GEODUCK CLAM RESEARCH AND MANAGEMENT: PACIFIC SHELLFISH INSTITUTE COMPONENT

DELIVERABLE 3: REPORT ON POTENTIAL SITING AND ENVIRONMENTAL CONSIDERATIONS IN GEODUCK FARMING AND SUMMARY OF SUBTIDAL METHODOLOGY ADVANCEMENTS.

PACIFIC SHELLFISH INSTITUTE
OLYMPIA, WASHINGTON

September 8, 2004

TABLE OF CONTENTS

Introduction

Deliverable 3 is a synthesis of available information from commercial geoduck interests on three major components: siting criteria, environmental considerations and subtidal methodology advancements. Each component is divided into its own section for ease of use. For this deliverable, PSI employees surveyed a majority of Washington state geoduck farmers and aquaculture interests in Alaska and British Columbia in person, via phone, or by e-mail. See Appendices for complete transcripts of interviews.

Intertidal geoduck culture in Puget Sound is far ahead of current British Columbia (and Alaska) intertidal culture operations. Conversely, subtidal geoduck culture is far more advanced in British Columbia as compared with Puget Sound where subtidal culture is limited to small research plots. Accordingly, most of the knowledge gained from this study on intertidal siting criteria, environmental considerations are the result of information gathered from WA geoduck interests. Generally, subtidal elements of environmental considerations, siting and methodologies are a result of interviews with BC growers and public officials.

In direct result of this split of component sources, some objectives are more complete than others. Initial communication with BC geoduck interests resulted in promising information. Discussions faltered as soon word was passed around that information gathered by this study had the possibility of being spread to competing geoduck producers, namely China. Subsequently, key BC geoduck subtidal farmers and biologists refused to provide detailed information and in the worst case refused to be interviewed.

Illustrations of characteristic intertidal farm sites, planting and harvest methods, and geoduck predators are shown in Figures 1 to 3

Siting Criteria

There are a myriad of variables that can be considered in determining if a section of beach or seafloor is suitable for geoduck aquaculture. The following is a discussion of a short list of variables that commercial interests included in their criteria:

Substrate: Overall, a sandy substrate was preferred for geoduck culture by all of those interviewed including BC interests. A small percentage of the substrate can consist of mud, or pea gravel but most should be sandy. Substantial amounts of shell, cobble, and woody debris should be avoided as it may impede growth, and result in off color and odd-shaped geoducks. This debris may also lead to increased mortalities by preventing geoducks from burrowing to a suitable refuge level.

Specifically for intertidal areas, growers noted that sand grain size is a key factor, as the larger the grain size the better chance the beach has to dry out. This allows for more siphon shows since it is harder to see shows in wet sand. The highly sandy substrates should extend to a depth of at least 3 feet. One farmer suggested a higher percentage of pea gravel should be targeted as it will produce better looking geoducks. Many noted that a high percentage of mud may produce off color geoducks.

Out of all siting characteristics, substrate was deemed the most valuable. Most growers survey areas for substrate content and depth before leasing, purchasing, or planting for geoduck aquaculture.

Temperature: While ambient water temperatures in Puget Sound, Strait of Juan de Fuca, and the Strait of Georgia are generally suitable for rearing geoduck, intertidal surface water temperatures must be closely monitored during out-planting of geoduck seed. High temperatures can kill or immobilize seed before they are able to bury into the substrate. Exact temperatures at which seed undergoes stress resulting in mortality were generally not discussed in an effort by participants to avoid distributing sensitive or proprietary information. While elevated incoming surface water temperatures may sometimes be of concern, the primary consideration on whether or not to plant seed is more directly related to air temperature and sun exposure during planting. Growers avoid planting during periods of high air temperatures and attempt to seed tubes only during an incoming tide to reduce temperature exposure.

Salinity/Riverine Influences: Laboratory/hatchery studies demonstrate that juvenile geoducks exhibit reduced burrowing rates and increased mortalities when challenged with low or reduced salinities. In efforts to circumvent this problem, research in now underway to determine if geoduck seed can be conditioned to withstand lower salinities. If so, seed could possibly be planted in areas and at times that where unfavorable in the past, opening up more ground and increasing planting times. While it is believed that low salinity may only influence geoduck seed, research targeting affects on larger geoducks has yet to be conducted.

Currently, the industry is dealing with potential low salinity problems by siting operations in areas that are not strongly influenced by freshwater. Some intertidal growers avoid planting near larger streams or rivers. In doing so, they also avoid other negative affects of riverine systems such as tube and net burial from increased sediment transport. Two growers suggested that all areas which experience salinities of 26 ppt and below should be avoided, noted it may be difficult to account for freshwater runoff during large rainfall events. One grower noted that siting on intertidal land that juts out at the mouths of inlets is an effective way to avoid this problem.

Conversely, it was suggested that subtidal geoduck may grow better in areas that are influenced by creeks. This observation was based on their wild harvest experience where subtidal areas offshore from creek channels were "loaded with geoduck". Other diver observations suggested that areas heavily influenced by rivers in North Puget Sound produced far few numbers of wild geoduck. Low salinity was pointed out as a possible reason for these low populations. If the above low salinity conditioning trials prove to be successful then perhaps cultured geoduck could be planted effectively in these areas.

pH and Dissolved Oxygen: These water quality variables were not considered to be key siting issues to the group interviewed.

Phytoplankton (chlorophyll) and Nutrients: Growers consider phytoplankton (chlorophyll) and nutrient levels to be major factors influencing the siting of geoduck farms. While, only anecdotal information was available from growers on nutrient and plankton levels; limited quantitative data for select Puget Sound locations are available from Washington Department of Ecology (WDOE) (Jan Newton), PSI (Aimee Christy), University of Washington Department of

Oceanography (Rita Horner) and Evergreen State College (Gerado Chin-Leo). Water clarity and growth in other shellfish species are indirect ways growers can assess phytoplankton and nutrient levels. Phytoplankton are seasonally abundant in most of Puget Sound, but especially in South Sound. Growers prefer locating their farms in the South Sound region because of this detail. South Sound is thought to have such an ample supply of nutrients that increased geoduck aquaculture is viewed as a way to reduce the potential of nutrient overloading. The northern regions of Hood Canal are also considered suitable since phytoplankton is made available from strong mixing and tidal currents. While abundant in nutrients, other regions of Hood Canal may produce slower growing geoduck due to low mixing.

Elevation: Tidal elevation is closely evaluated by growers, especially at the times geoduck are out-planted. Some growers are limited to certain bottom elevations due to the presence of eelgrass or poor substrate in otherwise suitable elevations. Most growers agree on suitable ranges. For intertidal culture, they focus on +2-ft MLLW (Mean Lower Low Water) to -4-ft MLLW or extreme low water. If ground is available, some growers will extend their planting from the upper +2-ft MLLW elevation to +4-ft MLLW. These higher elevations are not ideal, as they will produce a slower growing geoduck; however, they are used when other ground is limited.

Subtidally, growers would like to stay in the phototrophic zone of [illegible]-ft MLLW to -25-ft MLLW, but are willing to go deeper to -70-ft MLLW or, for one grower, as deep as -120-ft MLLW. In staying in the phototrophic zone, growers believe geoduck will have access to an increased supply of food (both phytoplankton and benthic microalgae) and exhibit faster growth than geoducks in deeper waters where there is reduced light penetration. However, one grower observed that the phototrophic zone may need to be avoided due to higher levels of macroalgae and eelgrass (*Zostera marina*) at these bottom elevations.

Biotoxins: The presence of marine biotoxins, Paralytic Shellfish Poisoning (PSP) in particular, is a major siting consideration for most growers. A majority of growers will reference past records and historical data on PSP closures before leasing or purchasing a site. There is a fear the PSP closures are spreading to areas that once were free of the toxin. Certainly, PSP levels will be closely watched and highly valued siting criteria. Growers in WA that are affected by PSP have to submit to increased and costly monitoring. Harvest restrictions may prevent them marketing product during periods of high demand.

One grower suggested that there are other ways to circumvent this problem as Alaskan geoduck harvesters have done in the past. In most instances, he stated, the toxins lay in the liver and intestinal organs or "gut ball" of the geoduck. This gut ball is taken out and the remaining geoduck is sold to the Asian market for a lower price. This process enables harvesters to work during seasons when PSP is prevalent, thus providing stable jobs and a more constant supply of geoduck to the market. However, this observation is not consistent with the ongoing Washington Department of Health (WDOH) practice to assess harvest risks and PSP closures based upon whole animal samples.

Human influence: If possible, it would be desirable to stay away from large upland human populations and access points. Bacteria from septic systems can close beaches and people have a history of trespassing, poaching, and vandalizing geoduck grow-out areas. Areas with histories of health closures must be avoided or assessed with great care. The WDOH is the lead agency in charge of certifying beaches for harvesting by issuing a required Heath License, and staff can be contacted directly regarding commercial requirements. Additional information is available at: http://www.doh.wa.gov/ehp/sf/Commercial.htm. Sites that are conditionally opened to harvesting (harvest is not allowed during periods of heavy rainfall or sewage overflows) may still be of interest to geoduck growers due to other favorable siting characteristics such as substrate and proximity to other operations.

Proximity to access points such as state parks should be avoided as people have a history of trespassing onto private geoduck ground to dig up geoduck adults and seed. Areas that have closed or limited access have few or no incidences of this behavior. Upland owners who lease their tidelands to geoduck farmers or are provided access rights will more than likely be concerned about new development taking place on what they consider "their" beach Communication with upland owners is important in establishing healthy relationships where concerns can be voiced and resolved amicably.

Growers should also employ husbandry practices that reduce the chance of confrontation. Some beach users may not like to see the expanse of white tubes on the beach especially when it is concert with increased noise from cars, people and harvest pumps. Farm debris and trash is another major concern, as it can accumulate quickly if not policed. Possible sources include: floats, mesh, stakes, rope, tubes, lines and cigarette butts. It is up to the farmer to keep abreast of potential farm waste and trash problems, and to retain acceptance of upland owners and other land users. Since farm waste is most noticeable in intertidal areas some growers believe that its effects will be reduced if geoduck are farmed subtidally. Unfortunately, they noted if farm waste is not controlled on-site it can eventually wash up on the adjacent beaches, plus it is harder to police subtidally due to money (diver) constraints. Perhaps, they observed, the DNR Codes of Practices or BMPs for geoduck aquaculture should include provisions for site clean up, noise control, and other possible human activity.

Current (water velocity): This criteria was deemed critical by interviewed growers. While increased water currents and tidal flows appear to enhance geoduck growth by boosting food availability, too much current can also become a problem. Strong currents may bury, dislodge and wash up predator exclusion devices. Moderate currents are favored by most growers for the above reasons. Exact velocity information is not available and has not been measured on farm sites; however, all of the existing intertidal farms are located in areas of low to moderate velocities with primarily long-shore water currents.

Wind/Wave action: While wind and wave action can influence currents, which is critical to site selection, little thought has been put into other possible benefits or detriments. Wind waves and boat wakes are a primary concern during planting and must be avoided. Seed can be washed out of planting tubes by very modest wave activity. One grower suggested that areas that are heavily influenced by wind accompanied with a large fetch can result in problems during growout. The resulting wave action can increase sediment movement similar to the affect of strong currents. Predator netting can also be torn off of PVC tubes if wind and wave action is strong. This results in a loss of predator exclusion protection as well as a trash problem that must be addressed to avoid a negative public image. One the other hand, one grower stated that areas with large fetches and southerly wind exposure were good as they provided warm surface water to intertidal geoduck grow-out areas. Overall though, most growers avoid areas that are influenced by wind over a large fetch since this can produce increased and undesirable wave affects.

Existing Geoduck Populations: The presence of an existing or nearby wild geoduck population is seen as a positive characteristic. This provides an immediate and definitive answer as to whether or not geoduck will grow in the proposed planting area. Growers noted that areas without wild populations on site or nearby may still have potential (see the Geographic Region section) and suggested it may be wise for DNR to consider such areas to avoid compensation and chain of custody issues.

Ulva/Enteromorpha: Macroalgae, specifically *Ulva* and *Enteromorpha*, have caused operational problems in the past as they are prone to settle on predator exclusion devises. High densities of these macroalgae can decrease circulation of food which in turn can decrease geoduck growth. Also, when the macroalgae die and decompose the resulting low oxygen and hydrogen sulfide (H_2S) rich conditions can cause seed and juvenile mortality, and the discoloration of harvestable animals. While it is thought nearly impossible to avoid areas where macroalgae will settle, there may be areas where it is less abundant and less of a problem. No one presented a clear understanding of criteria to determine where these areas are located

Geographic Region: A majority of established geoduck growers preferred sites located in south Puget Sound (SPS) and it is of no coincidence that a majority of geoduck operations are located is this region. The proximity to current culture operations is certainly a deciding factor for growers, as this reduces travel time and cost by eliminating the addition of infrastructure to other areas. Some growers have noted that SPS DNR beaches and subtidal areas hold similar promising characteristics. As noted above, food (phytoplankton) in SPS is abundant and in some cases overabundant through nutrient loading from increasing human populations. SPS also has substantial concentrations of wild geoduck -- a promising characteristic for farm siting.

Successful pilot scale operations have also been located in Sequim Bay and Thorndyke Bay (north Hood Canal). Sequim Bay and the nearby Dungeness spit present favorable farm siting characteristics, including the presence of wild geoduck, an adequate food supply, good infrastructure, and generally suitable substrate. While south and central Hood Canal is considered less suited to geoduck culture due to minimal mixing and slow growth, north Hood Canal has better potential since it is subjected to increased mixing and currents. Substantial wild populations are present in this area, which increases the likelihood it may be suitable for geoduck farming operations. There is also recent interest in the Hood Canal region to apply subtidal geoduck aquaculture as a tool to remediate nutrient overloading and worsening low dissolved oxygen levels

North Puget Sound wild geoduck populations are lower than SPS, although there are large areas of suitable bottom habitat. The decreased wild populations may be a result of lower salinities from major rivers in the region or the abundant population of Dungeness crab which prey on geoduck. One grower believed that low salinities may only be affecting wild geoduck recruitment and that hatchery seed could be acclimated to lower salinities before out-planting. To overcome Dungeness crab predation, [illegible] suggested one could protect the geoduck as they do in current operations.

Progress in Subtidal Culture

Subtidal planting of geoduck is still in the experimental stage in WA but new technology has recently been developed and subtidal trials have been initiated. Subtidal test plots in South East AK have been planted in 2002 with additional subtidal tenures just opening up to aquaculture. The Underwater harvesters Association (UHA) and FAN Seafoods Limited (FAN) in BC have 10 and 11 years respectively, of subtidal planting experience. Accordingly, the majority of information on subtidal culture methodology is a result from discussions with BC geoduck interests.

Washington: Washington experimental sites are very limited. Of the information gathered, only 3 growers have experimented in subtidal culture. Growers have used paper and PVC tubes and large Vexar® netting. One grower has developed a prototype seeding machine while another has access to a BC based machine.

While expensive, time intensive and laborious, PVC tubes have been used subtidally and have delivered some success. From the small data collected from one grower, it was found that survival rates were excellent in 2" tubes (75%) and good in 4" tubes (50%). Other growers did not reveal survival rates for PVC tubes.

Some success was seen during limited trials in the use of paper tubes to protect geoduck from predators. However, the paper did not biodegrade as hoped resulting in the blacking of the geoduck necks. This discoloration is a major concern for any geoduck farmer as it will greatly reduce the market value. Paper tubes may become an option in the future, and are still of interest to some growers, if a source of biodegradable tubes is found.

Covering areas with mesh for controlling predators is becoming a popular experimental method subtidally. Long tracts of netting 14-ft in width and 3,000-ft in length are being tested by one individual, who had no information on survival rates. Floating ¾-inch mesh netting has also been utilized in subtidal experiments and survival rates are expected to reach that of PVC tubes. Fouling is considered an issue in using large amounts of mesh as macroalgae has been known to attach to netting in intertidal areas causing flow and hydrogen sulfide problems. This has not been the case in the few subtidal experiments so far, so current results have been encouraging.

Many growers are anxious to see if subtidal planting via machine is feasible. Most are not willing to invest in the technology until it is a proven technology though. One grower, who is developing his own machine, has planted 4,000 seed on intertidal ground during high tide during machine trials. Information regarding survival rates was not divulged. None-the-less, this grower is willing to rent out or license this machine to other growers. Another grower has access to perhaps a more advanced machine through a BC business partnership. It is very likely that this relationship will be further explored if subtidal leases are made available.

Alaska: Experiments in subtidal geoduck planting are in their early stages. Groups have been focusing on the use of heavy Vexar® netting to protect the geoduck from predators. This netting is expensive and may become an issue if costs become a problem. More information was sought for Alaskan subtidal methodologies but phone calls and emails to Alaska geoduck interests were not returned. A paper regarding the final decision of leasing subtidal areas to Stephen Lacroix, a major geoduck aquaculture interest in AK was acquired through an internet search. This paper, from the State of Alaska Department of Natural Resources Division of Mining, Land and Water South Central Regional Land Office (attached), describes methodologies for the proposed subtidal lease:

Geoduck were proposed to be planted at a depth of -40-ft to -60-ft MLLW over a plot 597-ft x 359-ft x 502-ft x 253-ft in size. Predator control methods were to utilize 2-inch square by 6-inch long tubes space 1-ft apart. Geoduck were to be planted via diver at 2 to 4 per tube. After planting, areas with tubes were to be covered with ½ to ¾-inch mesh held down by stakes Corners of the planting areas were to be marked on the surface using buoys. Survival results obviously are not available since this operation is still in its early stages.

British Columbia: Some subtidal plantings have been successful in BC where mechanized seeding is preferred. The key players are the UHA, FAN, and Manatee Holdings Ltd. (Manatee). FAN is the only large tenure holder of subtidal lands. The UHA is a cooperative of every wild BC geoduck harvester. Only holders of an Individual Vessel Quota (IVQ) are able to harvest geoduck in BC, currently there are 55 IVQ holders. IVQ holders were determined when the wild geoduck shifted from an open fishery to a quota fishery. Most involved in the wild fishery were allocated an IVQ, in essence a 1/55 cut of the fishery. The UHA has been planting only on common resource grounds while Manatee has a small nursery tenure. There may be more leases available in 2005 but there is concern that additional leases will eliminate wild fishery ground which would directly affect UHA member fishing quotas. Establishing a stable hatchery system is needed for the advancement of this industry as US seed has been too expensive and difficult to acquire across international borders. Every key player has at least attempted to establish a hatchery system to provide seed for their efforts, but as of January 2004, there was not a successful geoduck hatchery in operation in BC. This is largely due to the high start up and operating costs and the lack of technological advancements. However, hatcheries are still of interest to all the major parties in BC and operations may start up again soon.

<u>FAN</u>, the leader in subtidal aquaculture, started operations in 1993 and holds most of the subtidal tenures. Unfortunately representatives were not interested in providing specific details, but information was gathered via other sources. FAN has 5 subtidal tenures established 9 years ago and totaling 86.5ha (213.8 acres) in the Strait of Georgia east of Vancouver Island. The tenures had to be harvested or "purged" of wild geoduck populations before seeding could be initiated. Geoduck were purged by UHA members and applied to their IVQ. A particular purge operation, initiated in 1994, took 4 years to accomplish due to the fact that after the majority of geoduck were harvested; there was little interest in harvesting in areas that had low geoduck densities. Harvesting in these areas would decrease harvester's catch per unit effort thus reducing the profit gained. Still, there are contentions from members of the UHA that wild geoduck remain in the area and should be included in the overall wild geoduck biomass predictions and not be harvested by FAN.

FAN has worked with Island Scallops in the past to produce geoduck seed. While successful in producing seed, Island Scallops decided to abandon its geoduck hatchery operation due to financial constraints. Subtidal planting was first initiated 9 years ago and planting and protection methodologies have been evolving ever since. FAN employs a partially mechanized method of planting and reports a 30 to 60% survival rate. Planting only takes place during certain times of year to avoid predators. Nets are used for predator control and are kept in place for 18 months to ensure maximum survival. Proper planting densities are still being assessed.

Currently FAN is in their 3rd year of harvesting 6 year old geoducks averaging 1.5lbs. The ideal target weight for harvesting farmed BC geoduck is 1kg (2.2 lbs) but FAN harvests at a smaller size primarily to provide income to cover expenses. It was suggested by another BC representative that it is a direct result of FAN not selecting particularly good sites.

The UHA's main focus in planting geoduck is to enhance common resource grounds. The UHA so far has planted 25 million geoduck on these grounds over 13 sites in the Strait of Georgia Surprisingly, there is no guarantee that these areas will be open to UHA harvest in the future. The UHA is resistant to subtidal aquaculture and considers their plantings as enhancement of wild grounds. They contend that it is too costly for aquaculture to be successful, as it is too expensive to produce seed, plant and operate the farm. Also it is great financial burden to take on initially as it will take 8 to 10 years until a profit is seen. Although these points are valid, it should be noted that UHA's position, along with others, may be biased as opening up additional subtidal lands to aquaculture may decrease their fishing quotas.

Hatchery development is in the works for the UHA, although some problems have been rumored. In the past, the UHA has purchased geoduck seed from BC companies such as Island Scallops which no longer is a geoduck seed supplier. Even though it is expected to take 8 to 10 years of growth to produce a harvestable geoduck, UHA representatives have said this to be acceptable since the areas that are planted were of need of wild recruitment. The UHA have been working with several seeding and protective methodologies. Machine seeding is the sole method of planting, but there are variations of its use.

Early protective methods employed protective mesh placed directly on the seeded ground. A machine would seed an area while dragging protective netting to cover the just seeded area. The netting was then held in place with rebar. The netting, made up of light plastic was 4 feet wide and 328 feet long. Netting was to cover the geoduck for 16 to 36 months. While protecting the geoduck from predators, it did not allow geoduck necks to grow freely and in some cases necks grew into the mesh. Mesh is now taken off of these areas earlier than expected due to that difficulty. The presence of kelp prevents this problem as when it is attached to the mesh, it promotes enough net movement that the necks don't grow through. Rather than rely on luck, another method was developed to completely solve this problem. This method is the current one being employed by the UHA.
Seed are planted by dropping seed via machine over a Vexar® netting canopy that is held into the substrate using rebar. By using a canopy, geoduck are able to freely move their necks without the possibility of being caught up in the mesh. The size of the netting is similar to the one used in previous trials, 4 feet wide and 328 feet long. Target densities are at 2 yd^2 or .22 ft^2 with planting rows spaced 5 ft apart. The seeding machine is said to be able to plant 20,000 to 100,000 geoduck onto the surface per day.

Manatee currently is focusing on acquiring lands for tenure and is in the process of shutting down their hatchery operation. The hatchery operation had been producing seed for 3 years and may be operational next year, depending on land acquirement. Presently, they only have a small tenure solely as a nursery to store and grow 500,000 seed until out-plant. Manatee is pressuring the Department of Fisheries and Oceans Canada (DFO) to open up an additional 20 ha (50 acres) on common resource land, not only for themselves but for others as well. They are promoting the establishment of an aquaculture park where other interests (1st nations, non-profits, fishermen, aquaculturists, etc) could get involved in geoduck aquaculture. Sites for this "park" have been surveyed under a joint venture with groups forming the Alliance of Independent Companies (AIC). For more information regarding this aquaculture park please see the attached, "Chain of Custody Conference Paper" authored by Eric Gant of AIC. Another topic of interest in this paper is that of sea otters. Manatee contends that sea otters are a major problem for wild harvesters and growers in BC waters. In the "Chain of Custody" paper it is detailed that sea otters should be eliminated inside the aquaculture park

AIC was formed to further develop underwater seeding gear and to solve seed and hatchery problems. Companies involved in AIC contain two 50% shareholders where Manatee is one and the other is another aquaculture interest. In agreements between the companies, Manatee is designated to be the major supplier of seed and will be in charge of seeding. The other shareholder is designated as being in charge of the overall growout operation on yet to be determined lease/tenure sites. Manatee is very interested in shifting its focus from BC to US waters if DNR opens up lands. Manatee has formed a joint company under AIC with a SPS grower and is willing to share information if subtidal lands become available.

When areas are opened up to plant, Manatee plans on planting at lower densities than are currently in practice. At these lower densities, which will be similar to wild harvest densities, it is thought that growth would be increased and mortality decreased. Manatee contends that their survival rate is at 50% and grow-out cycle will take 7 years.

Interest in Future DNR Leases/Studies:

All interviewed Washington geoduck growers expressed interest in DNR geoduck aquaculture leases and/or pilot projects in the near future (Table 1). Some concern was expressed regarding the overall process and possible fee structure. One grower suggested that the lease process should be similar to that of AK subtidal leases. Only one Washington grower did not want to participate in pilot scale projects with DNR. The remaining growers were willing to participate in intertidal and subtidal experiments if pilot leases could be available at no or minimal cost. Smaller, start-up companies also showed interest in leases and pilot projects but could not provide further details.

Table 1. Grower/tribal interest in a geoduck pilot project or leases, rated in level of interest from 0 (none), 1 (moderate) to 2 (highest).

Company:	Intertidal Pilot Project	Subtidal Pilot Project	Intertidal Leases	Subtidal Leases	Area
Chelsea Farms	2	1	2	1	South Sound/ North Hood Canal
Hama Hama Co.	2	1	2	1	Hood Canal
Seattle Shellfish LLC	1	2	2	1	South Sound
Washington Shellfish, Inc.	0	2	0	2	South Sound
Arcadia Point Shellfish	0	0	2	0	South Sound
Baywater Inc.	2	1	2	1	Hood Canal/Puget Sound
Sound Shellfish	1	2	1	2	South Sound
Taylor Shellfish Farms	2	1	2		South Sound
Jamestown S'Klallam Tribe	2	1	2	1	Dungeness Spit

Conclusions

Siting: Table 2 summarizes siting criteria that apply to both subtidal and intertidal geoduck aquaculture. Substrate, nutrients, phytoplankton, and geographic region were identified as vital siting characteristics by all geoduck interests interviewed. While the proper substrate properties, 3 feet of sand, can be found in all regions of Puget Sound, SPS is preferred by many growers as it has abundant seasonal phytoplankton levels and is close to many current operations.

Additional criteria such as Salinity/Riverine Influence, Elevation, Biotoxins, Human Influence, and Currents where highly regarded. Areas that have limited low salinity and riverine influences, a wide range of useable elevations, no history of PSP closures, decreased human interaction, and with moderate currents will be highly valuable. Characteristics that were deemed not as vital included: Temperature, Wind/Wave Action, Geoduck Populations, and Ulva/Enteromorpha. In determining a proper site these criteria should be factored in as long as they do not interfere with more important criteria. While ph and dissolved oxygen levels may be kev grow-out issues in the future, sites selection is not presently based on their levels.

Examples of Proven Intertidal Sites: A majority of areas that growers recommended as proven to grow geoduck effectively intertidally are located in SPS. Specific areas include: Eld Inlet, Totten Inlet, Hartstene Island and the Purdy spit. Other sites beyond SPS include Sequim Bay and Thorndyke Bay in northern Hood Canal. One grower suggested that any area with the right substrate will work, and one does not need to know other aspects of site suitability. Another suggested that all areas that are close to existing commercial sites should be considered by DNR for lease as they hold the most promise.

Examples of Proven Subtidal Sites: A small subtidal area adjacent to Purdy spit is also now being farmed in Washington State. Several subtidal sites have been established harvested in British Columbia east of Vancouver Island in the Strait of Georgia.

Table 2: Summary of siting criteria with priority scale: 1 (low priority) to 5 (high priority) and related key components.

Criteria	Priority	Key Components
Substrate:	5	High Percentage of Sand, Depth (3 ft)
Temperature:	3	Low Surface Water Temperature, Low Ambient Water Temperatures
Salinity/Riverine Influence:	4	Salinity above 26ppt, Freshwater Avoidance
pH/Dissolved Oxygen:	1	None noted
Phytoplankton/Nutrients:	5	Abundance
Elevation:	4	Intertidally: -2ft to -4ft MLLW, Subtidally: -4ft to -25ft MLLW
Biotoxins:	4	No PSP History
Human Influence:	4	Limited Access Points, Proper Husbandry Practices
Currents:	4	Moderate Current
Wind/Wave Action:	3	Small Fetch
Geoduck Populations:	3	Presence
Ulva/Enteromorpha:	3	Avoidance
Geographic Region:	5	Proximity to Current Operations, South Puget Sound preference

Subtidal methodologies: A recurring comment from those involved with subtidal aquaculture is that there is need of improvement. Subtidal planting is in it's infancy in Alaska and Washington. BC interests have developed a great deal of improvements but still are aware of their limitations such as a longer grow-out cycle, predator control, fouling, stable seed supply, and ownership issues.

It is possible for Washington growers to make rapid advancements in subtidal geoduck culture based on their dive harvesting experience, connections with BC interests, subtidal small scale trials and intertidal culture knowledge. Washington growers possess the infrastructure to begin subtidal geoduck culture. Geoduck seed supply is not as limited as it is in BC, and several producers have excellent research capabilities.

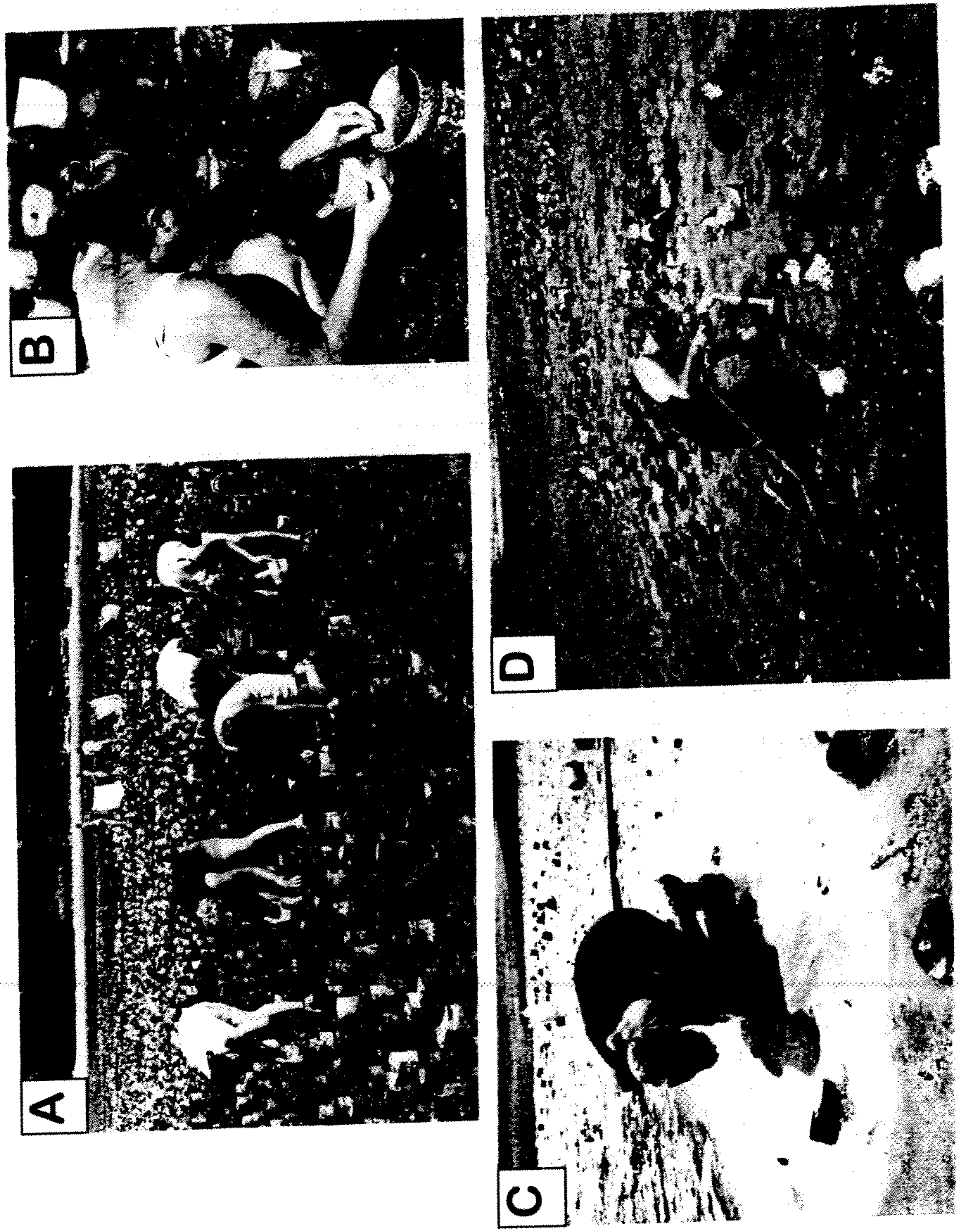

Figure 2. . Seeding and harvest. A. Large-scale seeding of tubes in a south Sound intertidal site. B. Close-up of planting process. C and D. Experimental harvest of near-market-ready geoducks using a hydraulic water jet at an intertidal site in Hammersley Inlet.

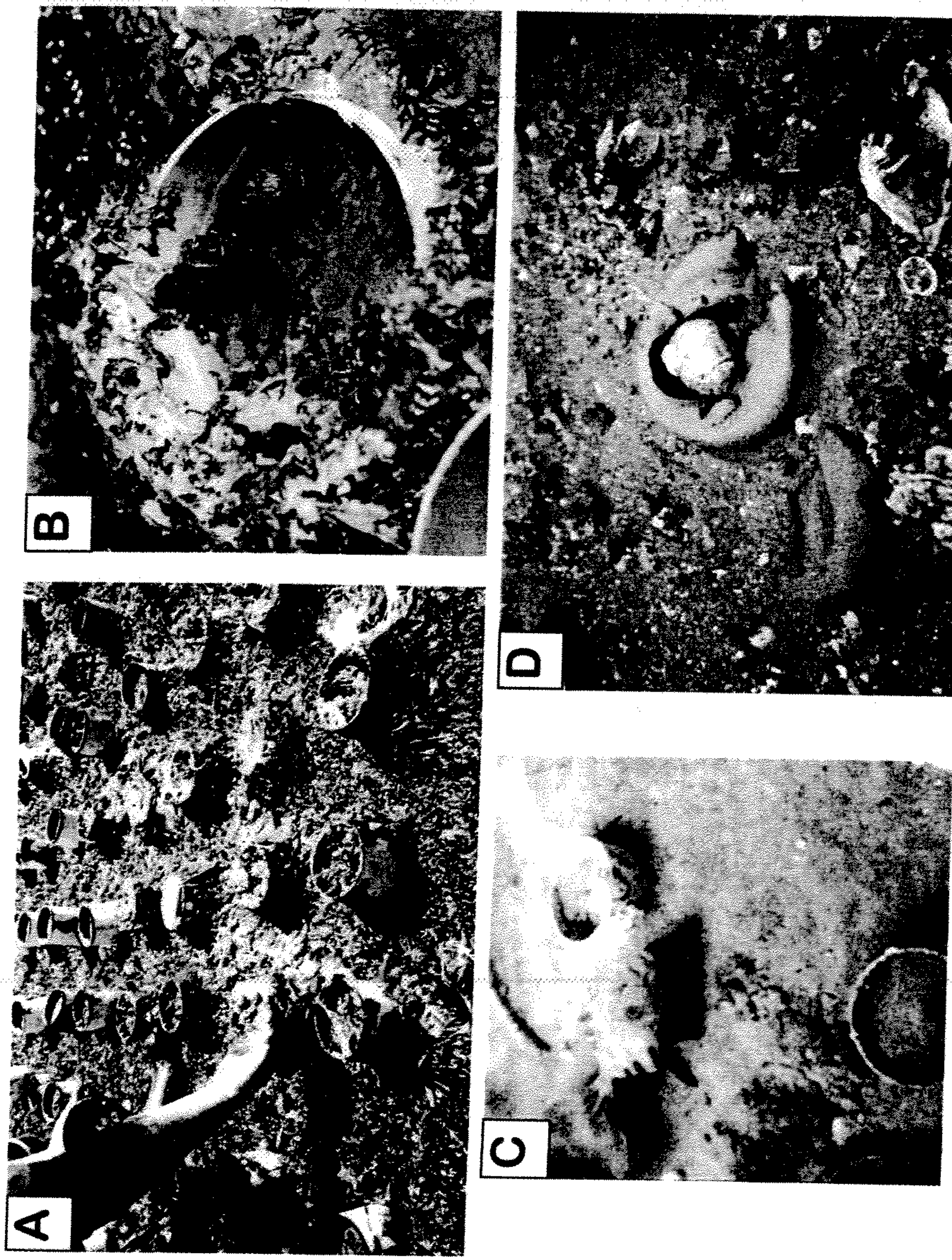

Figure 3. Fouling and predators. A. Heavy cover of *Ulva* on recently seeded tubes, Nisqually Reach. B. Close-up of the same with an extended geoduck siphon. C. Starry flounder exiting a tube, from video, Stretch Island. D. Moon snail with egg case.

APPENDIX 1

Transcripts of interviews with growers and biologists

Role in Geoduck Aquaculture: Researcher/Biologist for WDFW and Dive Crew Leader/Consultant

Siting Criteria

Substrate: Sand is the best, low levels of mud ok. Should be at least 3 feet deep of said substrate, other wise you will not get good growth and will be more vulnerable to predators. Same for both sub and inter tidal areas.

WQ: High temperatures can kill seed while out planting. Geoduck are cold water critters, 75*C and below is ok, but 75*C and higher results in mortality unless planting through the water column getting away from the initial heat shock of the incoming tide. Getting away from using tubes and using net may circumvent some temperature problems but predators can hide under the net, and in the substrate (crab, moonsnails) while the net is put on. Low salinity may have an effect.

Elevation: +2 to extreme low water for intertidal areas extreme low are harder to harvest though. For subtidal areas, any area from +4 to -70 ft would work. Wild geoduck populations increase density with depth but also get smaller with depth. This increase in density may be a result of increased predation in shallower areas.

Geographic Region: Central to South Sound are the best as they are proven and have wild stocks. The North Sound has a lot of great substrate but low wild geoduck populations which may be a low salinity consideration that only affects the embryos. Hatchery seed may be ok in this environment since they are big enough to withstand some lower salinities. Dungeness populations may be another reason why wild populations don't flourish in the North Sound, so protect your geoduck with screen or mesh. Hood canal may be a consideration to reduce nutrients but still have a huge circulation problem.

Human Influence: Stay away from large upland influences. Bacteria from septics and other human influences can become problems. Stay away from state parks as you will have problems with people coming over and digging. This has happened in some commercial beds already.

Oceanic Influence: N/A

Freshwater/Riverine influences: Low salinity may have an effect.

Nutrients or Plankon: Not a problem in South Sound, there maybe too much. Too many people increase our nutrient loads, so need shellfish!

Current: Very important, need moderate current. Not too fast or too slow.

Wind/Wave action: If there is too much of a fetch in one area you will have a problem with sand movement.

Examples of Proven sites: All Taylor and Seattle Shellfish Operations. Hartstine (subtidal and intertidal), Eld and Totten inlets.

Other: For DNR's perspective it would be wise to site areas that do not have wild stocks, but for the grower, it would be better to have areas that do. Ulva and enteromorpha can create problems as they can decrease circulation which in turn decreases available food, also when these plants decompose, H2S can settle inside the tubes. Try to find leases that don't have too much of a problem with these macroalgae, most sites have it but some have it in abundance.

Predation:

Predators and their effects: Mostly seed predation, but some can kill adults. Starfish can target medium to large geoduck that can't get down to 3 feet (1 meter). So substrate is consideration, since if geoduck can't get down to the refuge zone they have a higher probability of being preyed upon. There is a constant low level of predation until harvest time, look for pits (cone shaped) and will find an anesthetized siphon on occasion. Predation maybe a combination of diving ducks then crabs at high tide. Putting mesh (old salmon farm netting) on the whole area after pulling tubes might work.

The primary consideration is predator control, which should only be removed after it is causing a problem (tubes are being pushed out). Remove net only when it is causing a circulation problem, and then recover with larger mesh (salmon netting).

Moonsnails:

Cancer Gracilis: Will eat geoduck if predator net is taken off too soon. As they can get inside the tube. Will only eat tissue.
Cancer Magister: Will only eat tissue.
Cancer Productis: Will only eat tissue.
Pisaster brevispinus: Will target all sizes of geoduck.
Pycnopodia helianthoides: Will target all sizes of geoduck.
Flatfish (soles, Starry flounder, etc): Will take whole geoduck.

Siphon Snipping: Huge concern. Mainly juveniles, after tubes are pulled during/after the 2nd year until harvested. So, whenever protection is gone, snipping will occur even if at just a minor level. Has seen a siphon tip in a dogfish gut.

Birds: Most likely Scoters, as they probably rip out seed and siphons but hasn't seen. Gulls and Crows are also probable seed and siphon scavengers.

Environmental Factors: None known, most factors are farming related. How and how long you protect the geoduck.