Concerns and Questions Relevant to Infaunal and Epibenthic Impacts of Geoduck Aquaculture

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1. **Concern**: Seeding of young geoducks in netted PVC tubes on the beach is likely to alter local physical and biological conditions, both those on the surface of the sediment and those in the sediment. Much less invasive shoreline aquaculture techniques, such as gravelling beaches or adding surface netting, have been found to affect the size and oxygen level in the sediments, as well as the diversity and composition of non-target local organisms (see References below).
   Questions:
   a. How do surface biota (both mobile and sessile species) and infauna change with the addition (and then removal) of tubes? What species are gained or lost, and how might these interact with other ecosystem members such as herring, crabs, migrating salmon, etc? Are critical ‘corridors’ for migrating species disrupted? The study by Entrix (2004) discusses intertidal surveys but with the ‘limited’ number of transects they could not evaluate differences between planted and control beds.
   b. Are there proposals to establish geoduck farms on beaches with sand dollars? (Entrix, 2004, suggests that there are). Sand dollar beds are uncommon and may be declining in Puget Sound, are a key ecological species controlling local communities, may serve as refuges for young Dungeness crabs, and do not return to beaches once lost.
   c. What are the effects of large areas covered with aquaculture tubes on drift cell dynamics?
   d. What are the impacts of predator exclusion netting placed over the entire growing area (if employed) on the following:
      1. sediment composition.
      2. sediment movement (drift cell impacts).
      3. number and composition of benthic organisms under the netting.

2. **Concern:** Harvest of geoducks from high-density aquaculture beds will involve near-total liquefaction of the sediment to at least 50 cm. While organisms in the intertidal zone are adapted to small-scale physical disturbances (from waves, ghost shrimp, crab-pits, etc.), this large scale is not part of their evolutionary history. Other forms of intense habitat disruption, such as mechanical dredging for clams, have been outlawed. Intertidal holes are known to fill with sediment within weeks or months after small-scale digging, but there has been no research on recovery of normal intertidal sediment characteristics after liquefaction. A very limited amount of research has been done on impacts of subtidal geoduck harvesting on non-target species, but none

in the intertidal zone where the native flora and fauna are completely different. Thus many questions arise.

Questions:

a. What kinds of effects does harvest-caused liquefaction have on the sediment itself? Are fine silts and clays washed away, leaving only coarser grain sizes? Does this depend on the weather (waves) and tides (currents) during harvest periods? How is natural layering of grain sizes affected?
b. How do porosity of sediment and oxygen and nutrient levels in the sediment change during and immediately following harvest? Is organic detritus, consumed by many deposit-feeding worms and some clams, lost during harvest?
c. How much local mortality of infaunal and surface organisms results from harvest? Are the highly productive microalgae from surface sediments lost? How much of this mortality is direct (resulting from smothering or washing away of organisms) versus indirect (from loss of food or habitat structure, or from scavengers coming and feeding on disrupted animals)?
d. If geoducks are planted more sparsely and harvested individually rather than by liquefaction, how does this change the levels of ‘bycatch’ mortality?
e. What are the short and long term impacts of episodic increased turbidity caused by harvesting on adjacent forage fish spawning areas, eelgrass populations and macroalgae populations?

3. **Concern:** Natural soft-sediment habitats not only are part of the food web of Puget Sound but perform key ‘ecosystem functions’ such as nutrient cycling. These processes are highly dependent on the structure of the oxic/anoxic layers in the sediment. Bacteria, protozoa, and other microbes in the sediment are important decomposers of dead organic matter trapped in the sediment. Carbon, nitrogen, and sulfur are all cycled between the sediment, porewater, air and ocean by these species and by larger worms, clams, and crustaceans, as well as by chemical reactions that occur in the stable layers of sediment. Nutrients often get adsorbed onto sediment particles, and these may be released when sediment is resuspended in the water by harvesting.

   Questions:

   a. How are nutrient levels and cycling processes affected by high-density geoduck aquaculture and by disruptive harvest practices? After harvest, how long does it take before these organisms and reactions recover?
   b. What impacts are there to the local ecosystem of the disruption of these processes?
   c. If geoducks are planted more sparsely and harvested individually rather than by liquefaction, how rapidly do these processes recover?
   d. During harvesting, could the increased availability of nutrients contained in biodeposits lead to an increase in phytoplankton?

4. **Concern:** Nothing is known about actual post-harvest recovery time for the entire suite of animals and plants that normally inhabit these beaches. Statements have been made such as “recovery should be relatively quick” (Entrix 2004, p. 7-1) but there are *no directly*

relevant scientific data to support this claim. Recovery of small, highly mobile organisms with short life spans may indeed be rapid; these would likely include small crustaceans such as copepods and amphipods. For other species, such claims are unfounded. Long-lived species that inhabit potential geoduck beaches such as other clams and perhaps some worms will eventually recolonize beaches, but it would take years of growth before they returned to their previous sizes, densities, and interactions with the rest of the community. Rates of complete recovery of biodiversity may be slow.

Questions:

a. What organisms are able to recolonize harvested sediments via migration of adults? Does this depend on the size of the area harvested vs. size of undisturbed adjacent beaches? Can recovery be accelerated by planting geoducks in strips with undisturbed beach on each size? Once colonists migrate to harvested sediments, are they able to survive given the altered nature of the sediment and food supplies in it?
b. What organisms must rely on recruitment as larvae, spores, or seeds to recolonize? Does this recruitment occur annually, or more or less often? How good is survival of young recruits? Research in slightly coarser sediments in south Puget Sound shows that early mortality of young clams and worms is very high (Dethier et al. in prep.) so that survival to adulthood may be low and unpredictable.
c. Recruitment of some sediment-dwelling species (including some hardshell clams) relies on appropriate “cues” from the sediment, especially texture and chemistry of surface sediments (Marinelli and Woodin 2004). Are these cues lost in harvested sediments, and how long does it take them to re-form?
d. Recruitment of some species is facilitated by the presence of adults of their own species, by habitat-forming species such as tube worms, or by particular microbes such as some bacteria. If these are absent due to harvest disruption, will such species recruit and eventually recover anyway?
e. Do scavengers and predators that migrate to harvested areas immediately following harvest remain there, and if so do they affect the recovery of the natural community?
f. If geoducks are planted more sparsely and harvested individually rather than by liquefaction, how are recovery rates changed?
g. If recovery of some species critical to the food web (e.g. small crustacean prey of salmon) takes place within weeks but the predators are only feeding on these beaches during short periods each year, are there times when harvest impacts to these organisms can be minimized?

5. Concern. The flora and fauna of muddy-sand South Sound beaches, while less abundant than those of some other beach types, nonetheless are moderately diverse in lifestyle and position in the food web. Presumably they interact with the rest of the nearshore ecosystem in a variety of ways, but there has been minimal research about these interactions. Suggested ecological roles include: sand dollar beds providing nurseries for young Dungeness crabs; native (smaller) clams providing food for siphon-nipping fishes; small crustaceans living in tubes or on the surface providing key food for salmon and other fishes; and both worm tubes and seaweeds providing locations where herring lay their eggs.

Questions: What roles can be documented for organisms in targeted beaches? What species provide particularly crucial links with the rest of the nearshore ecosystem?

6. Concern. As more and more geoduck aquaculture areas are established, one of the possible impacts could be the genetic mixing of hatchery raised populations with existing wild populations. Hatchery raised stocks are potentially less genetically diverse than wild populations. It is likely that hatchery raised and outplanted geoducks will spawn at least once before they are harvested at approximately eight years of age. The concern is there will be a dilution of the genetic fitness of the wild stocks, resulting in a loss of genetic variability

Questions:

a**.** What will be the genetic impacts if farmed stocks interbreed with wild stocks?
b. Will there be a loss of genetic fitness in the diluted wild stocks?
c. What is the range of larval drift and survival?
d. What spatial separation between wild and hatchery populations will ensure that fertilization will not take place?

7. Concern. There are studies that indicate that the presence of a large filter feeding population can decrease phytoplankton biomass in the system. This process is more likely in areas with low tidal flow and high concentrations of filter feeders. One possible impact of this could be the reduction of food supplies for other filter feeders in the system.

Question:

a. What will be the impacts of intense phytoplankton grazing by aquaculture populations on other suspension-feeding organisms in the system such as zooplankton and benthic invertebrates?
b. Estimates of geoduck filtration rates have been made in lab environments. However, the filtration rates of geoducks under natural conditions should be investigated. This would add important information for the assessment of system-wide impacts of large aquaculture populations.

8. Concern: Eelgrass (*Zostera marina*) is an essential part of the nearshore marine ecosystem in Puget Sound. Eelgrass beds provide food and refuge for juvenile fish, Dungeness Crabs and Pacific herring. Migrating juvenile chum prey on harpacticoid copepods found in high densities in eelgrass beds. Herring deposit their eggs on eelgrass leaves and the eelgrass beds provide refuge for the young until they mature. Eelgrass grows in some areas where geoduck aquaculture takes place. There is little eelgrass in South Sound, so geoduck aquaculture impacts there are probably minimal. However, geoduck aquaculture projects are proposed in Samish Bay, where there is much more eelgrass, and hence, the possibility of more significant impacts.

Questions:

a. In areas where geoduck aquaculture and eelgrass are present, what are the short- and long-term impacts on eelgrass growth patterns and densities?
b. What are the recovery rates for eelgrass in these areas after harvesting disturbances over several harvesting cycles?
c. The above two questions can also be applied to areas adjacent to aquaculture plots where eelgrass is present.

d.Do the sediment plumes associated with geoduck harvesting have impacts on adjacent eelgrass beds?

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