



ASSESSING POTENTIAL BENTHIC HABITAT IMPACTS OF SMALL-SCALE, INTERTIDAL AQUACULTURE OF THE GEODUCK CLAM (*PANOPEA GENEROSA*)

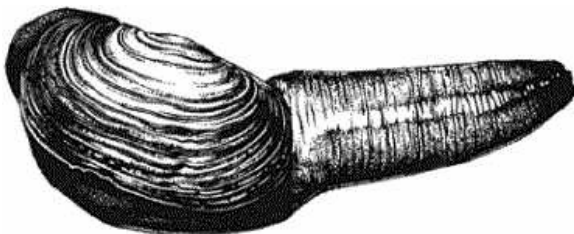


Figure 1: Geoduck clam (*Panopea generosa*).



Figure 2: Commercial-scale, intertidal culture of geoduck clams (*Panopea generosa*) in Washington state, using PVC tubes for predator protection of young seed. Photograph: C. Pearce.

Context:

The Pacific geoduck clam (*Panopea generosa*) is the largest burrowing clam in the world, adults living up to a metre below the sediment surface. In order to extract them, harvesters use high-volume water jets to liquefy the surrounding sediment. Expansion of geoduck aquaculture is highly desired by the shellfish culture industry, but is publicly contentious. High-density culture of geoduck clams and/or harvesting to a depth of a metre or more could have profound effects on the local benthic environment, but little research has examined the possibility. As a result, DFO Fisheries and Aquaculture Management requested an environmental impact assessment of culturing and harvesting cultured geoduck clams in the intertidal or subtidal marine environment. This report summarizes the results of the first in a series of experiments to assess the potential benthic impacts of geoduck out-planting and harvesting.

This Science Advisory Report is from the Fisheries and Oceans Canada, Canadian Science Advisory Secretariat, November 30 – December 2, 2010 Pacific Invertebrate Subcommittee Meeting: Pink and Spiny Scallop, Sea Cucumber, Central Coast Manila Clam, Geoduck Clam Aquaculture, and Shrimp Trawl. Additional publications from this process will be posted as they become available on the DFO Science Advisory Schedule at <http://www.dfo-mpo.gc.ca/csas-sccs/index-eng.htm>.

SUMMARY

- A small-scale (3 x 20 m) intertidal study was conducted in Nanoose Bay, British Columbia to assess the potential impacts of geoduck clam culture and harvest on the benthic environment.
- Sediment samples were collected within the harvest zone and at various distances (5, 10, 25, 50 m) along three transects from the area of culture/harvest at various times (ranging from 1 month prior to seed out-planting to 6 months post-harvest).
- Various sediment qualities (*i.e.* grain size, percent organics, total carbon, total nitrogen, sulphide concentration, and redox) as well as infaunal quantity and diversity were measured.
- There was a significant increase in the amount of silt and clay and a significant reduction in infaunal abundance and richness within the culture plot immediately after harvesting compared to immediately prior to harvest. There was also a significant decrease in the sulphide concentration after out-planting compared to before out-planting and a significant increase in total carbon content and redox potential after harvesting compared to prior to harvest. Significant changes in the silt and clay content and infaunal community were limited to the area within the harvest zone and recovery of the sediment size structure was rapid (within 123 days). There were no other significant effects of seeding or harvesting on any other measured variables.
- It is difficult to assess the rate of recovery of the infaunal community after harvesting, due to the seasonal decline in abundance and richness and lack of long-term sampling.
- The change in sulphide concentration, total carbon content, and redox potential was not great enough and/or in the right direction to have significant ecological implications.
- Although there were few ecologically significant, long-term impacts of small-scale, short-term intertidal geoduck culture/harvest in the present study, changes in habitat, size of the culture plot, frequency of culture, and seasonal timing of out-planting and harvest may alter the degree of impact on, and rate of recovery of, the marine environment.
- The interpretation of the results of the study should be used with caution until further research (currently underway) validates findings for larger-scale operations and over a broader range of potential ecological indicators.

INTRODUCTION

Background

The Pacific geoduck clam (*Panopea generosa*) (Fig. 1) supports the most valuable dive fishery in British Columbia (BC), Canada and Washington (WA), USA. In BC, from 2000 to 2007, the fishery's average total landing was 1.7 million kg yr⁻¹ and average total value was CAD 36 million yr⁻¹ (DFO statistics). In WA, in 2007, the wild fishery was valued at approximately USD 50 million (Gordon 2007). Since the early 1990s, there has been considerable interest in both geoduck enhancement and aquaculture as a potentially highly-valuable new industry in BC (Heath 2005) and commercially-harvested clams are currently being produced from both enhancement and subtidal culture. In WA, subtidal geoduck enhancement has been active since 1991 and commercial subtidal culture since 1996 (Beattie 1992). Unlike BC, WA began to

culture geoduck clams in the intertidal on a relatively large scale (with the first harvest in 2001) and produced 397,000 kg of cultured clams in 2007 (Gordon 2007).

Despite widespread interest in geoduck culture in BC and WA (and other regions), relatively little is known about the ecology or biology of this species and there is a dearth of information on the potential impacts of subtidal or intertidal culture and harvest on the marine environment. Intertidal geoduck clam culture involves out-planting hatchery-produced seed with predator protection [either PVC tubes (Fig. 2) or netting], growing out the geoducks for 5–8 years, and harvesting them using a high-volume water jet or ‘stinger’. This harvesting process liquefies the sediment around the clams, allowing them to be removed by the harvester. Adult geoducks may be buried up to 1 m and sediment liquefaction may occur down to such depths. There are concerns about the potential effects of high-density geoduck culture and harvesting on the benthic environment, but to date, other than a review by Dumbauld et al. (2009), no peer-reviewed literature exists on the potential impacts of geoduck culture/harvest.

The objective of the present study was to assess the potential benthic impacts of intertidal geoduck culture in a small test plot from out-planting of seed to 6 months post-harvest by:

1. Using industry-standard techniques for seeding and harvesting,
2. Analyzing various physical, chemical, and biological variables in benthic samples within the test plot and at various distances from the plot to determine the spatial extent of any potential impact, and
3. Analyzing various physical, chemical, and biological variables in benthic samples taken at various times before/after geoduck seeding and harvesting to determine the temporal extent of any potential impact.

Ecosystem Considerations

Potential impacts of geoduck culture on the marine environment may be due to three main activities: change in material processing (e.g. filter feeding, biodeposition), addition of physical structure [predator protection tubes (Fig. 2) or netting], and sediment disturbance caused during out-planting and harvesting (Dumbauld et al. 2009).

The introduction or increased density of geoducks may change the structure of the overlying planktonic community by an increased removal of live (phytoplankton and larval) and particulate matter by filter feeding. Geoducks may also alter nutrient fluxes with the uptake of dissolved nutrients. Biodeposition of faeces and/or pseudofaeces may lead to changes in physical, chemical, or biological characteristics of the benthic community. The addition of tubes or netting for predator protection of young juveniles may affect local hydrodynamics, increasing sedimentation rates (Spencer et al. 1997, Straus et al. 2008) and enhancing larval settlement and recruitment (Eckman 1983).

Among the several stages of culture, harvesting is likely to have the greatest impact on the marine environment. During harvesting activities, sediment is disturbed and re-suspended, potentially resulting in changes in various sediment chemical and physical characteristics and processes, as well as potentially impacting the local infaunal community or nearby vegetation.

ASSESSMENT

Methodology

The study was conducted over a 2-year period (2005–2007) on a relatively small-scale (*i.e.* 3 x 20 m) plot in Nanoose Bay, BC. The bay is situated on the east coast of Vancouver Island and opens to the Strait of Georgia to the east. The dominant northwest and southeast winds run the length of the bay and cross winds are rare. The study was conducted on the extensive, gradually-sloping sandflat at the western end of the bay. Industry-standard techniques were used for geoduck seeding and harvesting. The schedule of study activities is shown in Table 1. Hatchery-produced geoduck seed were hand planted in 240 PVC tubes. One year later, the geoducks were hand dug and the entire plot was ‘harvested’ to a depth of ~1 m using a high-volume, low-pressure water jet. Although the geoducks were obviously not of market size after a single year of growth, the plot was harvested as if they were adults. Harvesting was done while the plot was exposed during a low tide.

Benthic sediment samples were collected prior to out-planting and at various intervals after out-planting and harvesting (see Table 1). On each date, samples were collected at 0, 5, 10, 25, and 50 m along transects running onshore (shallow), parallel to shore (parallel), and offshore (deep) from the plot. Changes in sediment grain size, organic matter content, organic carbon content, nitrogen content, sulphide concentration, and redox potential were examined to assess potential abiotic impacts of geoduck culture and harvest. Patterns in the abundance, richness, evenness, and diversity of infauna were also examined to assess potential impacts on the infaunal community.

Table 1. Stage of geoduck farming and days from seed out-plant or harvest for each sampling date at Nanoose Bay, British Columbia.

| Sampling date | Stage of farming | Days from out-plant or harvest |
|------------------|---------------------|--------------------------------|
| 20 June 2005* | before out-planting | -32 |
| 16 August 2005* | after out-planting | 25 |
| 17 November 2005 | after out-planting | 118 |
| 29 January 2006* | after out-planting | 191 |
| 29 May 2006 | after out-planting | 311 |
| 10 July 2006 | after out-planting | 353 |
| 12 July 2006* | after harvesting | 1 |
| 5 November 2006 | after harvesting | 123 |
| 18 January 2007* | after harvesting | 191 |

* Dates at which infaunal samples were collected.

To test for an effect of geoduck culture on the benthic sediment characteristics at Nanoose Bay, separate analyses of variance (ANOVA) were used for median grain size, silt and clay content, organic matter content, total carbon content, total nitrogen content, sulphide concentration, and redox potential. Initially, three (fixed) factors were included in each analysis: time, transect (shallow, parallel, deep), and distance (0, 5, 10, 25, 50 m). In each analysis, however, the time and transect interaction term was significant, suggesting that the benthic environment along each transect was impacted in a different way. The sediment characteristics were therefore analyzed along each transect separately with two-way ANOVAs (time and distance) for median grain size, silt and clay content, organic matter content, total carbon content, and total nitrogen

content, and with three-way ANOVAs for sulphide level and redox potential [where depth (2 and 4 cm) was also included as a fixed factor].

To test for an effect of geoduck aquaculture on the infaunal community, two-way ANOVAs were used for infaunal abundance, species richness, Shannon-Weiner diversity, Margalef's species richness, Pielou's evenness, and abundance of dominant phyla with time and distance (0 and 10 m only) as factors.

Results

Sediment Analysis

At Nanoose Bay, 81% of the sediment was classified as coarse to fine sand. There was no significant change over time in the median grain size along the shallow and parallel transects. Along the deep transect, grain size peaked 191 days after out-planting due to an increase in grain size 50 m from the experimental plot. Median grain size was also similar across all distances, except at 50 m along the parallel and deep transects.

The silt and clay content of the sediment varied over time and across distance along each transect. With all distances considered together, the change in silt and clay content over time did not correspond with geoduck out-planting or harvesting. However, the significant time and distance interactions suggest different patterns of change over time at each distance. To determine if the silt and clay content varied with culture activity at any particular distance from the experimental plot, separate 1-way ANOVAs for each distance were conducted, with time as the single factor. Again, at 5, 10, 25, and 50 m, the variation in the silt and clay fraction did not correspond with culture/harvest activity. In contrast, at 0 m, the silt and clay content peaked in all 3 transects immediately after harvesting, with a return to baseline levels by the next sampling time (day 123).

The organic matter content varied over time along each transect; however, the changes did not correspond with geoduck culture/harvest activity. Along the shallow and parallel transects, the organic matter content was highest at 50 m, likely due to the presence of eelgrass. The difference among distances was less 353 days after out-planting and after harvesting, leading to a significant interaction term for the shallow and parallel transects. Along the deep transect, the organic matter content was highest at 10 and 25 m, particularly from 311 days after out-planting onwards. This difference was greatest 353 days after out-planting and 1 day post-harvest, again leading to a significant time and distance interaction term.

Along each transect, the total carbon content was significantly higher 123 and 191 days post-harvest compared to all other sampling dates. This increase was not observed 1 day after harvest though and was evident at all sampling distances, both observations suggesting that increased carbon content after harvesting was not directly linked to the harvest process *per se*. Across all sampling dates, total carbon content was highest at 50 m along the shallow and parallel transects, again likely due to the presence of eelgrass beds.

Like the organic matter content of the sediment, the total nitrogen content varied over time, but not in relation to culture activity. Rather, along the shallow and parallel transects, the total nitrogen content appeared to vary with season, being lowest in the winter (118 and 191 days after out-planting, and 123 and 191 days post-harvest) and highest in the summer (25 and 353 days after out-planting, and 1 day post-harvest). Like organic matter and total carbon content, total nitrogen content was highest at 50 m along the shallow and parallel transects. The

difference among distances was less 123 and 191 days post-harvest leading to a significant time and distance interaction term for both shallow and parallel transects. Along the deep transect, the total nitrogen content was highest at 25 m; however, not at every sampling date, again leading to a significant time and distance interaction.

The sulphide concentration of the sediment was highest before out-planting along all three transects. To determine if the sulphide concentration significantly decreased over time at each distance from the experimental plot, the significant time and distance interaction terms for the shallow and deep transects were assessed for each distance, with time as the single factor. This analysis revealed that the sulphide concentration was generally significantly higher before out-planting than after out-planting (but not for all distances). This change in sulphide level with out-planting, however, is unlikely to have had a significant ecological impact. Even prior to out-planting the sulphide concentration of the sediment was very low, with an average level across all distances and transects of 162 ± 17 (SE) μM and 332 ± 44 μM at 2- and 4-cm depths, respectively. These levels are below/near the transition from normal to oxic conditions at 300 μM sulphide (Wildish et al. 1999). Of the two depths sampled, the relative sulphide concentration was higher at 4 cm compared to 2 cm along all three transects; significantly higher for the shallow and deep transects and marginally non-significant for the parallel transect.

The redox potential of the sediment at 2- and 4-cm depths was highest 123 and 191 days post-harvest along all three transects. There was no time and distance interaction for any transect, indicating that changes in the redox potential occurred at all distances up to 50 m from the culture/harvest plot. Since the increased redox potential occurred at all distances and was not evident 1 d after harvest, the increase may have been due to a factor external to the harvesting activity (as is suggested with total carbon). Similar to sulphide concentration, this change in redox potential is unlikely to have negatively impacted the infaunal community (Pearson & Stanley 1979). Throughout the cultivation process, the average redox potential was greater than 150 mV, above the threshold of 100 mV below which normal conditions change to oxic ones (Wildish et al. 1999). Overall, the redox potential was lowest at 50 m along the shallow transect and highest at 0 m along the parallel and deep transects. Along all transects the redox potential was consistently higher at the 2-cm depth compared to the 4-cm one.

Infaunal Analysis

Infaunal abundance and two measures of species richness were highest immediately after out-planting and harvesting at a distance of 10 m. Although these measures appeared to vary with geoduck culture activity, they also varied with season (*i.e.* higher in the summer, which is when seeding and harvesting occurred). All three measures were highest in August 2005 (25 days after out-planting), lowest in January 2006 and 2007 (191 days after out-planting and 191 days post-harvest), and intermediate in June 2005 and July 2006 (before out-planting and 1 day post-harvest). There was a significant time and distance interaction term for infaunal abundance. Separate one-way ANOVAs for both distances revealed that the significant interaction term was due to the lack of increase in abundance at 0 m immediately after harvesting, compared to an increase pre- to post-harvest at 10 m (most likely a seasonal effect). Pielou's evenness was significantly higher 191 days after out-planting compared to 1 day after harvesting at 10 m only, leading to a significant interaction term. The Shannon-Weiner diversity index did not vary over time.

Similar to total infaunal abundance, the abundance of arthropods and echinoderms was higher in the summer, after out-planting and harvesting, and lower in the winter. For both arthropods and echinoderms there were also significant time and distance interaction terms. Again,

separate one-way ANOVAs for each distance revealed that the significant interaction terms were due to the absence of an increase in abundance at 0 m immediately after harvesting, compared to an increase pre- to post-harvest at 10 m (most likely a seasonal effect). Overall, arthropod abundance was higher at 10 m than at 0 m. Annelid abundance was highest 25 days after out-planting and higher at 10 m compared to 0 m. The abundance of nemerteans was highest and the abundance of molluscs lowest 191 days after harvesting.

Sources of Uncertainty

One of the largest sources of uncertainty lies in the scale of the study, the experimental plot being only 60 m². In contrast, commercial-scale intertidal plots may range from approximately 2,000 to 42,500 m² or from 0.5 to 10.5 acres (ENVIRON International Corporation 2009). It is unlikely that the intensity of impact per unit area in a commercial plot would be substantially different than in the current study (as industry-standard techniques were used for seeding and harvesting in the present work), but obviously a larger area will be affected during commercial-scale culture/harvest. Larger-scale research assessing potential impacts of geoduck harvesting is currently ongoing.

Factors such as habitat type, frequency of culture and harvest, and seasonal timing of out-planting and harvesting may alter the degree of impact on, and rate of recovery of, the marine environment. The potential effects of these various factors were not addressed in this research. Potential effects of geoduck culture/harvest on large infaunal organisms (e.g. bivalves) and sensitive aquatic vegetation (e.g. eelgrass) were also not examined in the present study and should be addressed in future research.

There was a lack of seasonal increase in infaunal abundance in the culture plot immediately after harvest that was evident 10 m outside the plot. Due to the lack of long-term sampling post-harvest, the study was not able to determine the rate of recovery of infaunal abundance after harvesting. Longer-term studies would be required.

Only three replicates were taken at each distance and time point and the same three replicates within the study plot were used as data points for each of the three transects. Power analyses were conducted on the various data sets and showed moderate to very high chances of committing a Type I error or rejecting the null hypothesis when it is in fact true. If Type I errors indeed occurred in the data analyses this would have caused an overestimation of potential culture/harvest effects (i.e. concluding there was a significant effect when there was in fact none). Power analyses revealed, however, that the chances of committing a Type II error – or not rejecting the null hypothesis when it is in fact false – in the data analyses were generally low (typically 0–22%, although with a few variables >50%). Further research should use increased sampling size, although there is always a trade off since increased replication may necessitate a reduction in the number of sampling points (either in time or space) as many of the measured variables require much time and effort to collect data on (e.g. infaunal identification).

CONCLUSIONS

During small-scale (3 x 20 m) and short-term (2-year) intertidal geoduck culture/harvest there was a significant increase in silt and clay content and a significant reduction in infaunal abundance and richness within the culture/harvest plot immediately after harvesting compared to immediately prior to harvesting. There was also a significant decrease in the sulphide concentration from before to after out-planting and a significant increase in total carbon content and redox potential after harvesting compared to before harvesting.

Changes in the silt and clay content and infaunal community were limited to the area within the harvest zone and recovery of the sediment size structure was rapid (within 123 days). Due to the seasonal variations in infaunal abundance and richness and lack of long-term sampling in the study, it is difficult to assess the rate of recovery of the infaunal community after harvesting. Since the changes in total carbon content and redox occurred at all distances (up to 50 m away from the study plot) and were not evident 1 day post-harvest, they may be linked to an external factor not related to the harvest activity. The change in sulphide concentration, total carbon content, and redox potential was not great enough and/or in the right direction to have significant ecological implications.

Although there were few ecologically significant effects of intertidal geoduck culture/harvest in this small-scale, short-term study, changes in habitat, size of the culture/harvest plot, frequency of culture, and seasonal timing of out-planting and harvest may alter the degree of impact on, and rate of recovery of, the marine environment. The larger-scale research required to address some of these concerns is currently ongoing.

SOURCES OF INFORMATION

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