depth of approximately 7 to 12 inches. Geoducks are left in the substrate without predator protection from nursery tubes for additional grow-out during the last 2 to 6 years of the culture cycle through harvest. After removal, tubes are either immediately reused at a location within the same growing area or taken to an upland facility for inspection and cleaning and reused at a different farm site. Nursery tubes last for approximately 20 years and are recycled at an approved facility after they are determined to no longer be useable.

1.2 Refined Culture Tubes

The proposed culture type uses a flexible HDPE mesh tube. The flexible HDPE mesh nursery tubes are 8 inches in diameter when stretched for insertion into the substrate, have a ¼-inch mesh, and are gray or black in color (see Attachment A, Photos 4-10). The manufacturer specifications indicate a degradation time of greater than 10 years.

The flexible HDPE mesh nursery tubes are installed using a modified clam gun that is approximately 8 inches in diameter (Attachment A, Photo 5). The mesh is pre-cut and loaded onto the clam gun. There are teeth on the bottom end of the clam gun that hold the mesh in place during insertion into the substrate. The clam gun is inserted approximately 8 inches into the substrate. When the clam gun is pulled out, the tube stays behind. The tube sticks up approximately 6-9 inches above the substrate. However, the material is flexible and can lie flat onto the substrate. No water or disturbance of the substrate is required beyond insertion of the modified clam gun. Installation may occur at low tide when the tideflat is exposed or when there is some water covering the area (less than 2 feet), depending on the effectiveness of the installation method and sediment conditions. Typically, 4 geoduck seed are planted per flexible HDPE mesh nursery tube (refer to Attachment A, Photo 8). Compared to the current method, spacing achieved by the proposed type of nursery tube would reduce the number of tubes per acre by about 20% (approximately 1 tube per 1.25 square foot), while increasing the number of geoduck per acre by 5.5%. Additionally, there is no need for area nets when using the flexible HDPE mesh nursery tubes. Area nets may be used after the tubes are removed for predator protection.

The flexible HDPE mesh nursery tubes would remain in the ground for 12 to 24 months to allow for the geoduck to fully establish in the substrate. The flexible HDPE mesh tubes are removed by loosening the substrate with low-pressure water pumped through a hose. Substrate may be disturbed to a depth of approximately 7 to 12 inches. The potential for reuse of the flexible HDPE mesh tubes is currently in testing but is likely more than 10 years, allowing 2-3 planting cycles. The same locations that accept PVC and HDPE can also recycle the proposed tubes when they are no longer useable.

2.0 ECOLOGICAL IMPACTS

Placement of nursery tubes in the substrate within an intertidal habitat has the potential to interact with the environment through several pathways. Primary mechanisms of effect are expected to occur through substrate disturbance and presence of the gear itself. These effect pathways may lead to the following potential ecological impacts:

- Generation of Turbidity/ Suspended Sediment
- Entanglement/ Entrainment of Fish and Wildlife
- Physical Disturbance of Benthic Invertebrates
- Effects to Submerged Aquatic Vegetation (SAV)
- Addition of Structured Habitat

The following sections review the best available science on potential ecological impacts from the proposed flexible HDPE mesh nursery tubes compared to the current predator protection methods for geoduck culture. Other concerns have been raised related to marine debris and aesthetics. These concerns will also be addressed in the following sections for both methods.

2.1 Current Methods

Impacts of geoduck predator protection methods have been reviewed and assessed in the scientific literature and during the programmatic consultation for shellfish aquaculture in Washington state (Corps 2015; USFWS 2016; NMFS 2016). The discussion of impacts is organized based on two primary mechanisms of effect: 1) substrate disturbance during installation/removal, and 2) presence of gear. These mechanisms have the potential to lead to the potential ecological impacts identified above. Additional effects and concerns related to predator protection gear are also discussed below.

2.1.1 Substrate Disturbance

Much of the scientific literature on substrate disturbance from geoduck culture has focused specifically on harvest. That literature is presented here as an analog for impacts from installation and removal of the current nursery tubes and nets used for predator protection during the first 3 years of the 5- to 7-year geoduck culture cycle. Similar to harvest, installation and removal of the PVC and rigid HDPE nursery tubes rely on low-pressure water to loosen the sediment. Impacts from installation or removal of nursery tubes are expected to be proportionally less than harvest impacts due to the shorter depth of disturbance (i.e., 7-12 inches vs. 40 inches) and smaller extent of substrate disturbance (i.e., every 12-16 inches vs. every 5 inches).

Turbidity and suspended sediment impacts of geoduck harvest are generally spatially limited and short-term. Golder (2019) modeled an intertidal geoduck harvest event in Burley Lagoon and found that suspended sediments reached a maximum concentration of 160 mg/L in the area directly associated with the harvest activity. The harvest plume had a decay rate of 1% of the suspended sediment fraction per minute and had decayed to background conditions after approximately 150 minutes following the end of harvest activities. This is higher compared to the concentrations observed by Short and Walton (1992) who reported concentrations up to 21 mg/L and a harvest plume that lasted for approximately 30 minutes during a harvest of 0.2 acre within the Nisqually Reach of south Puget Sound. The shorter extent of the harvest plume could be expected from subtidal conditions compared to intertidal conditions.

Data collected during actual geoduck harvest events indicate that the majority of the plume is limited to within approximately 16 to 30 feet of the harvest plot, with a small fraction of silts extending up to 150 feet (Liu et al. 2015; Golder 2019). Additionally, a harvest event does not result in significant overall sediment material changes down-current above natural background sedimentation levels (Liu et al. 2015). Golder (2019) reported that a majority of the coarse fraction of sediment would be deposited within 70 feet and the majority of the fine fraction within 80 feet. These results are consistent with measurements reported by Short and Walton

(1992) during a geoduck dive harvest in the Nisqually Reach, where it was noted that most of the sediment was deposited next to the harvest hole, and only "small quantities of material" were shown to be transported beyond 150 feet from the harvest zone. Based on the information presented above, increased turbidity or suspended sediment associated with substrate disturbance during installation or removal of PVC or rigid HDPE nursery tubes is expected to be temporary and highly localized but could result in minor effects within the farm footprint.

Substrate disturbance could also affect the benthic invertebrate community within a farm area. Geoduck harvesting effects on benthic invertebrate communities were evaluated in a 2-year study through a Washington Sea Grant-funded project (Price 2011; VanBlaricom et al. 2015), and a 2-year study in British Columbia (Liu et al. 2015). The authors of these reports consistently indicated that potential effects to benthic invertebrates from a geoduck harvest event are within the natural disturbance regime to which these species have adapted. Measurable disturbances to the benthic invertebrate community in the geoduck culture plot (not necessarily statistically significant differences) may continue for several months post-harvest, but then become indistinguishable from control plots (VanBlaricom et al. 2015). Recovery of the benthic invertebrate community is relatively rapid (from weeks up to 4 months) after a harvest event because they are still preserved in roughly the same area, which allows for faster recolonization (Price 2011). Given the rapid recovery following a harvest event, impacts to the benthic invertebrate community associated with installation or removal of PVC or rigid HDPE nursery tubes are expected to be temporary and short-term with recovery within a few weeks.

In another study, Ruesink and Rowell (2012) examined the effect of geoduck planting on the density and recovery of eelgrass. While eelgrass density quickly recovered following planting of geoduck, density and other metrics did differ over the course of the geoduck grow-out cycle. During summer, eelgrass density was reduced in the geoduck culture plots by 30%, although this result had marginal statistical significance based on an analysis of variance of eelgrass density. The geoduck-addition plots also resulted in 13% longer eelgrass shoots ($F_{1,18} = 4.36$, $P = 0.05$) and 9% more clonal branching ($F_{1,18} = 14.9$, $P = 0.001$). The authors indicated that the increased shoot length and clonal branching were likely related to reduced interspecific competition between eelgrass shoots at the lower density. During winter, geoduck did not reduce the density of eelgrass, and appeared to stabilize eelgrass density compared to control plots. While there may be a short-term impact on eelgrass during the grow-out cycle of geoduck in the substrate, the area is likely to recover quickly to initial densities and there may be benefits from the presence of certain types of gear in allowing for eelgrass colonization into new areas (Horwith 2013). Note that Ruesink and Rowell (2012) did not specifically examine the effect of predator protection gear on eelgrass dynamics; the planted geoduck were at a later stage of grow-out and did not require predator protection.

There are numerous examples along the West Coast where eelgrass expanded into shellfish culture beds. The information for most of these examples is primarily anecdotal, with notable exceptions (e.g., Ward et al. 2003), and the cause has not been directly linked to the aquaculture operation. Recent examples are from Samish Bay geoduck culture plots. Geoduck culture was initially introduced to Fisk Bar, a natural sand bar, where eelgrass was absent, but present in adjacent areas to the sand bar. After the installation of PVC nursery tubes, eelgrass began to spread into the geoduck culture plot that was previously unvegetated (Horwith 2013). This may be due to gear affecting the transport of sand along the bar or providing refuge to the eelgrass seeds, facilitating their establishment. After a harvest cycle, area nets were installed and a study was developed to evaluate the interactions of geoduck culture gear with eelgrass. There was an initial loss in eelgrass from the use of area nets but a full recovery of eelgrass 2 years after the nets were removed (Horwith, pers. comm., 2014). Therefore, eelgrass may be temporarily impacted by substrate disturbance associated with installation and removal of PVC or rigid HDPE nursery tubes, but recovery is likely to occur prior to subsequent disturbance and recovery from a geoduck harvest event.

Overall, substrate disturbance from the installation and removal of PVC and rigid HDPE nursery tubes may result in temporary and localized effects to turbidity, the benthic invertebrate community, and eelgrass. Due to the use of low-pressure water, the effects are likely similar in nature but reduced in magnitude compared to effects associated with harvest activities. Potential impacts to ecological endpoints result in rapid (generally within hours to weeks) recovery and would occur before any additional disturbance within a 5- to 7-year culture cycle.

2.1.2 Presence of Gear

Aquaculture gear is documented in the literature as providing appropriate substrate where macroalgae either attaches or accumulates (Powers et al. 2007; Horwith 2013). This accumulation of macroalgae can provide valuable structured habitat but can also result in shading out of other SAV under the gear. A case study of this effect was noted above in Samish Bay (Horwith 2013). After a harvest cycle (which reduced the eelgrass density but did not eliminate it) PVC nursery tubes were reinstalled, seeded, and covered by an area net. Eelgrass recovery was inhibited by shading caused by macroalgae fouling on the area nets. As noted above, once the area nets and nursery tubes were removed, the eelgrass fully recovered within 2 years (Horwith, pers. comm., 2014).

McDonald et al. (2015) examined resident and transient macrofauna associated with geoduck aquaculture gear at three sites within south Puget Sound. The resident community of macrofauna exhibited no consistent differences between the geoduck culture and reference plots. However, transient fish and macroinvertebrates were twice as abundant in geoduck culture plots compared to reference plots. During the initial phase of the culture cycle, community composition significantly differed between geoduck culture and reference plots, but this difference did not persist through the grow-out cycle after gear was removed (McDonald et al. 2015). These differences were likely due to the presence of predator protection gear and the additional structure provided in a relatively bare tideflat.

Another study looked at whether the change in structured habitat associated with PVC nursery tubes resulted in a population-level change to the food web at the scale of a geoduck culture plot. McPeek et al. (2015) published a study that tagged and measured >1,000 Pacific staghorn sculpin (*Leptocottus armatus*) per geoduck culture plot with gear present. Because Pacific staghorn sculpins are so ubiquitous in Puget Sound, their diet reflects the composition of the local benthic invertebrate community. While geoduck gear results in some changes in staghorn sculpin prey, it does not appear to alter the types of prey resources that sculpin exploit. The lack of differences between cultured and reference plots in the data was corroborated by the results of sculpin fitness metrics, which showed no differences between the geoduck culture and reference plots for sculpin gut fullness or body condition. Both the work by McDonald et al. (2015) and McPeek et al. (2015) suggests that the presence of gear initially changes community composition but does not have a lasting effect on the ecology, either locally or system wide.

Concerns have also been raised related to entanglement of fish and birds in aquaculture gear, primarily the use of area nets (USFWS 2016; NMFS 2016). The programmatic consultation accounted for the potential risk but acknowledged that the risk was low. Best management practices of securing gear and conducting routine inspections largely avoid and minimize the low risk of such interactions. Given the low likelihood and adherence to appropriate best management practices, this effect is considered to be discountable.

Overall, presence of the current predator protection gear (including area nets) can exclude eelgrass from the farm footprint temporarily. Assuming that there is a nearby seed source, eelgrass is expected to recover within 2 years and before a harvest event during a 3- to 9-year culture cycle. The macrofaunal and benthic invertebrate community present within the farm may also be temporarily affected by the presence of gear but these effects do not persist after gear is removed and are not considered to be ecologically significant.

2.1.3 Other Effects

Since predator protection gear started to be used for geoduck culture, concerns have been raised related to aesthetics and the introduction of marine debris through gear loss. A geoduck farm can require tens of thousands of nursery tubes per acre. Loss of PVC and rigid HDPE nursery tubes has occurred, leading to the introduction of marine debris. Taylor Shellfish has taken a variety of steps to alleviate the potential for gear loss, and current gear management practices effectively avoid and minimize the likelihood of marine debris introduction. The proposal to use flexible HDPE mesh nursery tubes is expected to further reduce this potential, as discussed below. Current methods can also lead to aesthetic impacts, especially in locations where geoduck farms are proximate to residential communities. The rigid HDPE mesh nursery tubes are less visible compared to PVC nursery tubes, but nonetheless can alter the view of nearby homes.

2.2 Refined Culture Tubes

The primary differences between the proposed flexible HDPE mesh nursery tubes and current predator exclusion gear include the installation method, flexibility of the material, lower density of nursery tubes present, and no need for additional netting. Using the information presented above and best available science about mechanisms of effect from sediment disturbance and presence of gear in the nearshore environment, potential effects of the proposed flexible HDPE mesh nursery tube method is presented below.

2.2.1 Substrate Disturbance

Based on the modified installation methods, substrate disturbance associated with installation of the proposed flexible HDPE mesh nursery tubes is expected to be less than disturbance associated with the PVC and rigid HDPE installation methods. The amount of substrate disturbed would be limited to the footprint of the modified clam gun. Additionally, associated increases in turbidity would be minimized. This is primarily due to the fact that installation would only occur when the site is exposed at low tide or when there is a small amount of water (less than 2 feet) on the site. Increases in turbidity would be short-term and highly localized. Substrate disturbance and subsequent turbidity effects are likely to be limited to effects from the presence of farm workers, as described below. Compared to the effects of current methods based on the impacts of a harvest event, effects associated with the presence of farm crews are considerably lower.

Two studies have looked at the effects of trampling on benthic invertebrate communities. Johnson et al. (2007) reported that benthic invertebrate communities were found to recover quickly (within 12-36 hours) following repeated human trampling. Rossi et al. (2007) reported that recruitment and population dynamics of two shellfish communities (*Macoma balthica* and *Cerastoderma edule*) did exhibit a response to human trampling, indicating that human trampling is a relevant source of disturbance within mudflat environments. However, both of these analyses assessed a frequency of human presence that is likely higher than would be associated with the installation of the proposed flexible HDPE mesh nursery tubes or geoduck farms more broadly. The frequency of human presence in the studies was up to 6 times per month (Johnson et al. 2007; Rossi et al. 2007). Farm crews are likely to be at a given location approximately 5 to 8 sequential days (i.e., a low tide series) for 3 to 6 workers during installation activities, and then transition to maintenance occurring 1 time per month for 1 to 2 years during the grow-out cycle. Impacts on benthic communities are expected to be minimal with relatively rapid recovery following disturbance. The effects of removal are expected to be consistent with current methods, as low-pressure water is still required to extract the tubes from the sediment. Therefore, the frequency of disturbance using low-pressure water for the flexible HDPE mesh nursery tubes would be less than PVC or rigid HDPE nursery tubes (2 times per culture cycle rather than 3 times), allowing for more recovery time between disturbance events.

Substrate disturbance associated with installation of the proposed flexible HDPE mesh nursery tubes could also affect eelgrass density and recovery. However, given that no low-pressure water is used for installation, effects are likely to be minimized compared to PVC or rigid HDPE nursery tubes. Given the reduction in sediment disturbance, the effects to eelgrass are likely smaller compared to the short-term impact reported during harvest by Ruesink and Rowell (2012). As shown in Attachment A, Photos 6 and 7, the proposed mesh tubes can be easily installed in a location with eelgrass with little apparent impact to the eelgrass itself. Based on available evidence, the installation of the proposed flexible HDPE mesh nursery tubes are likely to have minimal impact on eelgrass density. Effects of removal are likely to be consistent with current methods, and would include recovery of eelgrass.

2.2.2 Presence of Gear

The proposed flexible HDPE mesh nursery tubes are likely to interact with macroalgae and eelgrass in ways similar to those described above for the PVC and rigid HDPE methods, although the wider spacing and lack of nets will provide more natural movement of water and sediment in the surrounding area. Presence of gear may allow for the colonization of eelgrass beds in some locations (e.g., Horwith 2013). Based on anecdotal evidence, given the relatively new technology, flexible HDPE mesh nursery tubes appear to be a good method for supporting normal eelgrass functions when installed in areas that overlap with eelgrass. Flexible HDPE mesh nursery tubes are also likely to provide attachment points for macroalgae (as shown in Attachment A, Photo 10). Effects to eelgrass metrics may occur during the grow-out cycle of the geoduck clams themselves (Ruesink and Rowell 2012), but the impact of the flexible HDPE mesh nursery tubes is expected to be minor. Finally, the flexible HDPE mesh nursery tubes are in the sediment for up to 2 years compared to 3 years for PVC and rigid HDPE nursery tubes and fewer nursery tubes per acre are required for the flexible HDPE mesh nursery tubes. Both of these conditions will allow for more natural expansion and growth of eelgrass for longer periods without gear present.

Similar to the PVC and rigid HDPE nursery tube methods, presence of the flexible HDPE mesh nursery tubes may help to create a structured habitat that supports an abundant community of macrofauna (McDonald et al. 2015; McPeek et al. 2015). The community is expected to be aligned with the complement of species seen on other geoduck farms.

As noted above, the presence of aquaculture gear has the potential to result in entanglement of fish and bird species. Cover nets have been the gear of primary concern and they are not required with the flexible HDPE mesh nursery tubes. Therefore, there is no entanglement risk associated with the use of the proposed tubes.

2.2.3 Other Effects

Relative to current methods, the proposed flexible HDPE mesh nursery tubes appear to reduce the potential for gear to become marine debris. Initial testing has indicated that retention of the mesh tubes in the substrate is extremely high, largely due to the flexibility of the material. Use of the flexible HDPE mesh nursery tubes would also decrease the number of tubes required per acre by about 20%, reducing the overall amount of gear present. Aesthetically, the proposed flexible HDPE mesh nursery tubes are also expected to have a reduced impact. The gray and black colors of the mesh are less visible within the nearshore environment than the white of the PVC and lay down closer to the sediment surface compared to the rigid HDPE nursery tube. Proposed flexible HDPE mesh nursery tubes do not require individual or area netting, which further reduces potential aesthetic and debris impacts. Another concern raised for predator protection is the potential impact for tribal fishers to access their usual and accustomed tribal fishing areas. Taylor Shellfish worked with the Squaxin Island Tribal fishers to test their fishing gear on a test plot of recently inserted flexible HDPE mesh tubes. No resistance was identified from the nets, and no gear was pulled from the substrate as a result of the nets being dragged over the top. Finally, relative to current methods, the proposed flexible HDPE mesh nursery tubes would have a significantly reduced carbon footprint. The carbon input required for manufacturing, transport, and recycling would be minimized, helping to limit the carbon impact of geoduck cultivation. Overall, relative to current methods, the proposed flexible HDPE mesh nursery tubes are expected to reduce aesthetics impacts, the potential for the introduction of marine debris, interactions with other uses (e.g., fishing, recreation), and the carbon footprint.

3.0 CONCLUSION

Based on the best available science and information about the proposed method for predator protection, it is likely that the proposed flexible HDPE mesh nursery tubes will result in reduced ecological impacts relative to current methods. During installation, substrate disturbance would be minimized by relying on a modified clam gun rather than using the sediment corer or low-pressure water pumped through a hose. Additionally, fewer tubes would be required per acre, reducing the amount of gear introduced into the environment and sediment disturbance during installation and removal. This reduction in gear and disturbance, and the observed retention of the flexible HDPE mesh nursery tubes on the farm, will also help to reduce potential marine debris and aesthetic impacts. Overall, available evidence suggests that the proposed method would result in a reduction in ecological impacts associated with predator protection for geoduck cultivation compared to the current methods. Because the current methods result in minor impacts to substrate disturbance, physical disturbance of organisms, and potential changes in the habitat through the introduction of gear, potential impacts from proposed flexible HDPE mesh nursery tubes are expected to range between minor and discountable. Further, the current method allows for rapid recovery of the surrounding environment, and a reduction in impacts from the flexible HDPE mesh nursery tubes will further improve recovery of the system during a geoduck culture cycle.

4.0 REFERENCES

Corps. 2015. Programmatic Biological Assessment: Shellfish Activities in Washington State Inland Marine Waters. U.S. Army Corps of Engineers Regulatory Program, Seattle, WA.

Golder. 2019. Burley Lagoon hydrodynamic and sediment transport modeling. Prepared for Taylor Shellfish Farms, Project No. 1536648, Golder, Redmond, Washington.

Horwith, M. 2013. Changes in seagrass (*Zostera marina*) and infauna through a five-year crop cycle of geoduck clams (*Panopea generosa*) in Samish Bay, WA. Pages 107-122. Washington Sea Grant, Washington Sea Grant Technical Report WSG-TR 13-03, Seattle, Washington.

Johnson, G. E., M. J. Attrill, E. V. Sheehan, and P. J. Somerfield. 2007. Recovery of meiofauna communities following mudflat disturbance by trampling associated with crab-tiling. Marine Environmental Research 64(4):409–416.

Liu, W., C. M. Pearce, and G. Dovey. 2015. Assessing Potential Benthic Impacts of Harvesting the Pacific Geoduck Clam *Panopea generosa* in Intertidal and Subtidal Sites in British Columbia, Canada. Journal of Shellfish Research 34(3):757–775.

McDonald, P. S., A. Galloway, K. Mcpeek, and G. Vanblaricom. 2015. Effects of Geoduck (Panopea generosa Gould, 1850) Aquaculture Gear on Resident and Transient Macrofauna Communities of Puget Sound, Washington. Journal of Shellfish Research 34:189–202.

McPeek, K. C., P. S. McDonald, and G. R. VanBlaricom. 2015. Aquaculture Disturbance Impacts the Diet but not Ecological Linkages of a Ubiquitous Predatory Fish. Estuaries and Coasts 38(5):1520–1534.

NMFS. 2016. Endangered Species Act (ESA) Section 7(a)(2) Biological Programmatic Opinion and Magnuson-Stevens Fishery Conservation and Management Act Essential Fish Habitat Consultation: Washington State Commercial Shellfish Aquaculture and Restoration Programmatic. NOAA, NMFS, West Coast Region, NMFS Consultation Number WCR-2014-1502, Seattle, Washington.

Powers, M., C. Peterson, H. Summerson, and S. Powers. 2007. Macroalgal growth on bivalve aquaculture netting enhances nursery habitat for mobile invertebrates and juvenile fishes. Marine Ecology Progress Series 339:109–122.

Price, J. 2011. Quantifying the ecological impacts of geoduck (*Panopea generosa*) aquaculture harvest practices on benthic infauna. Masterof Science thesis, University of Washington, Seattle, Washington.

Rossi, F., R. M. Forster, F. Montserrat, M. Ponti, A. Terlizzi, T. Ysebaert, and J. J. Middelburg. 2007. Human trampling as short-term disturbance on intertidal mudflats: effects on macrofauna biodiversity and population dynamics of bivalves. Marine Biology 151(6):2077–2090.

Ruesink, J. L., and K. Rowell. 2012. Seasonal effects of clams *(Panopea generosa)* on eelgrass *(Zostera marina)* density but not recovery dynamics at an intertidal site. Aquatic Conservation: Marine and Freshwater Ecosystems 22(6):712–720.

Short, K. S., and R. Walton. 1992. The transport and fate of suspended sediment plumes associated with commercial geoduck harvesting, Final Report. Prepared for the State of Washington Department of Natural Resources. Prepared by Ebasco Environmental, Bellevue, Washington.

USFWS. 2016. Biological Opinion: Programmatic consultation for shellfish activities in Washington State inland marine waters. U.S. Fish and Wildlife Service, 01EWFW00-2016-F-0121, Lacey, WA.

VanBlaricom, G. R., J. L. Eccles, J. D. Olden, and P. S. Mcdonald. 2015. Ecological Effects of the Harvest Phase of Geoduck (*Panopea generosa* Gould, 1850) Aquaculture on Infaunal Communities in Southern Puget Sound, Washington. Journal of Shellfish Research 34(1):171–187.

Ward, D., A. Morton, T. Tibbitts, D. Douglas, and E. Carrera-González. 2003. Long-Term Change in Eelgrass Distribution at Bahía San Quintín, Baja California, Mexico, Using Satellite Imagery. Estuaries 26:1529–1539.

Photo 1. Current PVC tube predator protection.

Photo 2. Current PVC tube predator protection with area net.

Photo 3. Current HDPE mesh tube predator protection method.

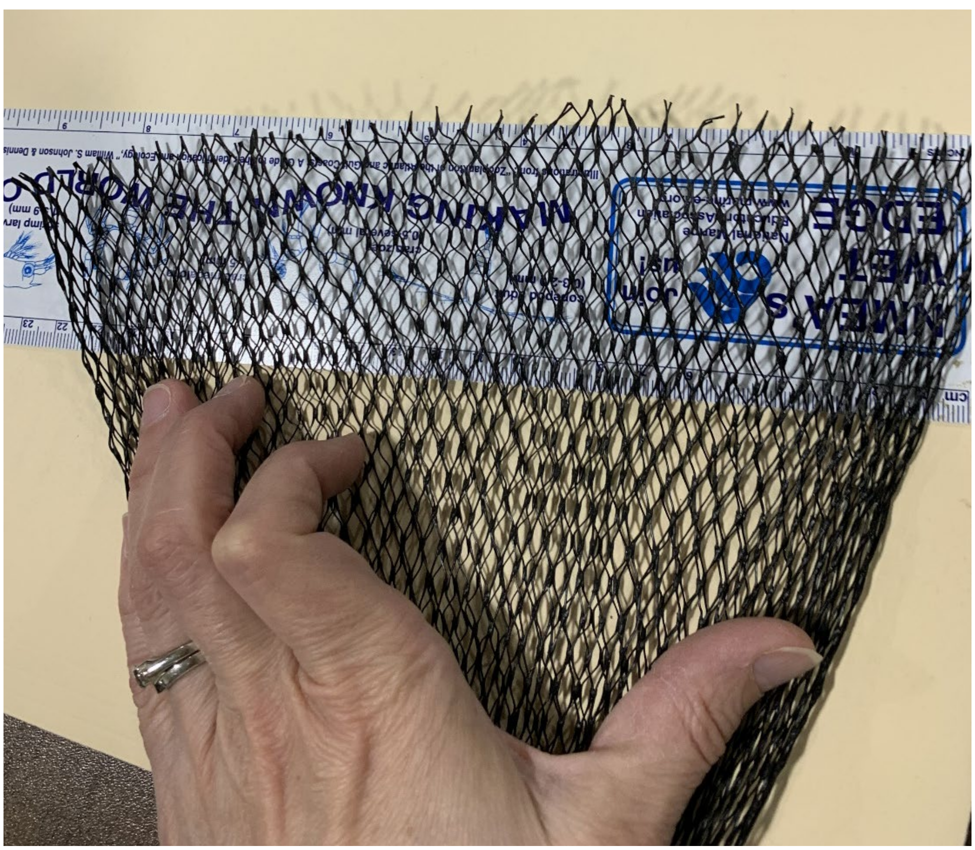

Photo 4. Proposed VEXAR mesh tube material.

Photo 5. Modified clam gun used to install VEXAR mesh tube.

Photo 6. Proposed VEXAR mesh tube predator protection installed in eelgrass.

Photo 7. Proposed VEXAR mesh tube within eelgrass.

Photo 8. Proposed VEXAR mesh tube with four planted geoduck seed.

Photo 9. Proposed VEXAR mesh tube predator protection.

Photo 10. Proposed VEXAR mesh tube predator protection, with prone tubes.